METAPOST

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1. Introduction.
This is METAPOST by John Hobby, a graphics-language processor based on D. E. Knuth's METAFONT.

Much of the original Pascal version of this program was copied with permission from MF.web Version 1.9. It interprets a language very similar to D.E. Knuth's METAFONT, but with changes designed to make it more suitable for PostScript output.

The main purpose of the following program is to explain the algorithms of METAPOST as clearly as possible. However, the program has been written so that it can be tuned to run efficiently in a wide variety of operating environments by making comparatively few changes. Such flexibility is possible because the documentation that follows is written in the WEB language, which is at a higher level than C.

A large piece of software like METAPOST has inherent complexity that cannot be reduced below a certain level of difficulty, although each individual part is fairly simple by itself. The WEB language is intended to make the algorithms as readable as possible, by reflecting the way the individual program pieces fit together and by providing the cross-references that connect different parts. Detailed comments about what is going on, and about why things were done in certain ways, have been liberally sprinkled throughout the program. These comments explain features of the implementation, but they rarely attempt to explain the METAPOST language itself, since the reader is supposed to be familiar with *The METAFONT book* as well as the manual *A User's Manual for MetaPost*, Computing Science Technical Report 162, AT&T Bell Laboratories.

2. The present implementation is a preliminary version, but the possibilities for new features are limited by the desire to remain as nearly compatible with METAFONT as possible.

On the other hand, the WEB description can be extended without changing the core of the program, and it has been designed so that such extensions are not extremely difficult to make. The *banner* string defined here should be changed whenever METAPOST undergoes any modifications, so that it will be clear which version of METAPOST might be the guilty party when a problem arises.

#define *default_banner* "This␣is␣MetaPost,␣Version␣2.11" ▷ printed when METAPOST starts ◁
#define *true* 1
#define *false* 0

⟨ METAPOST version header 2 ⟩ ≡
#define *metapost_version* "2.11"

This code is used in section 3.

3. The external library header for METAPOST is *mplib.h*. It contains a few typedefs and the header defintions for the externally used functions.

The most important of the typedefs is the definition of the structure *MP_options*, that acts as a small, configurable front-end to the fairly large *MP_instance* structure.

⟨ `mplib.h` 3 ⟩ ≡

```
#ifndef MPLIB_H
#define MPLIB_H 1
#include <stdlib.h>
#ifndef HAVE_BOOLEAN
  typedef int boolean;
#endif
  ⟨ METAPOST version header 2 ⟩
  typedef struct MP_instance *MP;
  ⟨ Exported types 19 ⟩
  typedef struct MP_options {
    ⟨ Option variables 30 ⟩
  } MP_options;
  ⟨ Exported function headers 22 ⟩
  ⟨ MPlib header stuff 205 ⟩
#endif
```

4. The internal header file is much longer: it not only lists the complete *MP_instance*, but also a lot of functions that have to be available to the PostScript backend, that is defined in a separate `WEB` file.

The variables from **MP_options** are included inside the *MP_instance* wholesale.

```
⟨ mpmp.h 4 ⟩ ≡
#ifndef MPMP_H
#define MPMP_H 1
#include "avl.h"
#include "mplib.h"
#include <setjmp.h>
  typedef struct psout_data_struct *psout_data;
  typedef struct svgout_data_struct *svgout_data;
  typedef struct pngout_data_struct *pngout_data;
#ifndef HAVE_BOOLEAN
  typedef int boolean;
#endif
#ifndef INTEGER_TYPE
  typedef int integer;
#define MPOST_ABS abs
#else   ▷ See source/texk/web2c/w2c/config.h ◁
#if INTEGER_MAX ≡ LONG_MAX    ▷ this should mean INTEGER_TYPE ≡ long ◁
#ifdef HAVE_LABS
#define MPOST_ABS labs
#else
#define MPOST_ABS abs
#endif
#else
#define MPOST_ABS abs
#endif   ▷ if INTEGER_TYPE ≡ long ◁
#endif   ▷ ifndef INTEGER_TYPE ◁
  ⟨ Declare helpers 171 ⟩
  ⟨ Enumeration types 189 ⟩
  ⟨ Types in the outer block 37 ⟩
  ⟨ Constants in the outer block 28 ⟩
  typedef struct MP_instance {
    ⟨ Option variables 30 ⟩
    ⟨ Global variables 18 ⟩
  } MP_instance;
  ⟨ Internal library declarations 14 ⟩
  ⟨ MPlib internal header stuff 8 ⟩
#endif
```

5. ▷ #define DEBUGENVELOPE ◁

```
#ifdef DEBUGENVELOPE
  static int DEBUGENVELOPECOUNTER ← 0;
#define dbg_str(A) printf("\n--[==[%03d␣DEBUGENVELOPE␣]==]␣%s", DEBUGENVELOPECOUNTER++, #A)
#define dbg_n(A) printf("\n--[==[%03d␣DEBUGENVELOPE␣]==]␣['%s']=%s,␣",
        DEBUGENVELOPECOUNTER++, #A, number_tostring(A))
#define dbg_in(A)
  printf("\n--[==[%03d␣DEBUGENVELOPE␣]==]␣['%s']=%d,␣", DEBUGENVELOPECOUNTER++, #A, (int)(A))
#define dbg_dn(A) printf("\n--[==[%03d␣DEBUGENVELOPE␣]==]␣['%s']=%.100f,␣",
        DEBUGENVELOPECOUNTER++, #A, (double)(A))
#define dbg_key(A)
  printf("\n--[==[%03d␣DEBUGENVELOPE␣]==]␣['%s']=␣", DEBUGENVELOPECOUNTER++, #A)
#define dbg_key_nval(K, V) printf("\n--[==[%03d␣DEBUGENVELOPE␣]==]␣['%s']=%s",
        DEBUGENVELOPECOUNTER++, #K, number_tostring(V))
#define dbg_key_ival(K, V)
  printf("\n--[==[%03d␣DEBUGENVELOPE␣]==]␣['%s']=%d", DEBUGENVELOPECOUNTER++, #K, (int)(V))
#define dbg_key_dval(K, V) printf("\n--[==[%03d␣DEBUGENVELOPE␣]==]␣['%s']=%.100f",
        DEBUGENVELOPECOUNTER++, #K, (double)(V))
#define dbg_comment(A)
  printf("\n--[==[%03d␣DEBUGENVELOPE␣]==]␣--[==[%s]==]", DEBUGENVELOPECOUNTER++, #A)
#define dbg_sp printf("\n--[==[%03d␣DEBUGENVELOPE␣]==]␣␣", DEBUGENVELOPECOUNTER++)
#define dbg_open_t printf("\n--[==[%03d␣DEBUGENVELOPE␣]==]␣{", DEBUGENVELOPECOUNTER++)
#define dbg_close_t printf("\n--[==[%03d␣DEBUGENVELOPE␣]==]␣}", DEBUGENVELOPECOUNTER++)
#define dbg_comma printf("\n--[==[%03d␣DEBUGENVELOPE␣]==]␣,", DEBUGENVELOPECOUNTER++)
#define dbg_nl printf("\n--[==[%03d␣DEBUGENVELOPE␣]==]␣\n", DEBUGENVELOPECOUNTER++)
#define dbg_CUBIC dbg_n(p→x_coord); dbg_n(p→y_coord); dbg_n(p→right_x); dbg_n(p→right_y);
  dbg_n(q→left_x); dbg_n(q→left_y); dbg_n(q→x_coord); dbg_n(q→y_coord)
#endif
#define KPATHSEA_DEBUG_H 1
#include <w2c/config.h>
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <stdarg.h>
#include <assert.h>
#include <math.h>
#ifdef HAVE_UNISTD_H
#include <unistd.h>    ▷ for access ◁
#endif
#include <time.h>    ▷ for struct tm & co ◁
#include <zlib.h>    ▷ for ZLIB_VERSION, zlibVersion() ◁
#include <png.h>    ▷ for PNG_LIBPNG_VER_STRING, png_libpng_ver ◁    ▷ #include <pixman.h> ◁
    ▷ for PIXMAN_VERSION_STRING, pixman_version_string() ◁    ▷ #include <cairo.h> ◁    ▷ for
      CAIRO_VERSION_STRING, cairo_version_string() ◁    ▷ #include <gmp.h> ◁    ▷ for gmp_version
      ◁    ▷ #include <mpfr.h> ◁    ▷ for MPFR_VERSION_STRING, mpfr_get_version() ◁
#include "mplibps.h"    ▷ external header ◁    ▷ #include "mplibsvg.h" ◁    ▷ external header ◁
    ▷ #include "mplibpng.h" ◁    ▷ external header ◁
#include "mpmp.h"    ▷ internal header ◁
#include "mppsout.h"    ▷ internal header ◁    ▷ #include "mpsvgout.h" ◁    ▷ internal header ◁
    ▷ #include "mppngout.h" ◁    ▷ internal header ◁
#include "mpmath.h"    ▷ internal header ◁
#include "mpmathdouble.h"    ▷ internal header ◁
```

```
#include "mpmathdecimal.h"    ▷ internal header ◁    ▷ #include "mpmathbinary.h" ◁
    ▷ internal header ◁    ▷ #include "mpmathinterval.h" ◁    ▷ internal header ◁
#include "mpstrings.h"    ▷ internal header ◁    ▷ BEGIN PATCH ◁
  mp_number dx_ap;    ▷ approximation of dx ◁
  mp_number dy_ap;    ▷ approximation of dy ◁
  mp_number dxin_ap;    ▷ approximation of dxin ◁
  mp_number dyin_ap;    ▷ approximation of dyin ◁
  mp_number ueps_ap;    ▷ epsilon for above approximations ◁
  boolean is_dxdy, is_dxindyin;    ▷ END PATCH ◁
```

6. We move the `cairo` and `pixman` libraries outside `mp.w`, to minimize dependencies.

```
extern const char *COMPILED_CAIRO_VERSION_STRING;
extern const char *cairo_version_string(void);
extern const char *COMPILED_MPFR_VERSION_STRING;
extern const char *mpfr_get_version(void);
extern const char *COMPILED_MPFI_VERSION_STRING;
extern const char *mpfi_get_version(void);
extern void *mp_initialize_binary_math(MP mp);
extern void *mp_initialize_interval_math(MP mp);
extern int COMPILED__GNU_MP_VERSION;
extern int COMPILED__GNU_MP_VERSION_MINOR;
extern int COMPILED__GNU_MP_VERSION_PATCHLEVEL;
extern const char *const COMPILED_gmp_version;
extern const char *COMPILED_PIXMAN_VERSION_STRING;
extern const char *pixman_version_string(void);
extern void mp_png_backend_initialize(MP mp);
extern void mp_png_backend_free(MP mp);
extern int mp_png_gr_ship_out(void *hh, const char *options, int standalone);
extern int mp_png_ship_out(void *hh, const char *options);
extern void mp_svg_backend_initialize(MP mp);
extern void mp_svg_backend_free(MP mp);
extern int mp_svg_ship_out(mp_edge_object *hh, int prologues);
extern int mp_svg_gr_ship_out(mp_edge_object *hh, int prologues, int standalone);
```

7.
```
extern font_number mp_read_font_info(MP mp, char *fname);    ▷ tfmin.w ◁
  ⟨ Preprocessor definitions ⟩
  ⟨ Declarations 10 ⟩
  ⟨ Basic printing procedures 91 ⟩
  ⟨ Error handling procedures 118 ⟩
```

8. Some debugging support for development. The trick with the variadic macros probably only works in gcc, as this preprocessor feature was not formalized until the c99 standard (and that is too new for us). Lets' hope that at least most compilers understand the non-debug version.

⟨ MPlib internal header stuff 8 ⟩ ≡ ▷ #define DEBUG 2 ◁

```
#if DEBUG
#define debug_number(A)
  printf("%d:␣%s=%.32f␣(%d)\n", __LINE__, #A, number_to_double(A), number_to_scaled(A))
#else
#define debug_number(A)
#endif
#if DEBUG > 1
  void do_debug_printf(MP mp, const char *prefix, const char *fmt, ...);
#define debug_printf(a1, a2, a3) do_debug_printf(mp, "", a1, a2, a3)
#define FUNCTION_TRACE1(a1) do_ debug_printf(mp, "FTRACE:␣", a1)
#define FUNCTION_TRACE2(a1, a2) do_debug_printf(mp, "FTRACE:␣", a1, a2)
#define FUNCTION_TRACE3(a1, a2, a3) do_debug_printf(mp, "FTRACE:␣", a1, a2, a3)
#define FUNCTION_TRACE3X(a1, a2, a3) (void) mp
#define FUNCTION_TRACE4(a1, a2, a3, a4) do_debug_printf(mp, "FTRACE:␣", a1, a2, a3, a4)
#else
#define debug_printf(a1, a2, a3)
#define FUNCTION_TRACE1(a1) (void) mp
#define FUNCTION_TRACE2(a1, a2) (void) mp
#define FUNCTION_TRACE3(a1, a2, a3) (void) mp
#define FUNCTION_TRACE3X(a1, a2, a3) (void) mp
#define FUNCTION_TRACE4(a1, a2, a3, a4) (void) mp
#endif
```

See also sections 40, 73, 88, 178, 197, 241, 257, 268, 273, 276, 279, 459, 462, 466, 472, 476, 480, 485, and 812.
This code is used in section 4.

9. This function occasionally crashes (if something is written after the log file is already closed), but that is not so important while debugging.

```
#if DEBUG
  void do_debug_printf(MP mp, const char *prefix, const char *fmt, ...)
  {
    va_list ap;
    va_start(ap, fmt);
#if 0
    if (mp→log_file ∧ ¬ferror((FILE *) mp→log_file)) {
      fputs(prefix, mp→log_file); vfprintf(mp→log_file, fmt, ap);
    }
    va_end(ap); va_start(ap, fmt);
    if (mp→term_out ∧ ¬ferror((FILE *) mp→term_out)) {
#else
      if (false) {
#endif
        fputs(prefix, mp→term_out); vfprintf(mp→term_out, fmt, ap);
      }
      else {
        fputs(prefix, stdout); vfprintf(stdout, fmt, ap);
      }
      va_end(ap);
#if 0
    }
#endif
  }
#endif    ▷ if DEBUG ◁
```

10. Here are the functions that set up the METAPOST instance.

⟨ Declarations 10 ⟩ ≡

```
  MP_options *mp_options(void);
  MP mp_initialize(MP_options *opt);
```

See also sections 12, 51, 76, 90, 101, 107, 113, 127, 181, 191, 209, 210, 218, 221, 227, 244, 247, 250, 252, 259, 261, 270, 285, 290, 292, 308, 316, 318, 320, 332, 353, 355, 364, 369, 375, 409, 423, 427, 438, 443, 471, 488, 494, 499, 504, 508, 515, 536, 554, 556, 559, 563, 570, 590, 625, 628, 630, 634, 639, 643, 646, 648, 650, 664, 669, 673, 683, 692, 711, 713, 729, 731, 734, 741, 753, 768, 787, 790, 793, 795, 803, 851, 861, 893, 900, 910, 921, 924, 927, 952, 956, 969, 974, 1035, 1038, 1040, 1044, 1046, 1058, 1061, 1086, 1092, 1167, 1229, 1233, 1235, 1267, 1269, 1278, 1282, and 1290.

This code is used in section 7.

11.

```
MP_options *mp_options(void)
  {
    MP_options *opt;
    size_t l ← sizeof(MP_options);
    opt ← malloc(l);
    if (opt ≠ Λ) {
      memset(opt, 0, l);
    }
    return opt;
  }
```

12. Here are the three primitives of the interval arithmetic adapted to the others number systems: *left_point* and *right_point* of a number a simply return a, while *interval_set* of the pair (a, b) returns the mid point.

⟨ Declarations 10 ⟩ +≡
```
static void mp_stub_m_get_left_endpoint(MP mp, mp_number *r, mp_number a);
static void mp_stub_m_get_right_endpoint(MP mp, mp_number *r, mp_number a);
static void mp_stub_m_interval_set(MP mp, mp_number *r, mp_number a, mp_number b);
```

13.
```
static void mp_stub_m_get_left_endpoint(MP mp, mp_number *r, mp_number a)
{
  number_clone(*r, a);
}
static void mp_stub_m_get_right_endpoint(MP mp, mp_number *r, mp_number a)
{
  number_clone(*r, a);
}
static void mp_stub_m_interval_set(MP mp, mp_number *r, mp_number a, mp_number b)
{
  mp_number x;
  new_number(x); number_add(x, a); number_add(x, b); number_half(x); number_clone(*r, x);
  free_number(x);
}
```

14. ⟨ Internal library declarations 14 ⟩ ≡
⟨ Declare subroutines for parsing file names 865 ⟩

See also sections 89, 99, 114, 119, 140, 142, 160, 177, 184, 335, 857, 874, 876, 1093, 1226, 1245, 1248, and 1256.
This code is used in section 4.

15. The whole instance structure is initialized with zeroes, this greatly reduces the number of statements needed in the ⟨ Allocate or initialize variables 32 ⟩ block.

```
#define set_callback_option(A)
        do {
          mp→A ← mp_##A;
          if (opt→A ≠ Λ) mp→A ← opt→A;
        } while (0)
static MP mp_do_new(jmp_buf *buf)
{
  MP mp ← malloc(sizeof(MP_instance));
  if (mp ≡ Λ) {
    xfree(buf); return Λ;
  }
  memset(mp, 0, sizeof(MP_instance)); mp→jump_buf ← buf; return mp;
}
```

16. **static void** *mp_free*(**MP** *mp*)

```
{
  int k;   ▷ loop variable ◁
  ⟨ Dealloc variables 31 ⟩;
  if (mp→noninteractive) ⟨ Finish non-interactive use 1067 ⟩
  xfree(mp→jump_buf); ⟨ Free table entries 187 ⟩;
  free_math(); xfree(mp);
}
```

17. **static void** *mp_do_initialize*(**MP** *mp*)

```
{
  ⟨ Local variables for initialization 39 ⟩;
  ⟨ Set initial values of key variables 42 ⟩;
}
```

18. For the retargetable math library, we need to have a pointer, at least.

⟨ Global variables 18 ⟩ ≡

```
  void *math;
```

See also sections 29, 33, 41, 53, 66, 71, 79, 82, 83, 111, 115, 117, 144, 148, 156, 172, 179, 185, 198, 212, 214, 220, 229, 297, 331, 346, 351, 372, 389, 435, 451, 546, 548, 607, 608, 613, 617, 626, 637, 670, 677, 682, 688, 694, 722, 733, 765, 769, 814, 829, 847, 850, 869, 897, 903, 929, 932, 988, 1001, 1059, 1127, 1137, 1146, 1154, 1163, 1192, 1200, 1206, 1220, 1222, 1242, 1250, 1258, 1274, and 1277.

This code is used in section 4.

19. ⟨ Exported types 19 ⟩ ≡

```
typedef enum {
  mp_nan_type ← 0, mp_scaled_type, mp_fraction_type, mp_angle_type, mp_double_type, mp_binary_type,
      mp_decimal_type, mp_interval_type
} mp_number_type;
typedef union {
  void *num;
  double dval;
  int val;
} mp_number_store;
typedef struct mp_number_data {
  mp_number_store data;
  mp_number_type type;
} mp_number_data;
typedef struct mp_number_data mp_number;
#define is_number(A) ((A).type ≠ mp_nan_type)
typedef void (*convert_func)(mp_number *r);
typedef void (*m_log_func)(MP mp, mp_number *r, mp_number a);
typedef void (*m_exp_func)(MP mp, mp_number *r, mp_number a);
typedef void (*m_unif_rand_func)(MP mp, mp_number *ret, mp_number x_orig);
typedef void (*m_norm_rand_func)(MP mp, mp_number *ret);
typedef void (*pyth_add_func)(MP mp, mp_number *r, mp_number a, mp_number b);
typedef void (*pyth_sub_func)(MP mp, mp_number *r, mp_number a, mp_number b);
typedef void (*n_arg_func)(MP mp, mp_number *r, mp_number a, mp_number b);
typedef void (*velocity_func)(MP mp, mp_number *r, mp_number a, mp_number
    b, mp_number c, mp_number d, mp_number e);
typedef void (*ab_vs_cd_func)(MP mp, mp_number *r, mp_number a, mp_number
    b, mp_number c, mp_number d);
typedef void (*crossing_point_func)(MP mp, mp_number *r, mp_number a, mp_number
    b, mp_number c);
typedef void (*number_from_int_func)(mp_number *A, int B);
typedef void (*number_from_boolean_func)(mp_number *A, int B);
typedef void (*number_from_scaled_func)(mp_number *A, int B);
typedef void (*number_from_double_func)(mp_number *A, double B);
typedef void (*number_from_addition_func)(mp_number *A, mp_number B, mp_number C);
typedef void (*number_from_substraction_func)(mp_number *A, mp_number B, mp_number
    C);
typedef void (*number_from_div_func)(mp_number *A, mp_number B, mp_number C);
typedef void (*number_from_mul_func)(mp_number *A, mp_number B, mp_number C);
typedef void (*number_from_int_div_func)(mp_number *A, mp_number B, int C);
typedef void (*number_from_int_mul_func)(mp_number *A, mp_number B, int C);
typedef void (*number_from_oftheway_func)(MP mp, mp_number *A, mp_number
    t, mp_number B, mp_number C);
typedef void (*number_negate_func)(mp_number *A);
typedef void (*number_add_func)(mp_number *A, mp_number B);
typedef void (*number_substract_func)(mp_number *A, mp_number B);
typedef void (*number_modulo_func)(mp_number *A, mp_number B);
typedef void (*number_half_func)(mp_number *A);
typedef void (*number_halfp_func)(mp_number *A);
typedef void (*number_double_func)(mp_number *A);
typedef void (*number_abs_func)(mp_number *A);
typedef void (*number_clone_func)(mp_number *A, mp_number B);
```

```
typedef void (*number_swap_func)(mp_number *A, mp_number *B);
typedef void (*number_add_scaled_func)(mp_number *A, int b);
typedef void (*number_multiply_int_func)(mp_number *A, int b);
typedef void (*number_divide_int_func)(mp_number *A, int b);
typedef int (*number_to_int_func)(mp_number A);
typedef int (*number_to_boolean_func)(mp_number A);
typedef int (*number_to_scaled_func)(mp_number A);
typedef int (*number_round_func)(mp_number A);
typedef void (*number_floor_func)(mp_number *A);
typedef double (*number_to_double_func)(mp_number A);
typedef int (*number_odd_func)(mp_number A);
typedef int (*number_equal_func)(mp_number A, mp_number B);
typedef int (*number_less_func)(mp_number A, mp_number B);
typedef int (*number_greater_func)(mp_number A, mp_number B);
typedef int (*number_nonequalabs_func)(mp_number A, mp_number B);
typedef void (*make_scaled_func)(MP mp, mp_number *ret, mp_number A, mp_number B);
typedef void (*make_fraction_func)(MP mp, mp_number *ret, mp_number A, mp_number B);
typedef void (*take_fraction_func)(MP mp, mp_number *ret, mp_number A, mp_number B);
typedef void (*take_scaled_func)(MP mp, mp_number *ret, mp_number A, mp_number B);
typedef void (*sin_cos_func)(MP mp, mp_number A, mp_number *S, mp_number *C);
typedef void (*slow_add_func)(MP mp, mp_number *A, mp_number S, mp_number C);
typedef void (*sqrt_func)(MP mp, mp_number *ret, mp_number A);
typedef void (*init_randoms_func)(MP mp, int seed);
typedef void (*new_number_func)(MP mp, mp_number *A, mp_number_type t);
typedef void (*free_number_func)(MP mp, mp_number *n);
typedef void (*fraction_to_round_scaled_func)(mp_number *n);
typedef void (*print_func)(MP mp, mp_number A);
typedef char *(*tostring_func)(MP mp, mp_number A);
typedef void (*scan_func)(MP mp, int A);
typedef void (*mp_free_func)(MP mp);
typedef void (*set_precision_func)(MP mp);    ▷ math interval new primitives ◁
typedef void (*m_get_left_endpoint_func)(MP mp, mp_number *r, mp_number a);
typedef void (*m_get_right_endpoint_func)(MP mp, mp_number *r, mp_number a);
typedef void (*m_interval_set_func)(MP mp, mp_number *r, mp_number a, mp_number b);
typedef struct math_data {
  mp_number precision_default;
  mp_number precision_max;
  mp_number precision_min;
  mp_number epsilon_t;
  mp_number inf_t;
  mp_number one_third_inf_t;
  mp_number zero_t;
  mp_number unity_t;
  mp_number two_t;
  mp_number three_t;
  mp_number half_unit_t;
  mp_number three_quarter_unit_t;
  mp_number fraction_one_t;
  mp_number fraction_half_t;
  mp_number fraction_three_t;
  mp_number fraction_four_t;
  mp_number one_eighty_deg_t;
```

mp_number *three_sixty_deg_t*;
mp_number *one_k*;
mp_number *sqrt_8_e_k*;
mp_number *twelve_ln_2_k*;
mp_number *coef_bound_k*;
mp_number *coef_bound_minus_1*;
mp_number *twelvebits_3*;
mp_number *arc_tol_k*;
mp_number *twentysixbits_sqrt2_t*;
mp_number *twentyeightbits_d_t*;
mp_number *twentysevenbits_sqrt2_d_t*;
mp_number *fraction_threshold_t*;
mp_number *half_fraction_threshold_t*;
mp_number *scaled_threshold_t*;
mp_number *half_scaled_threshold_t*;
mp_number *near_zero_angle_t*;
mp_number *p_over_v_threshold_t*;
mp_number *equation_threshold_t*;
mp_number *tfm_warn_threshold_t*;
mp_number *warning_limit_t*;
new_number_func *allocate*;
free_number_func *free*;
number_from_int_func *from_int*;
number_from_boolean_func *from_boolean*;
number_from_scaled_func *from_scaled*;
number_from_double_func *from_double*;
number_from_addition_func *from_addition*;
number_from_substraction_func *from_substraction*;
number_from_div_func *from_div*;
number_from_mul_func *from_mul*;
number_from_int_div_func *from_int_div*;
number_from_int_mul_func *from_int_mul*;
number_from_oftheway_func *from_oftheway*;
number_negate_func *negate*;
number_add_func *add*;
number_substract_func *substract*;
number_half_func *half*;
number_modulo_func *modulo*;
number_halfp_func *halfp*;
number_double_func *do_double*;
number_abs_func *abs*;
number_clone_func *clone*;
number_swap_func *swap*;
number_add_scaled_func *add_scaled*;
number_multiply_int_func *multiply_int*;
number_divide_int_func *divide_int*;
number_to_int_func *to_int*;
number_to_boolean_func *to_boolean*;
number_to_scaled_func *to_scaled*;
number_to_double_func *to_double*;
number_odd_func *odd*;
number_equal_func *equal*;

```
    number_less_func less;
    number_greater_func greater;
    number_nonequalabs_func nonequalabs;
    number_round_func round_unscaled;
    number_floor_func floor_scaled;
    make_scaled_func make_scaled;
    make_fraction_func make_fraction;
    take_fraction_func take_fraction;
    take_scaled_func take_scaled;
    velocity_func velocity;
    ab_vs_cd_func ab_vs_cd;
    crossing_point_func crossing_point;
    n_arg_func n_arg;
    m_log_func m_log;
    m_exp_func m_exp;
    m_unif_rand_func m_unif_rand;
    m_norm_rand_func m_norm_rand;
    pyth_add_func pyth_add;
    pyth_sub_func pyth_sub;
    fraction_to_round_scaled_func fraction_to_round_scaled;
    convert_func fraction_to_scaled;
    convert_func scaled_to_fraction;
    convert_func scaled_to_angle;
    convert_func angle_to_scaled;
    init_randoms_func init_randoms;
    sin_cos_func sin_cos;
    sqrt_func sqrt;
    slow_add_func slow_add;
    print_func print;
    tostring_func tostring;
    scan_func scan_numeric;
    scan_func scan_fractional;
    mp_free_func free_math;
    set_precision_func set_precision;    ▷ math interval new primitives ◁
    m_get_left_endpoint_func m_get_left_endpoint;
    m_get_right_endpoint_func m_get_right_endpoint;
    m_interval_set_func m_interval_set;
  } math_data;
```

See also sections 46, 78, 104, 110, 124, 168, 303, 304, 307, 890, 1056, and 1271.

This code is used in section 3.

20. This procedure gets things started properly.

```
MP mp_initialize(MP_options *opt)
{
  MP mp;
  jmp_buf *buf ← malloc(sizeof(jmp_buf));
  if (buf ≡ Λ ∨ setjmp(*buf) ≠ 0) return Λ;
  mp ← mp_do_new(buf);
  if (mp ≡ Λ) return Λ;
  mp→userdata ← opt→userdata; mp→noninteractive ← opt→noninteractive;
  mp→extensions ← opt→extensions; set_callback_option(find_file); set_callback_option(open_file);
  set_callback_option(read_ascii_file); set_callback_option(read_binary_file); set_callback_option(close_file);
  set_callback_option(eof_file); set_callback_option(flush_file); set_callback_option(write_ascii_file);
  set_callback_option(write_binary_file); set_callback_option(shipout_backend);
  set_callback_option(run_script); set_callback_option(make_text);
  if (opt→banner ∧ *(opt→banner)) {
    mp→banner ← xstrdup(opt→banner);
  }
  else {
    mp→banner ← xstrdup(default_banner);
  }
  if (opt→command_line ∧ *(opt→command_line)) mp→command_line ← xstrdup(opt→command_line);
  if (mp→noninteractive) ⟨Prepare function pointers for non-interactive use 1063⟩
  t_open_out();    ▷ open the terminal for output ◁
#if DEBUG
  setvbuf(stdout, (char *) Λ, _IONBF, 0); setvbuf(mp→term_out, (char *) Λ, _IONBF, 0);
#endif
  if (opt→math_mode ≡ mp_math_scaled_mode) {
    mp→math ← mp_initialize_scaled_math(mp);
  }
  else if (opt→math_mode ≡ mp_math_decimal_mode) {
    mp→math ← mp_initialize_decimal_math(mp);
  }
  else if (opt→math_mode ≡ mp_math_binary_mode) {
    mp→math ← mp_initialize_binary_math(mp);
  }
  else if (opt→math_mode ≡ mp_math_interval_mode) {
    mp→math ← mp_initialize_interval_math(mp);
  }
  else {
    mp→math ← mp_initialize_double_math(mp);
  }
  if (opt→math_mode ≠ mp_math_interval_mode) {
    ((math_data *) mp→math)→m_get_left_endpoint ← mp_stub_m_get_left_endpoint;
    ((math_data *) mp→math)→m_get_right_endpoint ← mp_stub_m_get_right_endpoint;
    ((math_data *) mp→math)→m_interval_set ← mp_stub_m_interval_set;
  }
  ⟨Find and load preload file, if required 859⟩;
  ⟨Allocate or initialize variables 32⟩;
  mp_reallocate_paths(mp, 1000); mp_reallocate_fonts(mp, 8); mp→history ← mp_fatal_error_stop;
    ▷ in case we quit during initialization ◁
  ⟨Check the "constant" values for consistency 34⟩;    ▷ consider also the raise of the bits for precision ◁
  if (mp→bad > 0) {
```

```
      char ss[256];
      mp_snprintf(ss, 256, "Ouch---my internal constants have been clobbered!\n" "---case %i",
          (int) mp→bad); mp_fputs((char *) ss, mp→err_out); return mp;
    }
    mp_do_initialize(mp);    ▷ erase preloaded mem ◁
    mp_init_tab(mp);    ▷ initialize the tables ◁
    if (opt→math_mode ≡ mp_math_scaled_mode) {
      set_internal_string(mp_number_system, mp_intern(mp, "scaled"));
    }
    else if (opt→math_mode ≡ mp_math_decimal_mode) {
      set_internal_string(mp_number_system, mp_intern(mp, "decimal"));
    }
    else if (opt→math_mode ≡ mp_math_binary_mode) {
      set_internal_string(mp_number_system, mp_intern(mp, "binary"));
    }
    else if (opt→math_mode ≡ mp_math_interval_mode) {
      set_internal_string(mp_number_system, mp_intern(mp, "interval"));
    }
    else {
      set_internal_string(mp_number_system, mp_intern(mp, "double"));
    }
    mp_init_prim(mp);    ▷ call primitive for each primitive ◁
    mp_fix_date_and_time(mp);
    if (¬mp→noninteractive) {
      ⟨Initialize the output routines 87⟩;
      ⟨Get the first line of input and prepare to start 1292⟩;
      ⟨Initializations after first line is read 21⟩;
      ⟨Fix up mp→internal[mp_job_name] 872⟩;
    }
    else {
      mp→history ← mp_spotless;
    }
    set_precision(); return mp;
  }
```

21. ⟨Initializations after first line is read 21⟩ ≡

```
  mp_open_log_file(mp); mp_set_job_id(mp); mp_init_map_file(mp, mp→troff_mode);
  mp→history ← mp_spotless;    ▷ ready to go! ◁
  if (mp→troff_mode) {
    number_clone(internal_value(mp_gtroffmode), unity_t);
    number_clone(internal_value(mp_prologues), unity_t);
  }
  if (mp→start_sym ≠ Λ) {    ▷ insert the 'everyjob' symbol ◁
    set_cur_sym(mp→start_sym); mp_back_input(mp);
  }
```

This code is used in section 20.

22. ⟨ Exported function headers 22 ⟩ ≡

```
extern MP_options *mp_options(void);
extern MP mp_initialize(MP_options *opt);
extern int mp_status(MP mp);
extern boolean mp_finished(MP mp);
extern void *mp_userdata(MP mp);
```

See also sections 122, 139, 201, 234, 382, 384, 1055, 1064, 1072, 1232, and 1287.

This code is used in section 3.

23.
```
int mp_status(MP mp)
{
  return mp→history;
}
```

24.
```
boolean mp_finished(MP mp)
{
  return mp→finished;
}
```

25.
```
void *mp_userdata(MP mp)
{
  return mp→userdata;
}
```

26. The overall METAPOST program begins with the heading just shown, after which comes a bunch of procedure declarations and function declarations. Finally we will get to the main program, which begins with the comment '*start_here*'. If you want to skip down to the main program now, you can look up '*start_here*' in the index. But the author suggests that the best way to understand this program is to follow pretty much the order of METAPOST's components as they appear in the WEB description you are now reading, since the present ordering is intended to combine the advantages of the "bottom up" and "top down" approaches to the problem of understanding a somewhat complicated system.

27. Some of the code below is intended to be used only when diagnosing the strange behavior that sometimes occurs when METAPOST is being installed or when system wizards are fooling around with METAPOST without quite knowing what they are doing. Such code will not normally be compiled; it is delimited by the preprocessor test **#ifdef** DEBUG ... **#endif**.

28. The following parameters can be changed at compile time to extend or reduce METAPOST's capacity.

⟨ Constants in the outer block 28 ⟩ ≡

```
#define bistack_size 1500   ▷ size of stack for bisection algorithms; should probably be left at this value ◁
```

This code is used in section 4.

29. Like the preceding parameters, the following quantities can be changed to extend or reduce METAPOST's capacity.

⟨ Global variables 18 ⟩ +≡

```
int pool_size;   ▷ maximum number of characters in strings, including all error messages and help texts,
    and the names of all identifiers ◁
int max_in_open;
  ▷ maximum number of input files and error insertions that can be going on simultaneously ◁
int param_size;   ▷ maximum number of simultaneous macro parameters ◁
```

30. ⟨ Option variables 30 ⟩ ≡

int *error_line*; ▷ width of context lines on terminal error messages ◁
int *half_error_line*;
▷ width of first lines of contexts in terminal error messages; should be between 30 and $error\_line - 15$ ◁
int *halt_on_error*; ▷ do we quit at the first error? ◁
int *max_print_line*; ▷ width of longest text lines output; should be at least 60 ◁
void ∗*userdata*; ▷ this allows the calling application to setup local ◁
char ∗*banner*; ▷ the banner that is printed to the screen and log ◁
int *ini_version*;
int *utf8_mode*;

See also sections 47, 54, 56, 72, 105, 125, 157, 169, 199, 858, 870, 891, and 1272.

This code is used in sections 3 and 4.

31. ⟨ Dealloc variables 31 ⟩ ≡

xfree(*mp*→*banner*);

See also sections 68, 81, 86, 159, 174, 226, 347, 352, 374, 391, 437, 453, 610, 615, 619, 679, 686, 691, 849, 860, 873, 880, 931, 1066, 1095, 1165, 1194, 1208, 1224, 1252, 1276, and 1284.

This code is used in section 16.

32. **#define** *set_lower_limited_value*(*a*, *b*, *c*)
do {
$a \leftarrow c$;
if $(b > c)$ $a \leftarrow b$;
} **while** (0)

⟨ Allocate or initialize variables 32 ⟩ ≡

mp→*param_size* ← 4; *mp*→*max_in_open* ← 0; *mp*→*pool_size* ← 10000;
set_lower_limited_value(*mp*→*error_line*, *opt*→*error_line*, 79);
set_lower_limited_value(*mp*→*half_error_line*, *opt*→*half_error_line*, 50);
if (*mp*→*half_error_line* > *mp*→*error_line* − 15) *mp*→*half_error_line* ← *mp*→*error_line* − 15;
mp→*max_print_line* ← 100; *set_lower_limited_value*(*mp*→*max_print_line*, *opt*→*max_print_line*, 79);
mp→*halt_on_error* ← (*opt*→*halt_on_error* ? *true* : *false*);
mp→*ini_version* ← (*opt*→*ini_version* ? *true* : *false*); *mp*→*utf8_mode* ← (*opt*→*utf8_mode* ? *true* : *false*);

See also sections 55, 57, 67, 80, 85, 106, 116, 126, 145, 149, 158, 170, 173, 200, 225, 609, 678, 685, 689, 871, 892, 898, 1164, 1223, and 1275.

This code is cited in sections 15 and 872.

This code is used in section 20.

33. In case somebody has inadvertently made bad settings of the "constants," METAPOST checks them using a global variable called *bad*.

This is the second of many sections of METAPOST where global variables are defined.

⟨ Global variables 18 ⟩ +≡

integer *bad*; ▷ is some "constant" wrong? ◁

34. Later on we will say '**if** (*int_packets* + (17 + 2) ∗ *int_increment* > *bistack_size*) *mp*→*bad* ← 19;', or something similar.

In case you are wondering about the non-consecutive values of *bad*: most of the things that used to be WEB constants are now runtime variables with checking at assignment time.

⟨ Check the "constant" values for consistency 34 ⟩ ≡

mp→*bad* ← 0;

See also section 611.

This code is used in section 20.

35. Here are some macros for common programming idioms.

#**define** $incr(A)$ $(A) \leftarrow (A) + 1$ ▷ increase a variable by unity ◁
#**define** $decr(A)$ $(A) \leftarrow (A) - 1$ ▷ decrease a variable by unity ◁
#**define** $negate(A)$ $(A) \leftarrow -(A)$ ▷ change the sign of a variable ◁
#**define** **double**(A) $(A) \leftarrow (A) + (A)$
#**define** $odd(A)$ $(abs(A) \% 2 \equiv 1)$

36. The character set. In order to make METAPOST readily portable to a wide variety of computers, all of its input text is converted to an internal eight-bit code that includes standard ASCII, the "American Standard Code for Information Interchange." This conversion is done immediately when each character is read in. Conversely, characters are converted from ASCII to the user's external representation just before they are output to a text file.

Such an internal code is relevant to users of METAPOST only with respect to the **char** and **ASCII** operations, and the comparison of strings.

37. Characters of text that have been converted to METAPOST's internal form are said to be of type *ASCII_code*, which is a subrange of the integers.

⟨ Types in the outer block 37 ⟩ ≡
  typedef unsigned char ASCII_code; ▷ eight-bit numbers ◁

See also sections 38, 45, 167, 196, 219, 254, 296, 388, 481, 676, 750, 828, 896, 1060, and 1221.

This code is used in section 4.

38. The present specification of METAPOST has been written under the assumption that the character set contains at least the letters and symbols associated with ASCII codes 040 through 0176; all of these characters are now available on most computer terminals.

⟨ Types in the outer block 37 ⟩ +≡
  typedef unsigned char text_char; ▷ the data type of characters in text files ◁

39. ⟨ Local variables for initialization 39 ⟩ ≡
  integer *i*;

See also section 155.

This code is used in section 17.

40. The METAPOST processor converts between ASCII code and the user's external character set by means of arrays *xord* and *xchr* that are analogous to Pascal's *ord* and *chr* functions.

⟨ MPlib internal header stuff 8 ⟩ +≡
#define *xchr*(*A*) *mp→xchr*[(*A*)]
#define *xord*(*A*) *mp→xord*[(*A*)]

41. ⟨ Global variables 18 ⟩ +≡
  ASCII_code *xord*[256]; ▷ specifies conversion of input characters ◁
  text_char *xchr*[256]; ▷ specifies conversion of output characters ◁

42. The core system assumes all 8-bit is acceptable. If it is not, a change file has to alter the below section.

Additionally, people with extended character sets can assign codes arbitrarily, giving an *xchr* equivalent to whatever characters the users of METAPOST are allowed to have in their input files. Appropriate changes to METAPOST's *char_class* table should then be made. (Unlike TeX, each installation of METAPOST has a fixed assignment of category codes, called the *char_class*.) Such changes make portability of programs more difficult, so they should be introduced cautiously if at all.

⟨ Set initial values of key variables 42 ⟩ ≡
  for ($i \leftarrow 0$; $i \leq$ °*377*; *i*++) {
    xchr(*i*) ← (**text_char**) *i*;
  }

See also sections 43, 203, 215, 298, 436, 549, 638, 770, 815, 830, 848, 904, 933, 989, 1138, 1147, 1166, 1227, 1243, and 1251.

This code is used in section 17.

43. The following system-independent code makes the *xord* array contain a suitable inverse to the information in *xchr*. Note that if $xchr[i] \leftarrow xchr[j]$ where $i < j < °177$, the value of $xord[xchr[i]]$ will turn out to be j or more; hence, standard ASCII code numbers will be used instead of codes below 040 in case there is a coincidence.

⟨ Set initial values of key variables 42 ⟩ +≡
```
for (i ← 0; i ≤ 255; i++) {
   xord(xchr(i)) ← °177;
}
for (i ← °200; i ≤ °377; i++) {
   xord(xchr(i)) ← (ASCII_code) i;
}
for (i ← 0; i ≤ °176; i++) {
   xord(xchr(i)) ← (ASCII_code) i;
}
```

44. Input and output. The bane of portability is the fact that different operating systems treat input and output quite differently, perhaps because computer scientists have not given sufficient attention to this problem. People have felt somehow that input and output are not part of "real" programming. Well, it is true that some kinds of programming are more fun than others. With existing input/output conventions being so diverse and so messy, the only sources of joy in such parts of the code are the rare occasions when one can find a way to make the program a little less bad than it might have been. We have two choices, either to attack I/O now and get it over with, or to postpone I/O until near the end. Neither prospect is very attractive, so let's get it over with.

The basic operations we need to do are (1) inputting and outputting of text, to or from a file or the user's terminal; (2) inputting and outputting of eight-bit bytes, to or from a file; (3) instructing the operating system to initiate ("open") or to terminate ("close") input or output from a specified file; (4) testing whether the end of an input file has been reached; (5) display of bits on the user's screen. The bit-display operation will be discussed in a later section; we shall deal here only with more traditional kinds of I/O.

45. Finding files happens in a slightly roundabout fashion: the METAPOST instance object contains a field that holds a function pointer that finds a file, and returns its name, or NULL. For this, it receives three parameters: the non-qualified name *fname*, the intended *fopen* operation type *fmode*, and the type of the file *ftype*.

The file types that are passed on in *ftype* can be used to differentiate file searches if a library like kpathsea is used, the fopen mode is passed along for the same reason.

⟨ Types in the outer block 37 ⟩ +≡

```
typedef unsigned char eight_bits;   ▷ unsigned one-byte quantity ◁
```

46. ⟨ Exported types 19 ⟩ +≡

```
enum mp_filetype {
  mp_filetype_terminal ← 0,   ▷ the terminal ◁
  mp_filetype_error,   ▷ the terminal ◁
  mp_filetype_program,   ▷ METAPOST language input ◁
  mp_filetype_log,   ▷ the log file ◁
  mp_filetype_postscript,   ▷ the postscript output ◁
  mp_filetype_bitmap,   ▷ the bitmap output file ◁
  mp_filetype_memfile,   ▷ memory dumps, obsolete ◁
  mp_filetype_metrics,   ▷ TeX font metric files ◁
  mp_filetype_fontmap,   ▷ PostScript font mapping files ◁
  mp_filetype_font,   ▷ PostScript type1 font programs ◁
  mp_filetype_encoding,   ▷ PostScript font encoding files ◁
  mp_filetype_text   ▷ first text file for readfrom and writeto primitives ◁
};
typedef char *(*mp_file_finder)(MP, const char *, const char *, int);
typedef char *(*mp_script_runner)(MP, const char *, size_t);
typedef char *(*mp_text_maker)(MP, const char *, size_t, int);
typedef void *(*mp_file_opener)(MP, const char *, const char *, int);
typedef char *(*mp_file_reader)(MP, void *, size_t *);
typedef void (*mp_binfile_reader)(MP, void *, void **, size_t *);
typedef void (*mp_file_closer)(MP, void *);
typedef int (*mp_file_eoftest)(MP, void *);
typedef void (*mp_file_flush)(MP, void *);
typedef void (*mp_file_writer)(MP, void *, const char *);
typedef void (*mp_binfile_writer)(MP, void *, void *, size_t);
```

47. ⟨ Option variables 30 ⟩ +≡

```
mp_file_finder find_file;
mp_file_opener open_file;
mp_script_runner run_script;
mp_text_maker make_text;
mp_file_reader read_ascii_file;
mp_binfile_reader read_binary_file;
mp_file_closer close_file;
mp_file_eoftest eof_file;
mp_file_flush flush_file;
mp_file_writer write_ascii_file;
mp_binfile_writer write_binary_file;
```

48. The default function for finding files is *mp_find_file*. It is pretty stupid: it will only find files in the current directory.

```
static char *mp_find_file(MP mp, const char *fname, const char *fmode, int ftype)
{
  (void) mp;
  if (fmode[0] ≠ 'r' ∨ (¬access(fname, R_OK)) ∨ ftype) {
    return mp_strdup(fname);
  }
  return Λ;
}
```

49.

```
static char *mp_run_script(MP mp, const char *str, size_t len)
{
  (void) mp; return mp_strldup(str, len);
}
```

50.

```
static char *mp_make_text(MP mp, const char *str, size_t len, int mode)
{
  (void) mp; return mp_strldup(str, len);
}
```

51. Because *mp_find_file* is used so early, it has to be in the helpers section.

⟨ Declarations 10 ⟩ +≡

```
static char *mp_find_file(MP mp, const char *fname, const char *fmode, int ftype);
static void *mp_open_file(MP mp, const char *fname, const char *fmode, int ftype);
static char *mp_read_ascii_file(MP mp, void *f, size_t *size);
static void mp_read_binary_file(MP mp, void *f, void **d, size_t *size);
static void mp_close_file(MP mp, void *f);
static int mp_eof_file(MP mp, void *f);
static void mp_flush_file(MP mp, void *f);
static void mp_write_ascii_file(MP mp, void *f, const char *s);
static void mp_write_binary_file(MP mp, void *f, void *s, size_t t);
static char *mp_run_script(MP mp, const char *str, size_t len);
static char *mp_make_text(MP mp, const char *str, size_t len, int mode);
```

52. The function to open files can now be very short.

```
void *mp_open_file(MP mp, const char *fname, const char *fmode, int ftype)
{
  char realmode[3];
  (void) mp; realmode[0] ← *fmode; realmode[1] ← 'b'; realmode[2] ← 0;
  if (ftype ≡ mp_filetype_terminal) {
    return (fmode[0] ≡ 'r' ? stdin : stdout);
  }
  else if (ftype ≡ mp_filetype_error) {
    return stderr;
  }
  else if (fname ≠ Λ ∧ (fmode[0] ≠ 'r' ∨ (¬access(fname, R_OK)))) {
    return (void *) fopen(fname, realmode);
  }
  return Λ;
}
```

53. (Almost) all file names pass through *name_of_file*.

⟨ Global variables 18 ⟩ +≡

```
char *name_of_file;   ▷ the name of a system file ◁
```

54. If this parameter is true, the terminal and log will report the found file names for input files instead of the requested ones. It is off by default because it creates an extra filename lookup.

⟨ Option variables 30 ⟩ +≡

```
int print_found_names;   ▷ configuration parameter ◁
```

55. ⟨ Allocate or initialize variables 32 ⟩ +≡

```
mp→print_found_names ← (opt→print_found_names > 0 ? true : false);
```

56. The *file_line_error_style* parameter makes METAPOST use a more standard compiler error message format instead of the Knuthian exclamation mark. It needs the actual version of the current input file name, that will be saved by *open_in* in the *long_name*.

TODO: currently these long strings cause memory leaks, because they cannot be safely freed as they may appear in the *input_stack* multiple times. In fact, the current implementation is just a quick hack in response to a bug report for metapost 1.205.

```
#define long_name  mp→cur_input.long_name_field   ▷ long name of the current file ◁
```

⟨ Option variables 30 ⟩ +≡

```
int file_line_error_style;   ▷ configuration parameter ◁
```

57. ⟨ Allocate or initialize variables 32 ⟩ +≡

```
mp→file_line_error_style ← (opt→file_line_error_style > 0 ? true : false);
```

58. METAPOST's file-opening procedures return *false* if no file identified by *name_of_file* could be opened. The *do_open_file* function takes care of the *print_found_names* parameter.

```
static boolean mp_do_open_file(MP mp, void **f, int ftype, const char *mode)
{
  if (mp→print_found_names ∨ mp→file_line_error_style) {
    char *s ← (mp→find_file)(mp, mp→name_of_file, mode, ftype);
    if (s ≠ Λ) {
      *f ← (mp→open_file)(mp, mp→name_of_file, mode, ftype);
      if (mp→print_found_names) {
        xfree(mp→name_of_file); mp→name_of_file ← xstrdup(s);
      }
      if ((*mode ≡ 'r') ∧ (ftype ≡ mp_filetype_program)) {
        long_name ← xstrdup(s);
      }
      xfree(s);
    }
    else {
      *f ← Λ;
    }
  }
  else {
    *f ← (mp→open_file)(mp, mp→name_of_file, mode, ftype);
  }
  return (*f ? true : false);
}
static boolean mp_open_in(MP mp, void **f, int ftype)
{    ▷ open a file for input ◁
  return mp_do_open_file(mp, f, ftype, "r");
}
static boolean mp_open_out(MP mp, void **f, int ftype)
{    ▷ open a file for output ◁
  return mp_do_open_file(mp, f, ftype, "w");
}
```

59.
```
static char *mp_read_ascii_file(MP mp, void *ff, size_t *size)
{
  int c;
  size_t len ← 0, lim ← 128;
  char *s ← Λ;
  FILE *f ← (FILE *) ff;
  *size ← 0; (void) mp;    ▷ for -Wunused ◁
  if (f ≡ Λ) return Λ;
  c ← fgetc(f);
  if (c ≡ EOF) return Λ;
  s ← malloc(lim);
  if (s ≡ Λ) return Λ;
  while (c ≠ EOF ∧ c ≠ '\n' ∧ c ≠ '\r') {
    if ((len + 1) ≡ lim) {
      s ← realloc(s, (lim + (lim ≫ 2)));
      if (s ≡ Λ) return Λ;
      lim += (lim ≫ 2);
    }
    s[len++] ← (char) c; c ← fgetc(f);
  }
  if (c ≡ '\r') {
    c ← fgetc(f);
    if (c ≠ EOF ∧ c ≠ '\n') ungetc(c, f);
  }
  s[len] ← 0; *size ← len; return s;
}
```

60.
```
void mp_write_ascii_file(MP mp, void *f, const char *s)
{
  (void) mp;
  if (f ≠ Λ) {
    fputs(s, (FILE *) f);
  }
}
```

61.
```
void mp_read_binary_file(MP mp, void *f, void **data, size_t *size)
{
  size_t len ← 0;
  (void) mp;
  if (f ≠ Λ) len ← fread(*data, 1, *size, (FILE *) f);
  *size ← len;
}
```

62.
```
void mp_write_binary_file(MP mp, void *f, void *s, size_t size)
{
  (void) mp;
  if (f ≠ Λ) (void) fwrite(s, size, 1, (FILE *) f);
}
```

63. **void** *mp_close_file*(**MP** *mp*, **void** **f*)

```
{
  (void) mp;
  if (f ≠ Λ) fclose((FILE *) f);
}
```

64. **int** *mp_eof_file*(**MP** *mp*, **void** **f*)

```
{
  (void) mp;
  if (f ≠ Λ) return feof((FILE *) f);
  else return 1;
}
```

65. **void** *mp_flush_file*(**MP** *mp*, **void** **f*)

```
{
  (void) mp;
  if (f ≠ Λ) fflush((FILE *) f);
}
```

66. Input from text files is read one line at a time, using a routine called *input_ln*. This function is defined in terms of global variables called *buffer*, *first*, and *last* that will be described in detail later; for now, it suffices for us to know that *buffer* is an array of **ASCII_code** values, and that *first* and *last* are indices into this array representing the beginning and ending of a line of text.

⟨ Global variables 18 ⟩ +≡

```
size_t buf_size;   ▷ maximum number of characters simultaneously present in current lines of open files ◁
ASCII_code *buffer;   ▷ lines of characters being read ◁
size_t first;   ▷ the first unused position in buffer ◁
size_t last;   ▷ end of the line just input to buffer ◁
size_t max_buf_stack;   ▷ largest index used in buffer ◁
```

67. ⟨ Allocate or initialize variables 32 ⟩ +≡

```
mp→buf_size ← 200;  mp→buffer ← xmalloc((mp→buf_size + 1), sizeof(ASCII_code));
```

68. ⟨ Dealloc variables 31 ⟩ +≡

```
xfree(mp→buffer);
```

69. **static void** *mp_reallocate_buffer*(**MP** *mp*, **size_t** *l*)

```
{
  ASCII_code *buffer;
  if (l > max_halfword) {
    mp_confusion(mp, "buffer␣size");   ▷ can't happen (I hope) ◁
  }
  buffer ← xmalloc((l + 1), sizeof(ASCII_code));
  (void) memcpy(buffer, mp→buffer, (mp→buf_size + 1));  xfree(mp→buffer);  mp→buffer ← buffer;
  mp→buf_size ← l;
}
```

70. The *input_ln* function brings the next line of input from the specified field into available positions of the buffer array and returns the value *true*, unless the file has already been entirely read, in which case it returns *false* and sets *last*: $\leftarrow$ *first*. In general, the **ASCII_code** numbers that represent the next line of the file are input into *buffer*[*first*], *buffer*[*first* + 1], ..., *buffer*[*last* − 1]; and the global variable *last* is set equal to *first* plus the length of the line. Trailing blanks are removed from the line; thus, either *last* $\leftarrow$ *first* (in which case the line was entirely blank) or *buffer*[*last* − 1] <> "␣".

The variable *max_buf_stack*, which is used to keep track of how large the *buf_size* parameter must be to accommodate the present job, is also kept up to date by *input_ln*.

```
static boolean mp_input_ln(MP mp, void *f)
{    ▷ inputs the next line or returns false ◁
  char *s;
  size_t size ← 0;
  mp→last ← mp→first;    ▷ cf. Matthew 19 : 30 ◁
  s ← (mp→read_ascii_file)(mp, f, &size);
  if (s ≡ Λ) return false;
  if (size > 0) {
    mp→last ← mp→first + size;
    if (mp→last ≥ mp→max_buf_stack) {
      mp→max_buf_stack ← mp→last + 1;
      while (mp→max_buf_stack > mp→buf_size) {
        mp_reallocate_buffer(mp, (mp→buf_size + (mp→buf_size ≫ 2)));
      }
    }
    (void) memcpy((mp→buffer + mp→first), s, size);
  }
  free(s); return true;
}
```

71. The user's terminal acts essentially like other files of text, except that it is used both for input and for output. When the terminal is considered an input file, the file variable is called *term_in*, and when it is considered an output file the file variable is *term_out*.

```
⟨ Global variables 18 ⟩ +≡
  void *term_in;    ▷ the terminal as an input file ◁
  void *term_out;    ▷ the terminal as an output file ◁
  void *err_out;    ▷ the terminal as an output file ◁
```

72. Here is how to open the terminal files. In the default configuration, nothing happens except that the command line (if there is one) is copied to the input buffer. The variable *command_line* will be filled by the *main* procedure.

```
#define t_open_out()
    do {    ▷ open the terminal for text output ◁
      mp→term_out ← (mp→open_file)(mp, "terminal", "w", mp_filetype_terminal);
      mp→err_out ← (mp→open_file)(mp, "error", "w", mp_filetype_error);
    } while (0)
#define t_open_in()
    do {    ▷ open the terminal for text input ◁
      mp→term_in ← (mp→open_file)(mp, "terminal", "r", mp_filetype_terminal);
      if (mp→command_line ≠ Λ) {
        mp→last ← strlen(mp→command_line);
        if (mp→last > (mp→buf_size + 1)) {
          mp_reallocate_buffer(mp, mp→last);
        }
        (void) memcpy((void *) mp→buffer, (void *) mp→command_line, mp→last);
        xfree(mp→command_line);
      }
      else {
        mp→last ← 0;
      }
    } while (0)
```

⟨ Option variables 30 ⟩ +≡

```
  char *command_line;
```

73. Sometimes it is necessary to synchronize the input/output mixture that happens on the user's terminal, and three system-dependent procedures are used for this purpose. The first of these, *update_terminal*, is called when we want to make sure that everything we have output to the terminal so far has actually left the computer's internal buffers and been sent. The second, *clear_terminal*, is called when we wish to cancel any input that the user may have typed ahead (since we are about to issue an unexpected error message). The third, *wake_up_terminal*, is supposed to revive the terminal if the user has disabled it by some instruction to the operating system. The following macros show how these operations can be specified:

⟨ MPlib internal header stuff 8 ⟩ +≡

```
#define update_terminal() (mp→flush_file)(mp, mp→term_out)    ▷ empty the terminal output buffer ◁
#define clear_terminal()    ▷ clear the terminal input buffer ◁
#define wake_up_terminal() (mp→flush_file)(mp, mp→term_out)
    ▷ cancel the user's cancellation of output ◁
```

74. We need a special routine to read the first line of METAPOST input from the user's terminal. This line is different because it is read before we have opened the transcript file; there is sort of a "chicken and egg" problem here. If the user types '`input cmr10`' on the first line, or if some macro invoked by that line does such an `input`, the transcript file will be named '`cmr10.log`'; but if no `input` commands are performed during the first line of terminal input, the transcript file will acquire its default name '`mpout.log`'. (The transcript file will not contain error messages generated by the first line before the first `input` command.)

The first line is even more special. It's nice to let the user start running a METAPOST job by typing a command line like '`MP cmr10`'; in such a case, METAPOST will operate as if the first line of input were '`cmr10`', i.e., the first line will consist of the remainder of the command line, after the part that invoked METAPOST.

75. Different systems have different ways to get started. But regardless of what conventions are adopted, the routine that initializes the terminal should satisfy the following specifications:

1) It should open file *term_in* for input from the terminal. (The file *term_out* will already be open for output to the terminal.)
2) If the user has given a command line, this line should be considered the first line of terminal input. Otherwise the user should be prompted with '`**`', and the first line of input should be whatever is typed in response.
3) The first line of input, which might or might not be a command line, should appear in locations *first* to $last - 1$ of the *buffer* array.
4) The global variable *loc* should be set so that the character to be read next by METAPOST is in *buffer*[*loc*]. This character should not be blank, and we should have $loc < last$.

(It may be necessary to prompt the user several times before a non-blank line comes in. The prompt is '`**`' instead of the later '`*`' because the meaning is slightly different: '`input`' need not be typed immediately after '`**`'.)

```
#define loc mp→cur_input.loc_field   ▷ location of first unread character in buffer ◁

  boolean mp_init_terminal(MP mp)
  {   ▷ gets the terminal input started ◁
    t_open_in();
    if (mp→last ≠ 0) {
      loc ← 0; mp→first ← 0; return true;
    }
    while (1) {
      if (¬mp→noninteractive) {
        wake_up_terminal(); mp_fputs("**", mp→term_out); update_terminal();
      }
      if (¬mp_input_ln(mp, mp→term_in)) {   ▷ this shouldn't happen ◁
        mp_fputs("\n!␣End␣of␣file␣on␣the␣terminal...␣why?", mp→term_out); return false;
      }
      loc ← (halfword) mp→first;
      while ((loc < (int) mp→last) ∧ (mp→buffer[loc] ≡ '␣')) incr(loc);
      if (loc < (int) mp→last) {
        return true;   ▷ return unless the line was all blank ◁
      }
      if (¬mp→noninteractive) {
        mp_fputs("Please␣type␣the␣name␣of␣your␣input␣file.\n", mp→term_out);
      }
    }
  }
```

76. ⟨ Declarations 10 ⟩ +≡

```
  static boolean mp_init_terminal(MP mp);
```

77. Globals for strings.

78. Symbolic token names and diagnostic messages are variable-length strings of eight-bit characters. Many strings METAPOST uses are simply literals in the compiled source, like the error messages and the names of the internal parameters. Other strings are used or defined from the METAPOST input language, and these have to be interned.

METAPOST uses strings more extensively than METAFONT does, but the necessary operations can still be handled with a fairly simple data structure. The avl tree *strings* contains all of the known string structures.

Each structure contains an **unsigned char** pointer containing the eight-bit data, a **size_t** that holds the length of that data, and an **int** that indicates how often this string is referenced (this will be explained below). Such strings are referred to by structure pointers called *mp_string*.

Besides the avl tree, there is a set of three variables called *cur_string*, *cur_length* and *cur_string_size* that are used for strings while they are being built.

⟨ Exported types 19 ⟩ +≡
```
typedef struct {
  unsigned char *str;   ▷ the string value ◁
  size_t len;   ▷ its length ◁
  int refs;   ▷ number of references ◁
} mp_lstring;
typedef mp_lstring *mp_string;   ▷ for pointers to string values ◁
```

79. The string handling functions are in `mpstrings.w`, but strings need a bunch of globals and those are defined here in the main file.

⟨ Global variables 18 ⟩ +≡
```
avl_tree strings;   ▷ string avl tree ◁
unsigned char *cur_string;   ▷ current string buffer ◁
size_t cur_length;   ▷ current index in that buffer ◁
size_t cur_string_size;   ▷ malloced size of cur_string ◁
```

80. ⟨ Allocate or initialize variables 32 ⟩ +≡
mp_initialize_strings(*mp*);

81. ⟨ Dealloc variables 31 ⟩ +≡
mp_dealloc_strings(*mp*);

82. The next four variables are for keeping track of string memory usage.

⟨ Global variables 18 ⟩ +≡
```
integer pool_in_use;   ▷ total number of string bytes actually in use ◁
integer max_pl_used;   ▷ maximum pool_in_use so far ◁
integer strs_in_use;   ▷ total number of strings actually in use ◁
integer max_strs_used;   ▷ maximum strs_in_use so far ◁
```

83. On-line and off-line printing. Messages that are sent to a user's terminal and to the transcript-log file are produced by several '*print*' procedures. These procedures will direct their output to a variety of places, based on the setting of the global variable *selector*, which has the following possible values:

term_and_log, the normal setting, prints on the terminal and on the transcript file.
log_only, prints only on the transcript file.
term_only, prints only on the terminal.
no_print, doesn't print at all. This is used only in rare cases before the transcript file is open.
pseudo, puts output into a cyclic buffer that is used by the *show_context* routine; when we get to that routine we shall discuss the reasoning behind this curious mode.
new_string, appends the output to the current string in the string pool.
≥ *write_file* prints on one of the files used for the **write** command.

The symbolic names '*term_and_log*', etc., have been assigned numeric codes that satisfy the convenient relations $no\_print + 1 \leftarrow term\_only$, $no\_print + 2 \leftarrow log\_only$, $term\_only + 2 \leftarrow log\_only + 1 \leftarrow term\_and\_log$. These relations are not used when *selector* could be *pseudo*, or *new_string*. We need not check for unprintable characters when $selector < pseudo$.

Three additional global variables, *tally*, *term_offset* and *file_offset* record the number of characters that have been printed since they were most recently cleared to zero. We use *tally* to record the length of (possibly very long) stretches of printing; *term_offset*, and *file_offset*, on the other hand, keep track of how many characters have appeared so far on the current line that has been output to the terminal, the transcript file, or the PostScript output file, respectively.

```
#define new_string 0     ▷ printing is deflected to the string pool ◁
#define pseudo 2     ▷ special selector setting for show_context ◁
#define no_print 3     ▷ selector setting that makes data disappear ◁
#define term_only 4     ▷ printing is destined for the terminal only ◁
#define log_only 5     ▷ printing is destined for the transcript file only ◁
#define term_and_log 6     ▷ normal selector setting ◁
#define write_file 7     ▷ first write file selector ◁

⟨ Global variables 18 ⟩ +≡
  void *log_file;     ▷ transcript of METAPOST session ◁
  void *output_file;     ▷ the generic font output goes here ◁
  unsigned int selector;     ▷ where to print a message ◁
  integer tally;     ▷ the number of characters recently printed ◁
  unsigned int term_offset;     ▷ the number of characters on the current terminal line ◁
  unsigned int file_offset;     ▷ the number of characters on the current file line ◁
  ASCII_code *trick_buf;     ▷ circular buffer for pseudoprinting ◁
  integer trick_count;     ▷ threshold for pseudoprinting, explained later ◁
  integer first_count;     ▷ another variable for pseudoprinting ◁
```

84. The first 128 strings will contain 95 standard ASCII characters, and the other 33 characters will be printed in three-symbol form like '`^^A`' unless a system-dependent change is made here. Installations that have an extended character set, where for example $xchr[\,^\circ\mathit{32}\,] \leftarrow$ '`≠`', would like string 032 to be printed as the single character 032 instead of the three characters 0136, 0136, 0132 (`^^Z`). On the other hand, even people with an extended character set will want to represent string 015 by `^^M`, since 015 is ASCII's "carriage return" code; the idea is to produce visible strings instead of tabs or line-feeds or carriage-returns or bell-rings or characters that are treated anomalously in text files.

The boolean expression defined here should be *true* unless METAPOST internal code number k corresponds to a non-troublesome visible symbol in the local character set. If character k cannot be printed, and $k < {}^\circ\mathit{200}$, then character $k + {}^\circ\mathit{100}$ or $k - {}^\circ\mathit{100}$ must be printable; moreover, ASCII codes $[\,^\circ\mathit{60}\,..071, {}^\circ\mathit{141}\,..0146]$ must be printable.

⟨ Character k cannot be printed 84 ⟩ ≡
$(k <$ '␣'$) \lor (k \equiv 127)$

This code is used in section 93.

85. ⟨ Allocate or initialize variables 32 ⟩ +≡
$mp\rightarrow trick\_buf \leftarrow xmalloc((mp\rightarrow error\_line + 1), \mathbf{sizeof}(\mathbf{ASCII\_code}));$

86. ⟨ Dealloc variables 31 ⟩ +≡
$xfree(mp\rightarrow trick\_buf);$

87. ⟨ Initialize the output routines 87 ⟩ ≡
$mp\rightarrow selector \leftarrow term\_only;$ $mp\rightarrow tally \leftarrow 0;$ $mp\rightarrow term\_offset \leftarrow 0;$ $mp\rightarrow file\_offset \leftarrow 0;$

See also section 96.

This code is used in sections 20 and 1068.

88. Macro abbreviations for output to the terminal and to the log file are defined here for convenience. Some systems need special conventions for terminal output, and it is possible to adhere to those conventions by changing *wterm*, *wterm_ln*, and *wterm_cr* here.

⟨ MPlib internal header stuff 8 ⟩ +≡

```
#define mp_fputs(b, f) (mp→write_ascii_file)(mp, f, b)
#define wterm(A) mp_fputs((A), mp→term_out)
#define wterm_chr(A)
  {
    unsigned char ss[2];
    ss[0] ← (A); ss[1] ← '\0'; wterm((char *) ss);
  }
#define wterm_cr mp_fputs("\n", mp→term_out)
#define wterm_ln(A)
  {
    wterm_cr; mp_fputs((A), mp→term_out);
  }
#define wlog(A) mp_fputs((A), mp→log_file)
#define wlog_chr(A)
  {
    unsigned char ss[2];
    ss[0] ← (A); ss[1] ← '\0'; wlog((char *) ss);
  }
#define wlog_cr mp_fputs("\n", mp→log_file)
#define wlog_ln(A)
  {
    wlog_cr; mp_fputs((A), mp→log_file);
  }
```

89. To end a line of text output, we call *print_ln*. Cases 0..*max_write_files* use an array *wr_file* that will be declared later.

```
#define mp_print_text(A) mp_print_str(mp, text((A)))
```

⟨ Internal library declarations 14 ⟩ +≡

```
  void mp_print(MP mp, const char *s);
  void mp_printf(MP mp, const char *ss, ...);
  void mp_print_ln(MP mp);
  void mp_print_char(MP mp, ASCII_code k);
  void mp_print_str(MP mp, mp_string s);
  void mp_print_nl(MP mp, const char *s);
  void mp_print_two(MP mp, mp_number x, mp_number y);
```

90. ⟨ Declarations 10 ⟩ +≡

```
  static void mp_print_visible_char(MP mp, ASCII_code s);
```

91. ⟨ Basic printing procedures 91 ⟩ ≡

```
void mp_print_ln(MP mp)
{    ▷ prints an end-of-line ◁
  switch (mp→selector) {
  case term_and_log: wterm_cr; wlog_cr; mp→term_offset ← 0; mp→file_offset ← 0; break;
  case log_only: wlog_cr; mp→file_offset ← 0; break;
  case term_only: wterm_cr; mp→term_offset ← 0; break;
  case no_print: case pseudo: case new_string: break;
  default: mp_fputs("\n", mp→wr_file[(mp→selector − write_file)]);
  }
}    ▷ note that tally is not affected ◁
```

See also sections 92, 93, 94, 95, 97, 98, 153, 192, 211, 213, and 855.

This code is used in section 7.

92. The *print_visible_char* procedure sends one character to the desired destination, using the *xchr* array to map it into an external character compatible with *input_ln*. (It assumes that it is always called with a visible ASCII character.) All printing comes through *print_ln* or *print_char*, which ultimately calls *print_visible_char*, hence these routines are the ones that limit lines to at most *max_print_line* characters. But we must make an exception for the PostScript output file since it is not safe to cut up lines arbitrarily in PostScript.

```
⟨ Basic printing procedures 91 ⟩ +≡
  static void mp_print_visible_char(MP mp, ASCII_code s)
  {    ▷ prints a single character ◁
    switch (mp→selector) {
    case term_and_log: wterm_chr(xchr(s)); wlog_chr(xchr(s)); incr(mp→term_offset);
      incr(mp→file_offset);
      if (mp→term_offset ≡ (unsigned) mp→max_print_line) {
        wterm_cr; mp→term_offset ← 0;
      }
      if (mp→file_offset ≡ (unsigned) mp→max_print_line) {
        wlog_cr; mp→file_offset ← 0;
      }
      break;
    case log_only: wlog_chr(xchr(s)); incr(mp→file_offset);
      if (mp→file_offset ≡ (unsigned) mp→max_print_line) mp_print_ln(mp);
      break;
    case term_only: wterm_chr(xchr(s)); incr(mp→term_offset);
      if (mp→term_offset ≡ (unsigned) mp→max_print_line) mp_print_ln(mp);
      break;
    case no_print: break;
    case pseudo:
      if (mp→tally < mp→trick_count) mp→trick_buf[mp→tally % mp→error_line] ← s;
      break;
    case new_string: append_char(s); break;
    default:
      {
        text_char ss[2] ← {0, 0};
        ss[0] ← xchr(s); mp_fputs((char *) ss, mp→wr_file[(mp→selector − write_file)]);
      }
    }
    incr(mp→tally);
  }
```

93. The *print_char* procedure sends one character to the desired destination. File names and string expressions might contain **ASCII_code** values that can't be printed using *print_visible_char*. These characters will be printed in three- or four-symbol form like '`^^A`' or '`^^e4`'. (This procedure assumes that it is safe to bypass all checks for unprintable characters when *selector* is in the range $0..max\_write\_files - 1$. The user might want to write unprintable characters.

⟨ Basic printing procedures 91 ⟩ +≡

```
void mp_print_char(MP mp, ASCII_code k)
{   ▷ prints a single character ◁
  if (mp→utf8_mode ∨ mp→selector < pseudo ∨ mp→selector ≥ write_file) {
    mp_print_visible_char(mp, k);
  }
  else if ((⟨ Character k cannot be printed 84 ⟩)) {
    mp_print(mp, "^^");
    if (k < °100) {
      mp_print_visible_char(mp, (ASCII_code)(k + °100));
    }
    else if (k < °200) {
      mp_print_visible_char(mp, (ASCII_code)(k − °100));
    }
    else {
      int l;   ▷ small index or counter ◁
      l ← (k/16); mp_print_visible_char(mp, xord(l < 10 ? l + '0' : l − 10 + 'a')); l ← (k % 16);
      mp_print_visible_char(mp, xord(l < 10 ? l + '0' : l − 10 + 'a'));
    }
  }
  else {
    mp_print_visible_char(mp, k);
  }
}
```

94. An entire string is output by calling *print*. Note that if we are outputting the single standard ASCII character `c`, we could call *print*(`"c"`), since `"c"` ← 99 is the number of a single-character string, as explained above. But *print_char*(`"c"`) is quicker, so METAPOST goes directly to the *print_char* routine when it knows that this is safe. (The present implementation assumes that it is always safe to print a visible ASCII character.)

⟨ Basic printing procedures 91 ⟩ +≡

```
static void mp_do_print(MP mp, const char *ss, size_t len)
{   ▷ prints string s ◁
  if (len ≡ 0) return;
  if (mp→selector ≡ new_string) {
    str_room(len); memcpy((mp→cur_string + mp→cur_length), ss, len); mp→cur_length += len;
  }
  else {
    size_t j ← 0;
    while (j < len) {   ▷ this was xord((int) ss[j]) but that doesn't work ◁
      mp_print_char(mp, (ASCII_code) ss[j]); j++;
    }
  }
}
```

95. ⟨ Basic printing procedures 91 ⟩ +≡

```
void mp_print(MP mp, const char *ss)
{
  assert(ss ≠ Λ); mp_do_print(mp, ss, strlen(ss));
}
void mp_printf(MP mp, const char *ss, ...)
{
  va_list ap;
  char pval[256];
  assert(ss ≠ Λ); va_start(ap, ss); vsnprintf(pval, 256, ss, ap); mp_do_print(mp, pval, strlen(pval));
  va_end(ap);
}
void mp_print_str(MP mp, mp_string s)
{
  assert(s ≠ Λ); mp_do_print(mp, (const char *) s→str, s→len);
}
```

96. Here is the very first thing that METAPOST prints: a headline that identifies the version number and base name. The *term_offset* variable is temporarily incorrect, but the discrepancy is not serious since we assume that the banner and mem identifier together will occupy at most *max_print_line* character positions.

⟨ Initialize the output routines 87 ⟩ +≡

```
wterm(mp→banner); mp_print_ln(mp); update_terminal();
```

97. The procedure *print_nl* is like *print*, but it makes sure that the string appears at the beginning of a new line.

⟨ Basic printing procedures 91 ⟩ +≡

```
void mp_print_nl(MP mp, const char *s)
{    ▷ prints string s at beginning of line ◁
  switch (mp→selector) {
  case term_and_log:
    if ((mp→term_offset > 0) ∨ (mp→file_offset > 0)) mp_print_ln(mp);
    break;
  case log_only:
    if (mp→file_offset > 0) mp_print_ln(mp);
    break;
  case term_only:
    if (mp→term_offset > 0) mp_print_ln(mp);
    break;
  case no_print: case pseudo: case new_string: break;
  }    ▷ there are no other cases ◁
  mp_print(mp, s);
}
```

98. The following procedure, which prints out the decimal representation of a given integer n, assumes that all integers fit nicely into a **int**.

⟨ Basic printing procedures 91 ⟩ +≡

```
void mp_print_int(MP mp, integer n)
{   ▷ prints an integer in decimal form ◁
  char s[12];
  mp_snprintf(s, 12, "%d", (int) n);  mp_print(mp, s);
}
void mp_print_pointer(MP mp, void *n)
{   ▷ prints an pointer in hexadecimal form ◁
  char s[12];
  mp_snprintf(s, 12, "%p", n);  mp_print(mp, s);
}
```

99. ⟨ Internal library declarations 14 ⟩ +≡

```
void mp_print_int(MP mp, integer n);
void mp_print_pointer(MP mp, void *n);
```

100. METAPOST also makes use of a trivial procedure to print two digits. The following subroutine is usually called with a parameter in the range $0 \le n \le 99$.

```
static void mp_print_dd(MP mp, integer n)
{   ▷ prints two least significant digits ◁
  n ← MPOST_ABS(n) % 100;  mp_print_char(mp, xord('0' + (n/10)));
  mp_print_char(mp, xord('0' + (n % 10)));
}
```

101. ⟨ Declarations 10 ⟩ +≡

```
static void mp_print_dd(MP mp, integer n);
```

102. Here is a procedure that asks the user to type a line of input, assuming that the *selector* setting is either *term_only* or *term_and_log*. The input is placed into locations *first* through $last - 1$ of the *buffer* array, and echoed on the transcript file if appropriate.

This procedure is never called when $interaction < mp\_scroll\_mode$.

```
#define prompt_input(A)
        do {
          if (¬mp→noninteractive) {
            wake_up_terminal( ); mp_print(mp, (A));
          }
          mp_term_input(mp);
        } while (0)      ▷ prints a string and gets a line of input ◁

void mp_term_input(MP mp)
{      ▷ gets a line from the terminal ◁
  size_t k;      ▷ index into buffer ◁
  if (mp→noninteractive) {
    if (¬mp_input_ln(mp, mp→term_in)) longjmp(∗(mp→jump_buf), 1);      ▷ chunk finished ◁
    mp→buffer[mp→last] ← xord('%');
  }
  else {
    update_terminal( );      ▷ Now the user sees the prompt for sure ◁
    if (¬mp_input_ln(mp, mp→term_in)) {
      mp_fatal_error(mp, "End␣of␣file␣on␣the␣terminal!");
    }
    mp→term_offset ← 0;      ▷ the user's line ended with ⟨return⟩ ◁
    decr(mp→selector);      ▷ prepare to echo the input ◁
    if (mp→last ≠ mp→first) {
      for (k ← mp→first; k < mp→last; k++) {
        mp_print_char(mp, mp→buffer[k]);
      }
    }
    mp_print_ln(mp); mp→buffer[mp→last] ← xord('%'); incr(mp→selector);
      ▷ restore previous status ◁
  }
}
```

103. Reporting errors.
The *print_err* procedure supplies a '!' before the official message, and makes sure that the terminal is awake if a stop is going to occur. The **error** procedure supplies a '.' after the official message, then it shows the location of the error; and if $interaction \leftarrow error\_stop\_mode$, it also enters into a dialog with the user, during which time the help message may be printed.

104. The global variable *interaction* has four settings, representing increasing amounts of user interaction:

⟨ Exported types 19 ⟩ +≡
```
enum mp_interaction_mode {
  mp_unspecified_mode ← 0,   ▷ extra value for command-line switch ◁
  mp_batch_mode,   ▷ omits all stops and omits terminal output ◁
  mp_nonstop_mode,   ▷ omits all stops ◁
  mp_scroll_mode,   ▷ omits error stops ◁
  mp_error_stop_mode   ▷ stops at every opportunity to interact ◁
};
```

105. ⟨ Option variables 30 ⟩ +≡
```
int interaction;   ▷ current level of interaction ◁
int noninteractive;   ▷ do we have a terminal? ◁
int extensions;
```

106. Set it here so it can be overwritten by the commandline

⟨ Allocate or initialize variables 32 ⟩ +≡
```
mp→interaction ← opt→interaction;
if (mp→interaction ≡ mp_unspecified_mode ∨ mp→interaction > mp_error_stop_mode)
  mp→interaction ← mp_error_stop_mode;
if (mp→interaction < mp_unspecified_mode) mp→interaction ← mp_batch_mode;
```

107. *print_err* is not merged in **error** because it is also used in *prompt_file_name*, where **error** is not called at all.

⟨ Declarations 10 ⟩ +≡
```
static void mp_print_err(MP mp, const char *A);
```

108.
```
static void mp_print_err(MP mp, const char *A)
{
  if (mp→interaction ≡ mp_error_stop_mode) wake_up_terminal();
  if (mp→file_line_error_style ∧ file_state ∧ ¬terminal_input) {
    mp_print_nl(mp, "");
    if (long_name ≠ Λ) {
      mp_print(mp, long_name);
    }
    else {
      mp_print(mp, mp_str(mp, name));
    }
    mp_print(mp, ":"); mp_print_int(mp, line); mp_print(mp, ":␣");
  }
  else {
    mp_print_nl(mp, "!␣");
  }
  mp_print(mp, A);
}
```

109. METAPOST is careful not to call **error** when the print *selector* setting might be unusual. The only possible values of *selector* at the time of error messages are

no_print (when *interaction* $\leftarrow$ *mp_batch_mode* and *log_file* not yet open);
term_only (when *interaction* $>$ *mp_batch_mode* and *log_file* not yet open);
log_only (when *interaction* $\leftarrow$ *mp_batch_mode* and *log_file* is open);
term_and_log (when *interaction* $>$ *mp_batch_mode* and *log_file* is open).

#define *initialize_print_selector*()
  mp→*selector* ← (*mp*→*interaction* ≡ *mp_batch_mode* ? *no_print* : *term_only*);

110. The global variable *history* records the worst level of error that has been detected. It has four possible values: *spotless*, *warning_issued*, *error_message_issued*, and *fatal_error_stop*.

Another global variable, *error_count*, is increased by one when an **error** occurs without an interactive dialog, and it is reset to zero at the end of every statement. If *error_count* reaches 100, METAPOST decides that there is no point in continuing further.

⟨ Exported types 19 ⟩ +≡
  enum mp_history_state {
    mp_spotless ← 0, ▷ *history* value when nothing has been amiss yet ◁
    mp_warning_issued, ▷ *history* value when *begin_diagnostic* has been called ◁
    mp_error_message_issued, ▷ *history* value when **error** has been called ◁
    mp_fatal_error_stop, ▷ *history* value when termination was premature ◁
    mp_system_error_stop ▷ *history* value when termination was due to disaster ◁
  };

111. ⟨ Global variables 18 ⟩ +≡
  int *history*; ▷ has the source input been clean so far? ◁
  int *error_count*; ▷ the number of scrolled errors since the last statement ended ◁

112. The value of *history* is initially *fatal_error_stop*, but it will be changed to *spotless* if METAPOST survives the initialization process.

113. Since errors can be detected almost anywhere in METAPOST, we want to declare the error procedures near the beginning of the program. But the error procedures in turn use some other procedures, which need to be declared *forward* before we get to **error** itself.

It is possible for **error** to be called recursively if some error arises when *get_next* is being used to delete a token, and/or if some fatal error occurs while METAPOST is trying to fix a non-fatal one. But such recursion is never more than two levels deep.

⟨ Declarations 10 ⟩ +≡
  static void *mp_get_next*(**MP** *mp*);
  static void *mp_term_input*(**MP** *mp*);
  static void *mp_show_context*(**MP** *mp*);
  static void *mp_begin_file_reading*(**MP** *mp*);
  static void *mp_open_log_file*(**MP** *mp*);
  static void *mp_clear_for_error_prompt*(**MP** *mp*);

114. ⟨ Internal library declarations 14 ⟩ +≡
  void *mp_normalize_selector*(**MP** *mp*);

115. ⟨ Global variables 18 ⟩ +≡
  boolean *use_err_help*; ▷ should the *err_help* string be shown? ◁
  mp_string *err_help*; ▷ a string set up by **errhelp** ◁

116. ⟨ Allocate or initialize variables 32 ⟩ +≡
$mp\rightarrow use\_err\_help \leftarrow false$;

117. The *jump_out* procedure just cuts across all active procedure levels and goes to *end_of_MP*. This is the only nonlocal **goto** statement in the whole program. It is used when there is no recovery from a particular error.

The program uses a *jump_buf* to handle this, this is initialized at three spots: the start of *mp_new*, the start of *mp_initialize*, and the start of *mp_run*. Those are the only library entry points.

⟨ Global variables 18 ⟩ +≡
jmp_buf $*jump\_buf$;

118. If the array of internals is still Λ when *jump_out* is called, a crash occurred during initialization, and it is not safe to run the normal cleanup routine.

⟨ Error handling procedures 118 ⟩ ≡
void *mp_jump_out*(**MP** *mp*)
{
if $(mp\rightarrow internal \neq \Lambda \wedge mp\rightarrow history < mp\_system\_error\_stop)$ *mp_close_files_and_terminate*(*mp*);
longjmp(∗(*mp*→*jump_buf*), 1);
}

See also sections 120, 138, 141, and 143.

This code is used in section 7.

119. ⟨ Internal library declarations 14 ⟩ +≡
void *mp_jump_out*(**MP** *mp*);

120. ⟨ Error handling procedures 118 ⟩ +≡
void *mp_warn*(**MP** *mp*, **const char** ∗*msg*)
{
unsigned *saved_selector* ← *mp*→*selector*;
mp_normalize_selector(*mp*); *mp_print_nl*(*mp*, "Warning:␣"); *mp_print*(*mp*, *msg*); *mp_print_ln*(*mp*);
mp→*selector* ← *saved_selector*;
}

121. Here now is the general **error** routine.

The argument *deletions_allowed* is set *false* if the *get_next* routine is active when **error** is called; this ensures that *get_next* will never be called recursively.

Individual lines of help are recorded in the array *help_line*, which contains entries in positions 0..(*help_ptr* − 1). They should be printed in reverse order, i.e., with *help_line*[0] appearing last.

```
void mp_error(MP mp, const char *msg, const char **hlp, boolean deletions_allowed)
{
  ASCII_code c;   ▷ what the user types ◁
  integer s1, s2;   ▷ used to save global variables when deleting tokens ◁
  mp_sym s3;   ▷ likewise ◁
  int i ← 0;
  const char *help_line[6];   ▷ helps for the next error ◁
  unsigned int help_ptr;   ▷ the number of help lines present ◁
  const char **cnt ← Λ;

  mp_print_err(mp, msg);
  if (hlp) {
    cnt ← hlp;
    while (*cnt) {
      i++; cnt++;
    }
    cnt ← hlp;
  }
  help_ptr ← i;
  while (i > 0) {
    help_line[--i] ← *cnt++;
  }
  if (mp→history < mp_error_message_issued) mp→history ← mp_error_message_issued;
  mp_print_char(mp, xord('.')); mp_show_context(mp);
  if (mp→halt_on_error) {
    mp→history ← mp_fatal_error_stop; mp_jump_out(mp);
  }
  if ((¬mp→noninteractive) ∧ (mp→interaction ≡ mp_error_stop_mode)) {
    ⟨Get user's advice and return 123⟩;
  }
  incr(mp→error_count);
  if (mp→error_count ≡ 100) {
    mp_print_nl(mp, "(That␣makes␣100␣errors;␣please␣try␣again.)");
    mp→history ← mp_fatal_error_stop; mp_jump_out(mp);
  }
  ⟨Put help message on the transcript file 136⟩;
}
```

122. ⟨Exported function headers 22⟩ +≡

```
extern void mp_error(MP mp, const char *msg, const char **hlp, boolean deletions_allowed);
extern void mp_warn(MP mp, const char *msg);
```

123. ⟨ Get user's advice and **return** 123 ⟩ ≡

```
while (true) {
CONTINUE: mp_clear_for_error_prompt(mp); prompt_input("? ");
  if (mp→last ≡ mp→first) return;
  c ← mp→buffer[mp→first];
  if (c ≥ 'a') c ← (ASCII_code)(c + 'A' − 'a');   ▷ convert to uppercase ◁
  ⟨ Interpret code c and return if done 129 ⟩;
}
```

This code is used in section 121.

124. It is desirable to provide an 'E' option here that gives the user an easy way to return from METAPOST to the system editor, with the offending line ready to be edited. But such an extension requires some system wizardry, so the present implementation simply types out the name of the file that should be edited and the relevant line number.

⟨ Exported types 19 ⟩ +≡

```
typedef void (*mp_editor_cmd)(MP, char *, int);
```

125. ⟨ Option variables 30 ⟩ +≡

```
mp_editor_cmd run_editor;
```

126. ⟨ Allocate or initialize variables 32 ⟩ +≡

```
set_callback_option(run_editor);
```

127. ⟨ Declarations 10 ⟩ +≡

```
static void mp_run_editor(MP mp, char *fname, int fline);
```

128.

```
void mp_run_editor(MP mp, char *fname, int fline)
{
  char *s ← xmalloc(256, 1);
  mp_snprintf(s, 256, "You want to edit file %s at line %d\n", fname, fline); wterm_ln(s);
}
```

129. ⟨ Interpret code *c* and **return** if done 129 ⟩ ≡

```
switch (c) {
case '0': case '1': case '2': case '3': case '4': case '5': case '6': case '7': case '8':
  case '9':
  if (deletions_allowed) {
    ⟨ Delete tokens and continue 133 ⟩;
  }
  break;
case 'E':
  if (mp→file_ptr > 0) {
    mp→interaction ← mp_scroll_mode; mp_close_files_and_terminate(mp);
    (mp→run_editor)(mp, mp_str(mp, mp→input_stack[mp→file_ptr].name_field), mp_true_line(mp));
    mp_jump_out(mp);
  }
  break;
case 'H': ⟨ Print the help information and continue 134 ⟩;   ▷ break; ◁
case 'I': ⟨ Introduce new material from the terminal and return 132 ⟩;   ▷ break; ◁
case 'Q': case 'R': case 'S': ⟨ Change the interaction level and return 131 ⟩;   ▷ break; ◁
case 'X': mp→interaction ← mp_scroll_mode; mp_jump_out(mp); break;
default: break;
}
⟨ Print the menu of available options 130 ⟩
```

This code is used in section 123.

130. ⟨ Print the menu of available options 130 ⟩ ≡

```
{
  mp_print(mp, "Type␣<return>␣to␣proceed,␣S␣to␣scroll␣future␣error␣messages,");
  mp_print_nl(mp, "R␣to␣run␣without␣stopping,␣Q␣to␣run␣quietly,");
  mp_print_nl(mp, "I␣to␣insert␣something,␣");
  if (mp→file_ptr > 0) mp_print(mp, "E␣to␣edit␣your␣file,");
  if (deletions_allowed)
    mp_print_nl(mp, "1␣or␣...␣or␣9␣to␣ignore␣the␣next␣1␣to␣9␣tokens␣of␣input,");
  mp_print_nl(mp, "H␣for␣help,␣X␣to␣quit.");
}
```

This code is used in section 129.

131. ⟨ Change the interaction level and **return** 131 ⟩ ≡

```
{
  mp→error_count ← 0; mp_print(mp, "OK,␣entering␣");
  switch (c) {
  case 'Q': mp→interaction ← mp_batch_mode; mp_print(mp, "batchmode"); decr(mp→selector);
    break;
  case 'R': mp→interaction ← mp_nonstop_mode; mp_print(mp, "nonstopmode"); break;
  case 'S': mp→interaction ← mp_scroll_mode; mp_print(mp, "scrollmode"); break;
  }   ▷ there are no other cases ◁
  mp_print(mp, "..."); mp_print_ln(mp); update_terminal(); return;
}
```

This code is used in section 129.

132. When the following code is executed, $buffer[(first + 1) \mathinner{..} (last - 1)]$ may contain the material inserted by the user; otherwise another prompt will be given. In order to understand this part of the program fully, you need to be familiar with METAPOST's input stacks.

⟨ Introduce new material from the terminal and **return** 132 ⟩ ≡

```
{
  mp_begin_file_reading(mp);    ▷ enter a new syntactic level for terminal input ◁
  if (mp→last > mp→first + 1) {
    loc ← (halfword)(mp→first + 1);  mp→buffer[mp→first] ← xord('␣');
  }
  else {
    prompt_input("insert>");  loc ← (halfword)mp→first;
  }
  mp→first ← mp→last + 1;  mp→cur_input.limit_field ← (halfword)mp→last;  return;
}
```

This code is used in section 129.

133. We allow deletion of up to 99 tokens at a time.

⟨ Delete tokens and **continue** 133 ⟩ ≡

```
{
  s1 ← cur_cmd();  s2 ← cur_mod();  s3 ← cur_sym();  mp→OK_to_interrupt ← false;
  if ((mp→last > mp→first + 1) ∧ (mp→buffer[mp→first + 1] ≥ '0') ∧ (mp→buffer[mp→first + 1] ≤ '9'))
    c ← xord(c * 10 + mp→buffer[mp→first + 1] − '0' * 11);
  else c ← (ASCII_code)(c − '0');
  while (c > 0) {
    mp_get_next(mp);    ▷ one-level recursive call of error is possible ◁
    ⟨ Decrease the string reference count, if the current token is a string 819 ⟩;
    c−−;
  }
  set_cur_cmd(s1);  set_cur_mod(s2);  set_cur_sym(s3);  mp→OK_to_interrupt ← true;  help_ptr ← 2;
  help_line[1] ← "I␣have␣just␣deleted␣some␣text,␣as␣you␣asked.";
  help_line[0] ← "You␣can␣now␣delete␣more,␣or␣insert,␣or␣whatever.";  mp_show_context(mp);
  goto CONTINUE;
}
```

This code is used in section 129.

134. Some wriggling with *help_line* is done here to avoid giving no information whatsoever, or presenting the same information twice in a row.

⟨ Print the help information and **continue** 134 ⟩ ≡

```
{
  if (mp→use_err_help) {
    ⟨ Print the string err_help, possibly on several lines 135 ⟩;
    mp→use_err_help ← false;
  }
  else {
    if (help_ptr ≡ 0) {
      help_ptr ← 2; help_line[1] ← "Sorry,␣I␣don't␣know␣how␣to␣help␣in␣this␣situation.";
      help_line[0] ← "Maybe␣you␣should␣try␣asking␣a␣human?";
    }
    do {
      decr(help_ptr); mp_print(mp, help_line[help_ptr]); mp_print_ln(mp);
    } while (help_ptr ≠ 0);
  }
  help_ptr ← 4; help_line[3] ← "Sorry,␣I␣already␣gave␣what␣help␣I␣could...";
  help_line[2] ← "Maybe␣you␣should␣try␣asking␣a␣human?";
  help_line[1] ← "An␣error␣might␣have␣occurred␣before␣I␣noticed␣any␣problems.";
  help_line[0] ← "``If␣all␣else␣fails,␣read␣the␣instructions.''"; goto CONTINUE;
}
```

This code is used in section 129.

135. ⟨ Print the string *err_help*, possibly on several lines 135 ⟩ ≡

```
{
  size_t j ← 0;
  while (j < mp→err_help→len) {
    if (*(mp→err_help→str + j) ≠ '%') mp_print(mp, (const char *)(mp→err_help→str + j));
    else if (j + 1 ≡ mp→err_help→len) mp_print_ln(mp);
    else if (*(mp→err_help→str + j) ≠ '%') mp_print_ln(mp);
    else {
      j++; mp_print_char(mp, xord('%'));
    }
    j++;
  }
}
```

This code is used in sections 134 and 136.

136. ⟨ Put help message on the transcript file 136 ⟩ ≡

```
if (¬mp→noninteractive) {
  if (mp→interaction > mp_batch_mode) {
    decr(mp→selector);   ▷ avoid terminal output ◁
  }
}
if (mp→use_err_help) {
  mp_print_nl(mp, ""); ⟨ Print the string err_help, possibly on several lines 135 ⟩;
}
else {
  while (help_ptr > 0) {
    decr(help_ptr); mp_print_nl(mp, help_line[help_ptr]);
  }
  mp_print_ln(mp);
  if (¬mp→noninteractive) {
    if (mp→interaction > mp_batch_mode) incr(mp→selector);   ▷ re-enable terminal output ◁
  }
  mp_print_ln(mp);
}
```

This code is used in section 121.

137. In anomalous cases, the print selector might be in an unknown state; the following subroutine is called to fix things just enough to keep running a bit longer.

```
void mp_normalize_selector(MP mp)
{
  if (mp→log_opened) mp→selector ← term_and_log;
  else mp→selector ← term_only;
  if (mp→job_name ≡ Λ) mp_open_log_file(mp);
  if (mp→interaction ≡ mp_batch_mode) decr(mp→selector);
}
```

138. The following procedure prints METAPOST's last words before dying.

⟨ Error handling procedures 118 ⟩ +≡

```
void mp_fatal_error(MP mp, const char *s)
{   ▷ prints s, and that's it ◁
  const char *hlp[] ← {s, Λ};
  mp_normalize_selector(mp);
  if (mp→interaction ≡ mp_error_stop_mode) mp→interaction ← mp_scroll_mode;
      ▷ no more interaction ◁
  if (mp→log_opened) mp_error(mp, "Emergency␣stop", hlp, true);
  mp→history ← mp_fatal_error_stop; mp_jump_out(mp);   ▷ irrecoverable error ◁
}
```

139. ⟨ Exported function headers 22 ⟩ +≡

```
extern void mp_fatal_error(MP mp, const char *s);
```

140. ⟨ Internal library declarations 14 ⟩ +≡

```
void mp_overflow(MP mp, const char *s, integer n);
```

141. ⟨ Error handling procedures 118 ⟩ +≡

```
void mp_overflow(MP mp, const char *s, integer n)
{   ▷ stop due to finiteness ◁
  char msg[256];
  const char *hlp[] ← {"If␣you␣really␣absolutely␣need␣more␣capacity,",
      "you␣can␣ask␣a␣wizard␣to␣enlarge␣me.", Λ};
  mp_normalize_selector(mp);
  mp_snprintf(msg, 256, "MetaPost␣capacity␣exceeded,␣sorry␣[%s=%d]", s, (int) n);
  if (mp→interaction ≡ mp_error_stop_mode) mp→interaction ← mp_scroll_mode;
      ▷ no more interaction ◁
  if (mp→log_opened) mp_error(mp, msg, hlp, true);
  mp→history ← mp_fatal_error_stop; mp_jump_out(mp);   ▷ irrecoverable error ◁
}
```

142. The program might sometime run completely amok, at which point there is no choice but to stop. If no previous error has been detected, that's bad news; a message is printed that is really intended for the METAPOST maintenance person instead of the user (unless the user has been particularly diabolical). The index entries for 'this can't happen' may help to pinpoint the problem.

⟨ Internal library declarations 14 ⟩ +≡

```
void mp_confusion(MP mp, const char *s);
```

143. Consistency check violated; *s* tells where.

⟨ Error handling procedures 118 ⟩ +≡

```
void mp_confusion(MP mp, const char *s)
{
  char msg[256];
  const char *hlp[] ← {"One␣of␣your␣faux␣pas␣seems␣to␣have␣wounded␣me␣deeply...",
      "in␣fact,␣I'm␣barely␣conscious.␣Please␣fix␣it␣and␣try␣again.", Λ};
  mp_normalize_selector(mp);
  if (mp→history < mp_error_message_issued) {
    mp_snprintf(msg, 256, "This␣can't␣happen␣(%s)", s);
    hlp[0] ← "I'm␣broken.␣Please␣show␣this␣to␣someone␣who␣can␣fix␣can␣fix"; hlp[1] ← Λ;
  }
  else {
    mp_snprintf(msg, 256, "I␣can\'t␣go␣on␣meeting␣you␣like␣this");
  }
  if (mp→interaction ≡ mp_error_stop_mode) mp→interaction ← mp_scroll_mode;
      ▷ no more interaction ◁
  if (mp→log_opened) mp_error(mp, msg, hlp, true);
  mp→history ← mp_fatal_error_stop; mp_jump_out(mp);   ▷ irrecoverable error ◁
}
```

144. Users occasionally want to interrupt METAPOST while it's running. If the runtime system allows this, one can implement a routine that sets the global variable *interrupt* to some nonzero value when such an interrupt is signaled. Otherwise there is probably at least a way to make *interrupt* nonzero using the C debugger.

```
#define check_interrupt
        {
          if (mp→interrupt ≠ 0) mp_pause_for_instructions(mp);
        }
⟨ Global variables 18 ⟩ +≡
  integer interrupt;   ▷ should METAPOST pause for instructions? ◁
  boolean OK_to_interrupt;   ▷ should interrupts be observed? ◁
  integer run_state;   ▷ are we processing input ? ◁
  boolean finished;   ▷ set true by close_files_and_terminate ◁
  boolean reading_preload;
```

145. ⟨ Allocate or initialize variables 32 ⟩ +≡

```
  mp→OK_to_interrupt ← true; mp→finished ← false;
```

146. When an interrupt has been detected, the program goes into its highest interaction level and lets the user have the full flexibility of the **error** routine. METAPOST checks for interrupts only at times when it is safe to do this.

```
  static void mp_pause_for_instructions(MP mp)
  {
    const char *hlp[] ← {"You␣rang?",
        "Try␣to␣insert␣some␣instructions␣for␣me␣(e.g.,‘I␣show␣x’),",
        "unless␣you␣just␣want␣to␣quit␣by␣typing␣‘X’.", Λ};
    if (mp→OK_to_interrupt) {
      mp→interaction ← mp_error_stop_mode;
      if ((mp→selector ≡ log_only) ∨ (mp→selector ≡ no_print)) incr(mp→selector);
      mp_error(mp, "Interruption", hlp, false); mp→interrupt ← 0;
    }
  }
```

147. Arithmetic with scaled numbers. The principal computations performed by METAPOST are done entirely in terms of integers less than 2^{31} in magnitude; thus, the arithmetic specified in this program can be carried out in exactly the same way on a wide variety of computers, including some small ones.

But C does not rigidly define the / operation in the case of negative dividends; for example, the result of $(-2*n-1)/2$ is $-(n+1)$ on some computers and $-n$ on others (is this true ?). There are two principal types of arithmetic: "translation-preserving," in which the identity $(a+q*b)/b \leftarrow (a/b)+q$ is valid; and "negation-preserving," in which $(-a)/b \leftarrow -(a/b)$. This leads to two METAPOSTs, which can produce different results, although the differences should be negligible when the language is being used properly. The TeX processor has been defined carefully so that both varieties of arithmetic will produce identical output, but it would be too inefficient to constrain METAPOST in a similar way.

```
#define inf_t ((math_data *) mp→math)→inf_t
```

148. A single computation might use several subroutine calls, and it is desirable to avoid producing multiple error messages in case of arithmetic overflow. So the routines below set the global variable *arith_error* to *true* instead of reporting errors directly to the user.

```
⟨Global variables 18⟩ +≡
  boolean arith_error;   ▷ has arithmetic overflow occurred recently? ◁
```

149. ⟨Allocate or initialize variables 32⟩ +≡

```
  mp→arith_error ← false;
```

150. At crucial points the program will say *check_arith*, to test if an arithmetic error has been detected.

```
#define check_arith()
        do {
          if (mp→arith_error) mp_clear_arith(mp);
        } while (0)

  static void mp_clear_arith(MP mp)
  {
    const char *hlp[] ← {"Uh,␣oh.␣A␣little␣while␣ago␣one␣of␣the␣quantities␣that␣I␣was",
        "computing␣got␣too␣large,␣so␣I'm␣afraid␣your␣answers␣will␣be",
        "somewhat␣askew.␣You'll␣probably␣have␣to␣adopt␣different",
        "tactics␣next␣time.␣But␣I␣shall␣try␣to␣carry␣on␣anyway.", Λ};
    mp_error(mp, "Arithmetic␣overflow", hlp, true);  mp→arith_error ← false;
  }
```

151. The definitions of these are set up by the math initialization.

```
#define arc_tol_k ((math_data *) mp→math)→arc_tol_k
#define coef_bound_k ((math_data *) mp→math)→coef_bound_k
#define coef_bound_minus_1 ((math_data *) mp→math)→coef_bound_minus_1
#define sqrt_8_e_k ((math_data *) mp→math)→sqrt_8_e_k
#define twelve_ln_2_k ((math_data *) mp→math)→twelve_ln_2_k
#define twelvebits_3 ((math_data *) mp→math)→twelvebits_3
#define one_k ((math_data *) mp→math)→one_k
#define epsilon_t ((math_data *) mp→math)→epsilon_t
#define unity_t ((math_data *) mp→math)→unity_t
#define zero_t ((math_data *) mp→math)→zero_t
#define two_t ((math_data *) mp→math)→two_t
#define three_t ((math_data *) mp→math)→three_t
#define half_unit_t ((math_data *) mp→math)→half_unit_t
#define three_quarter_unit_t ((math_data *) mp→math)→three_quarter_unit_t
#define twentysixbits_sqrt2_t ((math_data *) mp→math)→twentysixbits_sqrt2_t
#define twentyeightbits_d_t ((math_data *) mp→math)→twentyeightbits_d_t
#define twentysevenbits_sqrt2_d_t ((math_data *) mp→math)→twentysevenbits_sqrt2_d_t
#define warning_limit_t ((math_data *) mp→math)→warning_limit_t
#define precision_default ((math_data *) mp→math)→precision_default
#define precision_max ((math_data *) mp→math)→precision_max
#define precision_min ((math_data *) mp→math)→precision_min
```

152. In fact, the two sorts of scaling discussed above aren't quite sufficient; METAPOST has yet another, used internally to keep track of angles.

153. We often want to print two scaled quantities in parentheses, separated by a comma.

⟨ Basic printing procedures 91 ⟩ +≡

```
void mp_print_two(MP mp, mp_number x, mp_number y)
{    ▷ prints '(x, y)' ◁
  mp_print_char(mp, xord('(')); print_number(x); mp_print_char(mp, xord(',')); print_number(y);
  mp_print_char(mp, xord(')'));
}
```

154.

```
#define fraction_one_t ((math_data *) mp→math)→fraction_one_t
#define fraction_half_t ((math_data *) mp→math)→fraction_half_t
#define fraction_three_t ((math_data *) mp→math)→fraction_three_t
#define fraction_four_t ((math_data *) mp→math)→fraction_four_t
#define one_eighty_deg_t ((math_data *) mp→math)→one_eighty_deg_t
#define three_sixty_deg_t ((math_data *) mp→math)→three_sixty_deg_t
```

155. ⟨ Local variables for initialization 39 ⟩ +≡

```
integer k;    ▷ all-purpose loop index ◁
```

156. And now let's complete our collection of numeric utility routines by considering random number generation. METAPOST generates pseudo-random numbers with the additive scheme recommended in Section 3.6 of *The Art of Computer Programming*; however, the results are random fractions between 0 and *fraction_one* − 1, inclusive.

There's an auxiliary array *randoms* that contains 55 pseudo-random fractions. Using the recurrence $x_n = (x_{n-55} - x_{n-31}) \bmod 2^{28}$, we generate batches of 55 new x_n's at a time by calling *new_randoms*. The global variable *j_random* tells which element has most recently been consumed. The global variable *random_seed* was introduced in version 0.9, for the sole reason of stressing the fact that the initial value of the random seed is system-dependent. The initialization code below will initialize this variable to (*internal*[*mp_time*] div *unity*) + *internal*[*mp_day*], but this is not good enough on modern fast machines that are capable of running multiple MetaPost processes within the same second.

⟨ Global variables 18 ⟩ +≡
mp_number *randoms*[55]; ▷ the last 55 random values generated ◁
int *j_random*; ▷ the number of unused *randoms* ◁

157. ⟨ Option variables 30 ⟩ +≡
int *random_seed*; ▷ the default random seed ◁

158. ⟨ Allocate or initialize variables 32 ⟩ +≡
mp→*random_seed* ← *opt*→*random_seed*;
{
  int *i*;
  for (*i* ← 0; *i* < 55; *i*++) {
    new_fraction(*mp*→*randoms*[*i*]);
  }
}

159. ⟨ Dealloc variables 31 ⟩ +≡
{
  int *i*;
  for (*i* ← 0; *i* < 55; *i*++) {
    free_number(*mp*→*randoms*[*i*]);
  }
}

160. ⟨ Internal library declarations 14 ⟩ +≡
void *mp_new_randoms*(**MP** *mp*);

161. **void** *mp_new_randoms*(**MP** *mp*)

```
{
  int k;    ▷ index into randoms ◁
  mp_number x;    ▷ accumulator ◁
  new_number(x);
  for (k ← 0; k ≤ 23; k++) {
    set_number_from_substraction(x, mp→randoms[k], mp→randoms[k + 31]);
    if (number_negative(x)) number_add(x, fraction_one_t);
    number_clone(mp→randoms[k], x);
  }
  for (k ← 24; k ≤ 54; k++) {
    set_number_from_substraction(x, mp→randoms[k], mp→randoms[k − 24]);
    if (number_negative(x)) number_add(x, fraction_one_t);
    number_clone(mp→randoms[k], x);
  }
  free_number(x); mp→j_random ← 54;
}
```

162. To consume a random fraction, the program below will say '*next_random*'. Now each number system has its own implementation, true to the original as much as possible.

Unused.

```
#if 0
  static void mp_next_random(MP mp, mp_number *ret)
  {
    if (mp→j_random ≡ 0) mp_new_randoms(mp);
    else decr(mp→j_random);
    number_clone(*ret, mp→randoms[mp→j_random]);
  }
#endif
```

163. To produce a uniform random number in the range $0 \le u < x$ or $0 \ge u > x$ or $0 \leftarrow u \leftarrow x$, given a *scaled* value x, we proceed as shown here.

Note that the call of *take_fraction* will produce the values 0 and x with about half the probability that it will produce any other particular values between 0 and x, because it rounds its answers. This is the original one, that stays as reference: As said before, now each number system has its own implementation.

Unused.

```
#if 0
  static void mp_unif_rand(MP mp, mp_number *ret, mp_number x_orig)
  {
    mp_number y;    ◇ trial value
    mp_number x, abs_x;
    mp_number u;
    new_fraction(y); new_number(x); new_number(abs_x); new_number(u); number_clone(x, x_orig);
    number_clone(abs_x, x); number_abs(abs_x); mp_next_random(mp, &u); take_fraction(y, abs_x, u);
    free_number(u);
    if (number_equal(y, abs_x)) {
      set_number_to_zero(*ret);
    }
    else if (number_positive(x)) {
      number_clone(*ret, y);
    }
    else {
      number_clone(*ret, y); number_negate(*ret);
    }
    free_number(abs_x); free_number(x); free_number(y);
  }
#endif
```

164. Finally, a normal deviate with mean zero and unit standard deviation can readily be obtained with the ratio method (Algorithm 3.4.1R in *The Art of Computer Programming*). This is the original one, that stays as reference: Now each number system has its own implementation, true to the original as much as possible.

Unused.

```
#if 0
  static void mp_norm_rand(MP mp, mp_number *ret)
  {
    mp_number ab_vs_cd;
    mp_number abs_x;
    mp_number u;
    mp_number r;
    mp_number la, xa;
    new_number(ab_vs_cd); new_number(la); new_number(xa); new_number(abs_x); new_number(u);
    new_number(r);
    do {
      do {
        mp_number v;
        new_number(v); mp_next_random(mp, &v); number_substract(v, fraction_half_t);
        take_fraction(xa, sqrt_8_e_k, v); free_number(v); mp_next_random(mp, &u);
        number_clone(abs_x, xa); number_abs(abs_x);
      } while (number_greaterequal(abs_x, u));
      make_fraction(r, xa, u); number_clone(xa, r); m_log(la, u);
      set_number_from_substraction(la, twelve_ln_2_k, la); ab_vs_cd(ab_vs_cd, one_k, la, xa, xa);
    } while (number_negative(ab_vs_cd));
    number_clone(*ret, xa); free_number(ab_vs_cd); free_number(r); free_number(abs_x); free_number(la);
    free_number(xa); free_number(u);
  }
#endif
```

165. Packed data.

#define *max_quarterword* #3FFF ▷ largest allowable value in a *quarterword* ◁
#define *max_halfword* #FFFFFFF ▷ largest allowable value in a *halfword* ◁

166. The macros *qi* and *qo* are used for input to and output from quarterwords. These are legacy macros.

#define *qo*(*A*) (*A*) ▷ to read eight bits from a quarterword ◁
#define *qi*(*A*) (*quarterword*)(*A*) ▷ to store eight bits in a quarterword ◁

167. The reader should study the following definitions closely:

⟨ Types in the outer block 37 ⟩ +≡

```
typedef struct mp_value_node_data *mp_value_node;
typedef struct mp_node_data *mp_node;
typedef struct mp_symbol_entry *mp_sym;
typedef short quarterword;    ▷ 1/4 of a word ◁
typedef int halfword;    ▷ 1/2 of a word ◁
typedef struct {
  integer scale;    ▷ only for indep_scale, used together with serial ◁
  integer serial;    ▷ only for indep_value, used together with scale ◁
} mp_independent_data;
typedef struct {
  mp_independent_data indep;
  mp_number n;
  mp_string str;
  mp_sym sym;
  mp_node node;
  mp_knot p;
} mp_value_data;
typedef struct {
  mp_variable_type type;
  mp_value_data data;
} mp_value;
typedef struct {
  quarterword b0, b1, b2, b3;
} four_quarters;
typedef union {
  integer sc;
  four_quarters qqqq;
} font_data;
```

168. The global variable *math_mode* has four settings, representing the math value type that will be used in this run.

the typedef for **mp_number** is here because it has to come very early.

⟨ Exported types 19 ⟩ +≡

```
typedef enum {
  mp_math_scaled_mode ← 0, mp_math_double_mode ← 1, mp_math_binary_mode ← 2,
      mp_math_decimal_mode ← 3, mp_math_interval_mode ← 4
} mp_math_mode;
```

169. ⟨ Option variables 30 ⟩ +≡

```
int math_mode;    ▷ math mode ◁
```

170. ⟨ Allocate or initialize variables 32 ⟩ +≡
mp→*math_mode* ← *opt*→*math_mode*;

171. **#define** *xfree*(*A*)
do {
mp_xfree(*A*); *A* ← Λ;
} **while** (0)
#define *xrealloc*(*P*, *A*, *B*) *mp_xrealloc*(*mp*, *P*, (**size_t**) *A*, *B*)
#define *xmalloc*(*A*, *B*) *mp_xmalloc*(*mp*, (**size_t**) *A*, *B*)
#define *xstrdup*(*A*) *mp_xstrdup*(*mp*, *A*)
#define `XREALLOC`(*a*, *b*, *c*) *a* ← *xrealloc*(*a*, (*b* + 1), **sizeof** (*c*));

⟨ Declare helpers 171 ⟩ ≡
extern void *mp_xfree*(**void** ∗*x*);
extern void ∗*mp_xrealloc*(**MP** *mp*, **void** ∗*p*, **size_t** *nmem*, **size_t** *size*);
extern void ∗*mp_xmalloc*(**MP** *mp*, **size_t** *nmem*, **size_t** *size*);
extern void *mp_do_snprintf*(**char** ∗*str*, **int** *size*, **const char** ∗*fmt*, ...);
extern void ∗*do_alloc_node*(**MP** *mp*, **size_t** *size*);

This code is used in section 4.

172. This is an attempt to spend less time in *malloc*( ):

#define *max_num_token_nodes* 1000
#define *max_num_pair_nodes* 1000
#define *max_num_knot_nodes* 1000
#define *max_num_value_nodes* 1000
#define *max_num_symbolic_nodes* 1000

⟨ Global variables 18 ⟩ +≡
mp_node *token_nodes*;
int *num_token_nodes*;
mp_node *pair_nodes*;
int *num_pair_nodes*;
mp_knot *knot_nodes*;
int *num_knot_nodes*;
mp_node *value_nodes*;
int *num_value_nodes*;
mp_node *symbolic_nodes*;
int *num_symbolic_nodes*;

173. ⟨ Allocate or initialize variables 32 ⟩ +≡
mp→*token_nodes* ← Λ; *mp*→*num_token_nodes* ← 0; *mp*→*pair_nodes* ← Λ; *mp*→*num_pair_nodes* ← 0;
mp→*knot_nodes* ← Λ; *mp*→*num_knot_nodes* ← 0; *mp*→*value_nodes* ← Λ; *mp*→*num_value_nodes* ← 0;
mp→*symbolic_nodes* ← Λ; *mp*→*num_symbolic_nodes* ← 0;

174. ⟨ Dealloc variables 31 ⟩ +≡

while (*mp→value_nodes*) {
  mp_node *p* ← *mp→value_nodes*;
  mp→value_nodes ← *p→link*; *mp_free_node*(*mp*, *p*, *value_node_size*);
}
while (*mp→symbolic_nodes*) {
  mp_node *p* ← *mp→symbolic_nodes*;
  mp→symbolic_nodes ← *p→link*; *mp_free_node*(*mp*, *p*, *symbolic_node_size*);
}
while (*mp→pair_nodes*) {
  mp_node *p* ← *mp→pair_nodes*;
  mp→pair_nodes ← *p→link*; *mp_free_node*(*mp*, *p*, *pair_node_size*);
}
while (*mp→token_nodes*) {
  mp_node *p* ← *mp→token_nodes*;
  mp→token_nodes ← *p→link*; *mp_free_node*(*mp*, *p*, *token_node_size*);
}
while (*mp→knot_nodes*) {
  mp_knot *p* ← *mp→knot_nodes*;
  mp→knot_nodes ← *p→next*; *mp_free_knot*(*mp*, *p*);
}

175. This is a nicer way of allocating nodes.

#**define** *malloc_node*(*A*) *do_alloc_node*(*mp*, (*A*))

void ∗*do_alloc_node*(**MP** *mp*, **size_t** *size*)
{
  void ∗*p*;
  p ← *xmalloc*(1, *size*); *add_var_used*(*size*); ((**mp_node**) *p*)→*link* ← Λ;
  ((**mp_node**) *p*)→*has_number* ← 0; **return** *p*;
}

176. The *max_size_test* guards against overflow, on the assumption that **size_t** is at least 31bits wide.

```
#define max_size_test #7FFFFFFF
  void mp_xfree(void *x)
  {
    if (x ≠ Λ) free(x);
  }
  void *mp_xrealloc(MP mp, void *p, size_t nmem, size_t size)
  {
    void *w;
    if ((max_size_test/size) < nmem) {
      mp_fputs("Memory␣size␣overflow!\n", mp→err_out); mp→history ← mp_fatal_error_stop;
      mp_jump_out(mp);
    }
    w ← realloc(p, (nmem * size));
    if (w ≡ Λ) {
      mp_fputs("Out␣of␣memory!\n", mp→err_out); mp→history ← mp_system_error_stop;
      mp_jump_out(mp);
    }
    return w;
  }
  void *mp_xmalloc(MP mp, size_t nmem, size_t size)
  {
    void *w;
#if DEBUG
    if ((max_size_test/size) < nmem) {
      mp_fputs("Memory␣size␣overflow!\n", mp→err_out); mp→history ← mp_fatal_error_stop;
      mp_jump_out(mp);
    }
#endif
    w ← calloc(nmem, size);    ▷ TODO: check an un-initialized use of w and replace calloc with malloc. ◁
    if (w ≡ Λ) {
      mp_fputs("Out␣of␣memory!\n", mp→err_out); mp→history ← mp_system_error_stop;
      mp_jump_out(mp);
    }
    return w;
  }
```

177. ⟨Internal library declarations 14⟩ +≡   ▷ Avoid warning on format truncation ◁

```
#define mp_snprintf(...) (snprintf(__VA_ARGS__) < 0 ? abort() : (void) 0)
```

178. Dynamic memory allocation.

The METAPOST system does nearly all of its own memory allocation, so that it can readily be transported into environments that do not have automatic facilities for strings, garbage collection, etc., and so that it can be in control of what error messages the user receives.

#define MP_VOID (**mp_node**)(1) ▷ $\Lambda + 1$, a Λ pointer different from Λ ◁
#define *mp_link*(*A*) (*A*)→*link* ▷ the *link* field of a node ◁
#define *set_mp_link*(*A*, *B*)
do {
mp_node *d* ← (*B*);
▷ *printf* ("set␣link␣␣␣␣of␣%p␣to␣%p␣on␣line␣%d\n", (*A*), *d*, __LINE__); ◁
mp_link((*A*)) ← *d*;
} **while** (0)
#define *mp_type*(*A*) (*A*)→*type* ▷ identifies what kind of value this is ◁
#define *mp_name_type*(*A*) (*A*)→*name_type* ▷ a clue to the name of this value ◁

⟨ MPlib internal header stuff 8 ⟩ +≡
#define NODE_BODY
mp_variable_type *type*;
mp_name_type_type *name_type*;
unsigned short *has_number*;
struct mp_node_data ∗*link*
typedef struct mp_node_data {
NODE_BODY;
mp_value_data *data*;
} **mp_node_data**;
typedef struct mp_node_data ∗**mp_symbolic_node**;

179. Users who wish to study the memory requirements of particular applications can can use the special features that keep track of current and maximum memory usage. METAPOST will report these statistics when *mp_tracing_stats* is positive.

#define *add_var_used*(*a*)
do {
mp→*var_used* += (*a*);
if (*mp*→*var_used* > *mp*→*var_used_max*) *mp*→*var_used_max* ← *mp*→*var_used*;
} **while** (0)

⟨ Global variables 18 ⟩ +≡
size_t *var_used*; ▷ how much memory is in use ◁
size_t *var_used_max*; ▷ how much memory was in use max ◁

180. These redirect to function to aid in debugging.

```
#if DEBUG
#define mp_sym_info(A) get_mp_sym_info(mp, (A))
#define set_mp_sym_info(A, B) do_set_mp_sym_info(mp, (A), (B))
#define mp_sym_sym(A) get_mp_sym_sym(mp, (A))
#define set_mp_sym_sym(A, B) do_set_mp_sym_sym(mp, (A), (mp_sym)(B))
  static void do_set_mp_sym_info(MP mp, mp_node p, halfword v)
  {
    FUNCTION_TRACE3("do_set_mp_sym_info(%p,%d)\n", p, v); assert(p→type ≡ mp_symbol_node);
    set_indep_value(p, v);
  }
  static halfword get_mp_sym_info(MP mp, mp_node p)
  {
    FUNCTION_TRACE3("%d␣=␣get_mp_sym_info(%p)\n", indep_value(p), p);
    assert(p→type ≡ mp_symbol_node); return indep_value(p);
  }
  static void do_set_mp_sym_sym(MP mp, mp_node p, mp_sym v)
  {
    mp_symbolic_node pp ← (mp_symbolic_node) p;
    FUNCTION_TRACE3("do_set_mp_sym_sym(%p,%p)\n", pp, v); assert(pp→type ≡ mp_symbol_node);
    pp→data.sym ← v;
  }
  static mp_sym get_mp_sym_sym(MP mp, mp_node p)
  {
    mp_symbolic_node pp ← (mp_symbolic_node) p;
    FUNCTION_TRACE3("%p␣=␣get_mp_sym_sym(%p)\n", pp→data.sym, pp);
    assert(pp→type ≡ mp_symbol_node); return pp→data.sym;
  }
#else
#define mp_sym_info(A) indep_value(A)
#define set_mp_sym_info(A, B) set_indep_value(A, (B))
#define mp_sym_sym(A) (A)→data.sym
#define set_mp_sym_sym(A, B) (A)→data.sym ← (mp_sym)(B)
#endif
```

181. ⟨ Declarations 10 ⟩ +≡

```
#if DEBUG
  static void do_set_mp_sym_info(MP mp, mp_node A, halfword B);
  static halfword get_mp_sym_info(MP mp, mp_node p);
  static void do_set_mp_sym_sym(MP mp, mp_node A, mp_sym B);
  static mp_sym get_mp_sym_sym(MP mp, mp_node p);
#endif
```

182. The function *get_symbolic_node* returns a pointer to a new symbolic node whose *link* field is null.

```
#define symbolic_node_size sizeof(mp_node_data)
  static mp_node mp_get_symbolic_node(MP mp)
  {
    mp_symbolic_node p;
    if (mp→symbolic_nodes) {
      p ← (mp_symbolic_node) mp→symbolic_nodes; mp→symbolic_nodes ← p→link;
      mp→num_symbolic_nodes −−; p→link ← Λ;
    }
    else {
      p ← malloc_node(symbolic_node_size); new_number(p→data.n); p→has_number ← 1;
    }
    p→type ← mp_symbol_node; p→name_type ← mp_normal_sym;
    FUNCTION_TRACE2("%p␣=␣mp_get_symbolic_node()\n", p); return (mp_node) p;
  }
```

183. Conversely, when some node p of size s is no longer needed, the operation *free_node*(p, s) will make its words available, by inserting p as a new empty node just before where *rover* now points.

A symbolic node is recycled by calling *free_symbolic_node*.

```
void mp_free_node(MP mp, mp_node p, size_t siz)
{   ▷ node liberation ◁
  FUNCTION_TRACE3("mp_free_node(%p,%d)\n", p, (int) siz);
  if (¬p) return;
  mp→var_used −= siz;
  if (mp→math_mode > mp_math_double_mode) {
    if (p→has_number ≥ 1 ∧ is_number(((mp_symbolic_node) p)→data.n)) {
      free_number(((mp_symbolic_node) p)→data.n);
    }
    if (p→has_number ≡ 2 ∧ is_number(((mp_value_node) p)→subscript_)) {
      free_number(((mp_value_node) p)→subscript_);
    }   ▷ There was a quite large switch here first, but the mp_dash_node case was the only one that
          did anything ... ◁
    if (mp_type(p) ≡ mp_dash_node_type) {
      free_number(((mp_dash_node) p)→start_x); free_number(((mp_dash_node) p)→stop_x);
      free_number(((mp_dash_node) p)→dash_y);
    }
  }
  xfree(p);
}

void mp_free_symbolic_node(MP mp, mp_node p)
{   ▷ node liberation ◁
  FUNCTION_TRACE2("mp_free_symbolic_node(%p)\n", p);
  if (¬p) return;
  if (mp→num_symbolic_nodes < max_num_symbolic_nodes) {
    p→link ← mp→symbolic_nodes; mp→symbolic_nodes ← p; mp→num_symbolic_nodes++; return;
  }
  mp→var_used −= symbolic_node_size; xfree(p);
}

void mp_free_value_node(MP mp, mp_node p)
{   ▷ node liberation ◁
  FUNCTION_TRACE2("mp_free_value_node(%p)\n", p);
  if (¬p) return;
  if (mp→num_value_nodes < max_num_value_nodes) {
    p→link ← mp→value_nodes; mp→value_nodes ← p; mp→num_value_nodes++; return;
  }
  mp→var_used −= value_node_size; assert(p→has_number ≡ 2);
  if (mp→math_mode > mp_math_double_mode) {
    free_number(((mp_value_node) p)→data.n); free_number(((mp_value_node) p)→subscript_);
  }
  xfree(p);
}
```

184. ⟨ Internal library declarations 14 ⟩ +≡

```
void mp_free_node(MP mp, mp_node p, size_t siz);
void mp_free_symbolic_node(MP mp, mp_node p);
void mp_free_value_node(MP mp, mp_node p);
```

185. Memory layout. Some nodes are created statically, since static allocation is more efficient than dynamic allocation when we can get away with it.

⟨ Global variables 18 ⟩ +≡
mp_dash_node *null_dash*;
mp_value_node *dep_head*;
mp_node *inf_val*;
mp_node *zero_val*;
mp_node *temp_val*;
mp_node *end_attr*;
mp_node *bad_vardef*;
mp_node *temp_head*;
mp_node *hold_head*;
mp_node *spec_head*;

186. The following code gets the memory off to a good start.

⟨ Initialize table entries 186 ⟩ ≡
mp→spec_head ← *mp_get_symbolic_node*(*mp*); *mp→last_pending* ← *mp→spec_head*;
mp→temp_head ← *mp_get_symbolic_node*(*mp*); *mp→hold_head* ← *mp_get_symbolic_node*(*mp*);

See also sections 206, 207, 230, 231, 264, 373, 390, 452, 482, 614, 618, 631, 671, 766, 836, 930, 972, 1002, 1188, 1193, 1202, and 1207.

This code is used in section 1291.

187. ⟨ Free table entries 187 ⟩ ≡
mp_free_symbolic_node(*mp*, *mp→spec_head*); *mp_free_symbolic_node*(*mp*, *mp→temp_head*);
mp_free_symbolic_node(*mp*, *mp→hold_head*);

See also sections 265, 483, 632, 672, 767, 905, 973, 1003, 1189, and 1203.

This code is used in section 16.

188. The procedure *flush_node_list*(p) frees an entire linked list of nodes that starts at a given position, until coming to a Λ pointer.

```
static void mp_flush_node_list(MP mp, mp_node p)
{
  mp_node q;    ▷ the node being recycled ◁
  FUNCTION_TRACE2("mp_flush_node_list(%p)\n", p);
  while (p ≠ Λ) {
    q ← p; p ← p→link;
    if (q→type ≠ mp_symbol_node) mp_free_token_node(mp, q);
    else mp_free_symbolic_node(mp, q);
  }
}
```

189. The command codes. Before we can go much further, we need to define symbolic names for the internal code numbers that represent the various commands obeyed by METAPOST. These codes are somewhat arbitrary, but not completely so. For example, some codes have been made adjacent so that **case** statements in the program need not consider cases that are widely spaced, or so that **case** statements can be replaced by **if** statements. A command can begin an expression if and only if its code lies between *min_primary_command* and *max_primary_command*, inclusive. The first token of a statement that doesn't begin with an expression has a command code between *min_command* and *max_statement_command*, inclusive. Anything less than *min_command* is eliminated during macro expansions, and anything no more than *max_pre_command* is eliminated when expanding TEX material. Ranges such as *min_secondary_command* .. *max_secondary_command* are used when parsing expressions, but the relative ordering within such a range is generally not critical.

The ordering of the highest-numbered commands ($comma < semicolon < end\_group < stop$) is crucial for the parsing and error-recovery methods of this program as is the ordering $if\_test < fi\_or\_else$ for the smallest two commands. The ordering is also important in the ranges *numeric_token* .. *plus_or_minus* and *left_brace* .. *ampersand*.

At any rate, here is the list, for future reference.

```
#define mp_max_command_code mp_stop
#define mp_max_pre_command mp_mpx_break
#define mp_min_command (mp_defined_macro + 1)
#define mp_max_statement_command mp_type_name
#define mp_min_primary_command mp_type_name
#define mp_min_suffix_token mp_internal_quantity
#define mp_max_suffix_token mp_numeric_token
#define mp_max_primary_command mp_plus_or_minus   ▷ should also be numeric_token + 1 ◁
#define mp_min_tertiary_command mp_plus_or_minus
#define mp_max_tertiary_command mp_tertiary_binary
#define mp_min_expression_command mp_left_brace
#define mp_max_expression_command mp_equals
#define mp_min_secondary_command mp_and_command
#define mp_max_secondary_command mp_secondary_binary
#define mp_end_of_statement (cur_cmd() > mp_comma)

⟨Enumeration types 189⟩ ≡
  typedef enum {
    mp_start_tex ← 1,   ▷ begin TEX material (btex, verbatimtex) ◁
    mp_etex_marker,   ▷ end TEX material (etex) ◁
    mp_mpx_break,   ▷ stop reading an MPX file (mpxbreak) ◁
    mp_if_test,   ▷ conditional text (if) ◁
    mp_fi_or_else,   ▷ delimiters for conditionals (elseif, else, fi) ◁
    mp_input,   ▷ input a source file (input, endinput) ◁
    mp_iteration,   ▷ iterate (for, forsuffixes, forever, endfor) ◁
    mp_repeat_loop,   ▷ special command substituted for endfor ◁
    mp_exit_test,   ▷ premature exit from a loop (exitif) ◁
    mp_relax,   ▷ do nothing (\) ◁
    mp_scan_tokens,   ▷ put a string into the input buffer ◁
    mp_runscript,   ▷ put a script result string into the input buffer ◁
    mp_maketext,   ▷ put a script result string into the input buffer ◁
    mp_expand_after,   ▷ look ahead one token ◁
    mp_defined_macro,   ▷ a macro defined by the user ◁
    mp_save_command,   ▷ save a list of tokens (save) ◁
    mp_interim_command,   ▷ save an internal quantity (interim) ◁
    mp_let_command,   ▷ redefine a symbolic token (let) ◁
    mp_new_internal,   ▷ define a new internal quantity (newinternal) ◁
    mp_macro_def,   ▷ define a macro (def, vardef, etc.) ◁
```

mp_ship_out_command, ▷ output a character (**shipout**) ◁
mp_add_to_command, ▷ add to edges (**addto**) ◁
mp_bounds_command, ▷ add bounding path to edges (**setbounds**, **clip**) ◁
mp_tfm_command, ▷ command for font metric info (**ligtable**, etc.) ◁
mp_protection_command, ▷ set protection flag (**outer**, **inner**) ◁
mp_show_command, ▷ diagnostic output (**show**, **showvariable**, etc.) ◁
mp_mode_command, ▷ set interaction level (**batchmode**, etc.) ◁
mp_random_seed, ▷ initialize random number generator (**randomseed**) ◁
mp_message_command, ▷ communicate to user (**message**, **errmessage**) ◁
mp_every_job_command, ▷ designate a starting token (**everyjob**) ◁
mp_delimiters, ▷ define a pair of delimiters (**delimiters**) ◁
mp_special_command,
▷ output special info (**special**) or font map info (**fontmapfile**, **fontmapline**) ◁
mp_write_command, ▷ write text to a file (**write**) ◁
mp_type_name, ▷ declare a type (**numeric**, **pair**, etc.) ◁
mp_left_delimiter, ▷ the left delimiter of a matching pair ◁
mp_begin_group, ▷ beginning of a group (**begingroup**) ◁
mp_nullary, ▷ an operator without arguments (e.g., **normaldeviate**) ◁
mp_unary, ▷ an operator with one argument (e.g., **sqrt**) ◁
mp_str_op, ▷ convert a suffix to a string (**str**) ◁
mp_void_op, ▷ convert a suffix to a boolean (**void**) ◁
mp_cycle, ▷ close a cyclic path (**cycle**) ◁
mp_primary_binary, ▷ binary operation taking '**of**' (e.g., **point**) ◁
mp_capsule_token, ▷ a value that has been put into a token list ◁
mp_string_token, ▷ a string constant (e.g., `"hello"`) ◁
mp_internal_quantity, ▷ internal numeric parameter (e.g., **pausing**) ◁
mp_tag_token, ▷ a symbolic token without a primitive meaning ◁
mp_numeric_token, ▷ a numeric constant (e.g., `3.14159`) ◁
mp_plus_or_minus, ▷ either '+' or '−' ◁
mp_tertiary_secondary_macro, ▷ a macro defined by **secondarydef** ◁
mp_tertiary_binary, ▷ an operator at the tertiary level (e.g., '++') ◁
mp_left_brace, ▷ the operator '`{`' ◁
mp_path_join, ▷ the operator '`..`' ◁
mp_ampersand, ▷ the operator '`&`' ◁
mp_expression_tertiary_macro, ▷ a macro defined by **tertiarydef** ◁
mp_expression_binary, ▷ an operator at the expression level (e.g., '<') ◁
mp_equals, ▷ the operator '=' ◁
mp_and_command, ▷ the operator '**and**' ◁
mp_secondary_primary_macro, ▷ a macro defined by **primarydef** ◁
mp_slash, ▷ the operator '/' ◁
mp_secondary_binary, ▷ an operator at the binary level (e.g., **shifted**) ◁
mp_param_type, ▷ type of parameter (**primary**, **expr**, **suffix**, etc.) ◁
mp_controls, ▷ specify control points explicitly (**controls**) ◁
mp_tension, ▷ specify tension between knots (**tension**) ◁
mp_at_least, ▷ bounded tension value (**atleast**) ◁
mp_curl_command, ▷ specify curl at an end knot (**curl**) ◁
mp_macro_special, ▷ special macro operators (**quote**, `#@!`, etc.) ◁
mp_right_delimiter, ▷ the right delimiter of a matching pair ◁
mp_left_bracket, ▷ the operator '`[`' ◁
mp_right_bracket, ▷ the operator '`]`' ◁
mp_right_brace, ▷ the operator '`}`' ◁
mp_with_option, ▷ option for filling (**withpen**, **withweight**, etc.) ◁

mp_thing_to_add, ▷ variant of **addto** (**contour**, **doublepath**, **also**) ◁
mp_of_token, ▷ the operator '**of**' ◁
mp_to_token, ▷ the operator '**to**' ◁
mp_step_token, ▷ the operator '**step**' ◁
mp_until_token, ▷ the operator '**until**' ◁
mp_within_token, ▷ the operator '**within**' ◁
mp_lig_kern_token, ▷ the operators '**kern**' and '=:' and '=:|', etc. ◁
mp_assignment, ▷ the operator ':=' ◁
mp_skip_to, ▷ the operation '**skipto**' ◁
mp_bchar_label, ▷ the operator '||:' ◁
mp_double_colon, ▷ the operator '::' ◁
mp_colon, ▷ the operator ':' ◁
mp_comma, ▷ the operator ',', must be $colon + 1$ ◁
mp_semicolon, ▷ the operator ';', must be $comma + 1$ ◁
mp_end_group, ▷ end a group (**endgroup**), must be $semicolon + 1$ ◁
mp_stop, ▷ end a job (**end**, **dump**), must be $end\_group + 1$ ◁
mp_outer_tag, ▷ protection code added to command code ◁
mp_undefined_cs, ▷ protection code added to command code ◁
} **mp_command_code**;

See also sections 190 and 193.

This code is used in section 4.

190. Variables and capsules in METAPOST have a variety of "types," distinguished by the code numbers defined here. These numbers are also not completely arbitrary. Things that get expanded must have types $>$ *mp_independent*; a type remaining after expansion is numeric if and only if its code number is at least *numeric_type*; objects containing numeric parts must have types between *transform_type* and *pair_type*; all other types must be smaller than *transform_type*; and among the types that are not unknown or vacuous, the smallest two must be *boolean_type* and *string_type* in that order.

```
#define unknown_tag 1   ▷ this constant is added to certain type codes below ◁
#define unknown_types mp_unknown_boolean: case mp_unknown_string: case mp_unknown_pen:
        case mp_unknown_picture: case mp_unknown_path
```

⟨ Enumeration types 189 ⟩ +≡

```
typedef enum {
  mp_undefined ← 0,   ▷ no type has been declared ◁
  mp_vacuous,   ▷ no expression was present ◁
  mp_boolean_type,   ▷ boolean with a known value ◁
  mp_unknown_boolean, mp_string_type,   ▷ string with a known value ◁
  mp_unknown_string, mp_pen_type,   ▷ pen with a known value ◁
  mp_unknown_pen, mp_path_type,   ▷ path with a known value ◁
  mp_unknown_path, mp_picture_type,   ▷ picture with a known value ◁
  mp_unknown_picture, mp_transform_type,   ▷ transform variable or capsule ◁
  mp_color_type,   ▷ color variable or capsule ◁
  mp_cmykcolor_type,   ▷ cmykcolor variable or capsule ◁
  mp_pair_type,   ▷ pair variable or capsule ◁
  mp_numeric_type,   ▷ variable that has been declared numeric but not used ◁
  mp_known,   ▷ numeric with a known value ◁
  mp_dependent,   ▷ a linear combination with fraction coefficients ◁
  mp_proto_dependent,   ▷ a linear combination with scaled coefficients ◁
  mp_independent,   ▷ numeric with unknown value ◁
  mp_token_list,   ▷ variable name or suffix argument or text argument ◁
  mp_structured,   ▷ variable with subscripts and attributes ◁
  mp_unsuffixed_macro,   ▷ variable defined with vardef but no @!# ◁
  mp_suffixed_macro,   ▷ variable defined with vardef and @!# ◁
    ▷ here are some generic node types ◁
  mp_symbol_node, mp_token_node_type, mp_value_node_type, mp_attr_node_type, mp_subscr_node_type,
      mp_pair_node_type, mp_transform_node_type, mp_color_node_type, mp_cmykcolor_node_type,
    ▷ it is important that the next 7 items remain in this order, for export ◁
  mp_fill_node_type, mp_stroked_node_type, mp_text_node_type, mp_start_clip_node_type,
      mp_start_bounds_node_type, mp_stop_clip_node_type, mp_stop_bounds_node_type, mp_dash_node_type,
      mp_dep_node_type, mp_if_node_type, mp_edge_header_node_type,
} mp_variable_type;
```

191. ⟨ Declarations 10 ⟩ +≡

```
static void mp_print_type(MP mp, quarterword t);
```

192. ⟨ Basic printing procedures 91 ⟩ +≡

```
static const char *mp_type_string(quarterword t)
{
  const char *s ← Λ;
  switch (t) {
  case mp_undefined: s ← "undefined"; break;
  case mp_vacuous: s ← "vacuous"; break;
  case mp_boolean_type: s ← "boolean"; break;
  case mp_unknown_boolean: s ← "unknown␣boolean"; break;
  case mp_string_type: s ← "string"; break;
  case mp_unknown_string: s ← "unknown␣string"; break;
  case mp_pen_type: s ← "pen"; break;
  case mp_unknown_pen: s ← "unknown␣pen"; break;
  case mp_path_type: s ← "path"; break;
  case mp_unknown_path: s ← "unknown␣path"; break;
  case mp_picture_type: s ← "picture"; break;
  case mp_unknown_picture: s ← "unknown␣picture"; break;
  case mp_transform_type: s ← "transform"; break;
  case mp_color_type: s ← "color"; break;
  case mp_cmykcolor_type: s ← "cmykcolor"; break;
  case mp_pair_type: s ← "pair"; break;
  case mp_known: s ← "known␣numeric"; break;
  case mp_dependent: s ← "dependent"; break;
  case mp_proto_dependent: s ← "proto-dependent"; break;
  case mp_numeric_type: s ← "numeric"; break;
  case mp_independent: s ← "independent"; break;
  case mp_token_list: s ← "token␣list"; break;
  case mp_structured: s ← "mp_structured"; break;
  case mp_unsuffixed_macro: s ← "unsuffixed␣macro"; break;
  case mp_suffixed_macro: s ← "suffixed␣macro"; break;
  case mp_symbol_node: s ← "symbol␣node"; break;
  case mp_token_node_type: s ← "token␣node"; break;
  case mp_value_node_type: s ← "value␣node"; break;
  case mp_attr_node_type: s ← "attribute␣node"; break;
  case mp_subscr_node_type: s ← "subscript␣node"; break;
  case mp_pair_node_type: s ← "pair␣node"; break;
  case mp_transform_node_type: s ← "transform␣node"; break;
  case mp_color_node_type: s ← "color␣node"; break;
  case mp_cmykcolor_node_type: s ← "cmykcolor␣node"; break;
  case mp_fill_node_type: s ← "fill␣node"; break;
  case mp_stroked_node_type: s ← "stroked␣node"; break;
  case mp_text_node_type: s ← "text␣node"; break;
  case mp_start_clip_node_type: s ← "start␣clip␣node"; break;
  case mp_start_bounds_node_type: s ← "start␣bounds␣node"; break;
  case mp_stop_clip_node_type: s ← "stop␣clip␣node"; break;
  case mp_stop_bounds_node_type: s ← "stop␣bounds␣node"; break;
  case mp_dash_node_type: s ← "dash␣node"; break;
  case mp_dep_node_type: s ← "dependency␣node"; break;
  case mp_if_node_type: s ← "if␣node"; break;
  case mp_edge_header_node_type: s ← "edge␣header␣node"; break;
  default:
    {
```

```
      char ss[256];
      mp_snprintf(ss, 256, "<unknown␣type␣%d>", t);  s ← strdup(ss);
    }
    break;
  }
  return s;
}
void mp_print_type(MP mp, quarterword t)
{
  if (t ≥ 0 ∧ t ≤ mp_edge_header_node_type) mp_print(mp, mp_type_string(t));
  else mp_print(mp, "unknown");
}
```

193. Values inside METAPOST are stored in non-symbolic nodes that have a *name_type* as well as a *type*. The possibilities for *name_type* are defined here; they will be explained in more detail later.

⟨ Enumeration types 189 ⟩ +≡

```
typedef enum {
  mp_root ← 0,   ▷ name_type at the top level of a variable ◁
  mp_saved_root,   ▷ same, when the variable has been saved ◁
  mp_structured_root,   ▷ name_type where a mp_structured branch occurs ◁
  mp_subscr,   ▷ name_type in a subscript node ◁
  mp_attr,   ▷ name_type in an attribute node ◁
  mp_x_part_sector,   ▷ name_type in the xpart of a node ◁
  mp_y_part_sector,   ▷ name_type in the ypart of a node ◁
  mp_xx_part_sector,   ▷ name_type in the xxpart of a node ◁
  mp_xy_part_sector,   ▷ name_type in the xypart of a node ◁
  mp_yx_part_sector,   ▷ name_type in the yxpart of a node ◁
  mp_yy_part_sector,   ▷ name_type in the yypart of a node ◁
  mp_red_part_sector,   ▷ name_type in the redpart of a node ◁
  mp_green_part_sector,   ▷ name_type in the greenpart of a node ◁
  mp_blue_part_sector,   ▷ name_type in the bluepart of a node ◁
  mp_cyan_part_sector,   ▷ name_type in the redpart of a node ◁
  mp_magenta_part_sector,   ▷ name_type in the greenpart of a node ◁
  mp_yellow_part_sector,   ▷ name_type in the bluepart of a node ◁
  mp_black_part_sector,   ▷ name_type in the greenpart of a node ◁
  mp_grey_part_sector,   ▷ name_type in the bluepart of a node ◁
  mp_capsule,   ▷ name_type in stashed-away subexpressions ◁
  mp_token,   ▷ name_type in a numeric token or string token ◁
    ▷ Symbolic nodes also have name_type, which is a different enumeration ◁
  mp_normal_sym, mp_internal_sym,   ▷ for values of internals ◁
  mp_macro_sym,   ▷ for macro names ◁
  mp_expr_sym,   ▷ for macro parameters if type expr ◁
  mp_suffix_sym,   ▷ for macro parameters if type suffix ◁
  mp_text_sym,   ▷ for macro parameters if type text ◁
  ⟨ Operation codes 194 ⟩
} mp_name_type_type;
```

194. Primitive operations that produce values have a secondary identification code in addition to their command code; it's something like genera and species. For example, '*' has the command code *primary_binary*, and its secondary identification is *times*. The secondary codes start such that they don't overlap with the type codes; some type codes (e.g., *mp_string_type*) are used as operators as well as type identifications. The relative values are not critical, except for *true_code* .. *false_code*, *or_op* .. *and_op*, and *filled_op* .. *bounded_op*. The restrictions are that *and_op* − *false_code* ← *or_op* − *true_code*, that the ordering of *x_part* ... *blue_part* must match that of *x_part_sector* .. *mp_blue_part_sector*, and the ordering of *filled_op* .. *bounded_op* must match that of the code values they test for.

#**define** *mp_min_of* *mp_substring_of*

⟨ Operation codes 194 ⟩ ≡
mp_true_code, ▷ operation code for `true` ◁
mp_false_code, ▷ operation code for `false` ◁
mp_null_picture_code, ▷ operation code for `nullpicture` ◁
mp_null_pen_code, ▷ operation code for `nullpen` ◁
mp_read_string_op, ▷ operation code for `readstring` ◁
mp_pen_circle, ▷ operation code for `pencircle` ◁
mp_normal_deviate, ▷ operation code for `normaldeviate` ◁
mp_read_from_op, ▷ operation code for `readfrom` ◁
mp_close_from_op, ▷ operation code for `closefrom` ◁
mp_odd_op, ▷ operation code for `odd` ◁
mp_known_op, ▷ operation code for `known` ◁
mp_unknown_op, ▷ operation code for `unknown` ◁
mp_not_op, ▷ operation code for `not` ◁
mp_decimal, ▷ operation code for `decimal` ◁
mp_reverse, ▷ operation code for `reverse` ◁
mp_make_path_op, ▷ operation code for `makepath` ◁
mp_make_pen_op, ▷ operation code for `makepen` ◁
mp_oct_op, ▷ operation code for `oct` ◁
mp_hex_op, ▷ operation code for `hex` ◁
mp_ASCII_op, ▷ operation code for `ASCII` ◁
mp_char_op, ▷ operation code for `char` ◁
mp_length_op, ▷ operation code for `length` ◁
mp_turning_op, ▷ operation code for `turningnumber` ◁
mp_color_model_part, ▷ operation code for `colormodel` ◁
mp_x_part, ▷ operation code for `xpart` ◁
mp_y_part, ▷ operation code for `ypart` ◁
mp_xx_part, ▷ operation code for `xxpart` ◁
mp_xy_part, ▷ operation code for `xypart` ◁
mp_yx_part, ▷ operation code for `yxpart` ◁
mp_yy_part, ▷ operation code for `yypart` ◁
mp_red_part, ▷ operation code for `redpart` ◁
mp_green_part, ▷ operation code for `greenpart` ◁
mp_blue_part, ▷ operation code for `bluepart` ◁
mp_cyan_part, ▷ operation code for `cyanpart` ◁
mp_magenta_part, ▷ operation code for `magentapart` ◁
mp_yellow_part, ▷ operation code for `yellowpart` ◁
mp_black_part, ▷ operation code for `blackpart` ◁
mp_grey_part, ▷ operation code for `greypart` ◁
mp_font_part, ▷ operation code for `fontpart` ◁
mp_text_part, ▷ operation code for `textpart` ◁
mp_path_part, ▷ operation code for `pathpart` ◁
mp_pen_part, ▷ operation code for `penpart` ◁

mp_dash_part, ▷ operation code for `dashpart` ◁
mp_prescript_part, ▷ operation code for `prescriptpart` ◁
mp_postscript_part, ▷ operation code for `postscriptpart` ◁
mp_sqrt_op, ▷ operation code for `sqrt` ◁
mp_m_exp_op, ▷ operation code for `mexp` ◁
mp_m_log_op, ▷ operation code for `mlog` ◁
mp_sin_d_op, ▷ operation code for `sind` ◁
mp_cos_d_op, ▷ operation code for `cosd` ◁
mp_floor_op, ▷ operation code for `floor` ◁
mp_uniform_deviate, ▷ operation code for `uniformdeviate` ◁
mp_char_exists_op, ▷ operation code for `charexists` ◁
mp_font_size, ▷ operation code for `fontsize` ◁
mp_ll_corner_op, ▷ operation code for `llcorner` ◁
mp_lr_corner_op, ▷ operation code for `lrcorner` ◁
mp_ul_corner_op, ▷ operation code for `ulcorner` ◁
mp_ur_corner_op, ▷ operation code for `urcorner` ◁
mp_arc_length, ▷ operation code for `arclength` ◁
mp_angle_op, ▷ operation code for `angle` ◁
mp_cycle_op, ▷ operation code for `cycle` ◁
mp_filled_op, ▷ operation code for `filled` ◁
mp_stroked_op, ▷ operation code for `stroked` ◁
mp_textual_op, ▷ operation code for `textual` ◁
mp_clipped_op, ▷ operation code for `clipped` ◁
mp_bounded_op, ▷ operation code for `bounded` ◁
mp_plus, ▷ operation code for `+` ◁
mp_minus, ▷ operation code for `-` ◁
mp_times, ▷ operation code for `*` ◁
mp_over, ▷ operation code for `/` ◁
mp_pythag_add, ▷ operation code for `++` ◁
mp_pythag_sub, ▷ operation code for `+-+` ◁
mp_or_op, ▷ operation code for `or` ◁
mp_and_op, ▷ operation code for `and` ◁
mp_less_than, ▷ operation code for `<` ◁
mp_less_or_equal, ▷ operation code for `<=` ◁
mp_greater_than, ▷ operation code for `>` ◁
mp_greater_or_equal, ▷ operation code for `>=` ◁
mp_equal_to, ▷ operation code for `=` ◁
mp_unequal_to, ▷ operation code for `<>` ◁
mp_concatenate, ▷ operation code for `&` ◁
mp_rotated_by, ▷ operation code for `rotated` ◁
mp_slanted_by, ▷ operation code for `slanted` ◁
mp_scaled_by, ▷ operation code for `scaled` ◁
mp_shifted_by, ▷ operation code for `shifted` ◁
mp_transformed_by, ▷ operation code for `transformed` ◁
mp_x_scaled, ▷ operation code for `xscaled` ◁
mp_y_scaled, ▷ operation code for `yscaled` ◁
mp_z_scaled, ▷ operation code for `zscaled` ◁
mp_in_font, ▷ operation code for `infont` ◁
mp_intersect, ▷ operation code for `intersectiontimes` ◁
mp_double_dot, ▷ operation code for improper `..` ◁
mp_substring_of, ▷ operation code for `substring` ◁
mp_subpath_of, ▷ operation code for `subpath` ◁

mp_direction_time_of, ▷ operation code for `directiontime` ◁
mp_point_of, ▷ operation code for `point` ◁
mp_precontrol_of, ▷ operation code for `precontrol` ◁
mp_postcontrol_of, ▷ operation code for `postcontrol` ◁
mp_pen_offset_of, ▷ operation code for `penoffset` ◁
mp_arc_time_of, ▷ operation code for `arctime` ◁
mp_version, ▷ operation code for `mpversion` ◁
mp_envelope_of, ▷ operation code for `envelope` ◁
mp_boundingpath_of, ▷ operation code for `boundingpath` ◁
mp_glyph_infont, ▷ operation code for `glyph` ◁
mp_kern_flag, ▷ operation code for `kern` ◁
mp_m_get_left_endpoint_op,
▷ math interval new primitives operation code for `interval_get_left_endpoint` ◁
mp_m_get_right_endpoint_op,
▷ math interval new primitives operation code for `interval_get_right_endpoint` ◁
mp_interval_set_op, ▷ math interval new primitives operation code for `interval_set` ◁

This code is used in section 193.

195. **static void** *mp_print_op*(**MP** *mp*, **quarterword** *c*)

```
{
  if (c ≤ mp_numeric_type) {
    mp_print_type(mp, c);
  }
  else {
    switch (c) {
    case mp_true_code: mp_print(mp, "true"); break;
    case mp_false_code: mp_print(mp, "false"); break;
    case mp_null_picture_code: mp_print(mp, "nullpicture"); break;
    case mp_null_pen_code: mp_print(mp, "nullpen"); break;
    case mp_read_string_op: mp_print(mp, "readstring"); break;
    case mp_pen_circle: mp_print(mp, "pencircle"); break;
    case mp_normal_deviate: mp_print(mp, "normaldeviate"); break;
    case mp_read_from_op: mp_print(mp, "readfrom"); break;
    case mp_close_from_op: mp_print(mp, "closefrom"); break;
    case mp_odd_op: mp_print(mp, "odd"); break;
    case mp_known_op: mp_print(mp, "known"); break;
    case mp_unknown_op: mp_print(mp, "unknown"); break;
    case mp_not_op: mp_print(mp, "not"); break;
    case mp_decimal: mp_print(mp, "decimal"); break;
    case mp_reverse: mp_print(mp, "reverse"); break;
    case mp_make_path_op: mp_print(mp, "makepath"); break;
    case mp_make_pen_op: mp_print(mp, "makepen"); break;
    case mp_oct_op: mp_print(mp, "oct"); break;
    case mp_hex_op: mp_print(mp, "hex"); break;
    case mp_ASCII_op: mp_print(mp, "ASCII"); break;
    case mp_char_op: mp_print(mp, "char"); break;
    case mp_length_op: mp_print(mp, "length"); break;
    case mp_turning_op: mp_print(mp, "turningnumber"); break;
    case mp_x_part: mp_print(mp, "xpart"); break;
    case mp_y_part: mp_print(mp, "ypart"); break;
    case mp_xx_part: mp_print(mp, "xxpart"); break;
    case mp_xy_part: mp_print(mp, "xypart"); break;
    case mp_yx_part: mp_print(mp, "yxpart"); break;
    case mp_yy_part: mp_print(mp, "yypart"); break;
    case mp_red_part: mp_print(mp, "redpart"); break;
    case mp_green_part: mp_print(mp, "greenpart"); break;
    case mp_blue_part: mp_print(mp, "bluepart"); break;
    case mp_cyan_part: mp_print(mp, "cyanpart"); break;
    case mp_magenta_part: mp_print(mp, "magentapart"); break;
    case mp_yellow_part: mp_print(mp, "yellowpart"); break;
    case mp_black_part: mp_print(mp, "blackpart"); break;
    case mp_grey_part: mp_print(mp, "greypart"); break;
    case mp_color_model_part: mp_print(mp, "colormodel"); break;
    case mp_font_part: mp_print(mp, "fontpart"); break;
    case mp_text_part: mp_print(mp, "textpart"); break;
    case mp_prescript_part: mp_print(mp, "prescriptpart"); break;
    case mp_postscript_part: mp_print(mp, "postscriptpart"); break;
    case mp_path_part: mp_print(mp, "pathpart"); break;
    case mp_pen_part: mp_print(mp, "penpart"); break;
    case mp_dash_part: mp_print(mp, "dashpart"); break;
```

```
case mp_sqrt_op: mp_print(mp, "sqrt"); break;
case mp_m_exp_op: mp_print(mp, "mexp"); break;
case mp_m_log_op: mp_print(mp, "mlog"); break;
case mp_sin_d_op: mp_print(mp, "sind"); break;
case mp_cos_d_op: mp_print(mp, "cosd"); break;
case mp_floor_op: mp_print(mp, "floor"); break;
case mp_uniform_deviate: mp_print(mp, "uniformdeviate"); break;
case mp_char_exists_op: mp_print(mp, "charexists"); break;
case mp_font_size: mp_print(mp, "fontsize"); break;
case mp_ll_corner_op: mp_print(mp, "llcorner"); break;
case mp_lr_corner_op: mp_print(mp, "lrcorner"); break;
case mp_ul_corner_op: mp_print(mp, "ulcorner"); break;
case mp_ur_corner_op: mp_print(mp, "urcorner"); break;
case mp_arc_length: mp_print(mp, "arclength"); break;
case mp_angle_op: mp_print(mp, "angle"); break;
case mp_cycle_op: mp_print(mp, "cycle"); break;
case mp_filled_op: mp_print(mp, "filled"); break;
case mp_stroked_op: mp_print(mp, "stroked"); break;
case mp_textual_op: mp_print(mp, "textual"); break;
case mp_clipped_op: mp_print(mp, "clipped"); break;
case mp_bounded_op: mp_print(mp, "bounded"); break;
case mp_plus: mp_print_char(mp, xord('+')); break;
case mp_minus: mp_print_char(mp, xord('-')); break;
case mp_times: mp_print_char(mp, xord('*')); break;
case mp_over: mp_print_char(mp, xord('/')); break;
case mp_pythag_add: mp_print(mp, "++"); break;
case mp_pythag_sub: mp_print(mp, "+-+"); break;
case mp_or_op: mp_print(mp, "or"); break;
case mp_and_op: mp_print(mp, "and"); break;
case mp_less_than: mp_print_char(mp, xord('<')); break;
case mp_less_or_equal: mp_print(mp, "<="); break;
case mp_greater_than: mp_print_char(mp, xord('>')); break;
case mp_greater_or_equal: mp_print(mp, ">="); break;
case mp_equal_to: mp_print_char(mp, xord('=')); break;
case mp_unequal_to: mp_print(mp, "<>"); break;
case mp_concatenate: mp_print(mp, "&"); break;
case mp_rotated_by: mp_print(mp, "rotated"); break;
case mp_slanted_by: mp_print(mp, "slanted"); break;
case mp_scaled_by: mp_print(mp, "scaled"); break;
case mp_shifted_by: mp_print(mp, "shifted"); break;
case mp_transformed_by: mp_print(mp, "transformed"); break;
case mp_x_scaled: mp_print(mp, "xscaled"); break;
case mp_y_scaled: mp_print(mp, "yscaled"); break;
case mp_z_scaled: mp_print(mp, "zscaled"); break;
case mp_in_font: mp_print(mp, "infont"); break;
case mp_intersect: mp_print(mp, "intersectiontimes"); break;
case mp_substring_of: mp_print(mp, "substring"); break;
case mp_subpath_of: mp_print(mp, "subpath"); break;
case mp_direction_time_of: mp_print(mp, "directiontime"); break;
case mp_point_of: mp_print(mp, "point"); break;
case mp_precontrol_of: mp_print(mp, "precontrol"); break;
case mp_postcontrol_of: mp_print(mp, "postcontrol"); break;
```

```
case mp_pen_offset_of: mp_print(mp, "penoffset"); break;
case mp_arc_time_of: mp_print(mp, "arctime"); break;
case mp_version: mp_print(mp, "mpversion"); break;
case mp_envelope_of: mp_print(mp, "envelope"); break;
case mp_boundingpath_of: mp_print(mp, "boundingpath"); break;
case mp_glyph_infont: mp_print(mp, "glyph"); break;   ▷ math interval new primitives ◁
case mp_m_get_left_endpoint_op: mp_print(mp, "interval_get_left_endpoint"); break;
case mp_m_get_right_endpoint_op: mp_print(mp, "interval_get_right_endpoint"); break;
case mp_interval_set_op: mp_print(mp, "interval_set"); break;
default: mp_print(mp, ".."); break;
}
  }
}
```

196. METAPOST also has a bunch of internal parameters that a user might want to fuss with. Every such parameter has an identifying code number, defined here.

⟨ Types in the outer block 37 ⟩ +≡
enum mp_given_internal {
mp_output_template ← 1, ▷ a string set up by **outputtemplate** ◁
mp_output_filename, ▷ the output file name, accessible as **outputfilename** ◁
mp_output_format, ▷ the output format set up by **outputformat** ◁
mp_output_format_options, ▷ the output format options set up by **outputformatoptions** ◁
mp_number_system, ▷ the number system as set up by **numbersystem** ◁
mp_number_precision, ▷ the number system precision as set up by **numberprecision** ◁
mp_job_name, ▷ the perceived jobname, as set up from the options structure, the name of the input file, or by **jobname** ◁
mp_tracing_titles, ▷ show titles online when they appear ◁
mp_tracing_equations, ▷ show each variable when it becomes known ◁
mp_tracing_capsules, ▷ show capsules too ◁
mp_tracing_choices, ▷ show the control points chosen for paths ◁
mp_tracing_specs, ▷ show path subdivision prior to filling with polygonal a pen ◁
mp_tracing_commands, ▷ show commands and operations before they are performed ◁
mp_tracing_restores, ▷ show when a variable or internal is restored ◁
mp_tracing_macros, ▷ show macros before they are expanded ◁
mp_tracing_output, ▷ show digitized edges as they are output ◁
mp_tracing_stats, ▷ show memory usage at end of job ◁
mp_tracing_lost_chars, ▷ show characters that aren't **infont** ◁
mp_tracing_online, ▷ show long diagnostics on terminal and in the log file ◁
mp_year, ▷ the current year (e.g., 1984) ◁
mp_month, ▷ the current month (e.g., 3 ≡ March) ◁
mp_day, ▷ the current day of the month ◁
mp_time, ▷ the number of minutes past midnight when this job started ◁
mp_hour, ▷ the number of hours past midnight when this job started ◁
mp_minute, ▷ the number of minutes in that hour when this job started ◁
mp_char_code, ▷ the number of the next character to be output ◁
mp_char_ext, ▷ the extension code of the next character to be output ◁
mp_char_wd, ▷ the width of the next character to be output ◁
mp_char_ht, ▷ the height of the next character to be output ◁
mp_char_dp, ▷ the depth of the next character to be output ◁
mp_char_ic, ▷ the italic correction of the next character to be output ◁
mp_design_size, ▷ the unit of measure used for *mp_char_wd* .. *mp_char_ic*, in points ◁
mp_pausing, ▷ positive to display lines on the terminal before they are read ◁
mp_showstopping, ▷ positive to stop after each **show** command ◁
mp_fontmaking, ▷ positive if font metric output is to be produced ◁
mp_texscriptmode, ▷ controls spacing in texmode ◁
mp_linejoin, ▷ as in PostScript: 0 for mitered, 1 for round, 2 for beveled ◁
mp_linecap, ▷ as in PostScript: 0 for butt, 1 for round, 2 for square ◁
mp_miterlimit, ▷ controls miter length as in PostScript ◁
mp_warning_check, ▷ controls error message when variable value is large ◁
mp_boundary_char, ▷ the right boundary character for ligatures ◁
mp_prologues, ▷ positive to output conforming PostScript using built-in fonts ◁
mp_true_corners, ▷ positive to make **llcorner** etc. ignore **setbounds** ◁
mp_default_color_model, ▷ the default color model for unspecified items ◁
mp_restore_clip_color, *mp_procset*, ▷ whether or not create PostScript command shortcuts ◁
mp_hppp, ▷ horizontal pixels per point (for png output) ◁
mp_vppp, ▷ vertical pixels per point (for png output) ◁

```
    mp_gtroffmode,     ▷ whether the user specified -troff on the command line ◁
  };
  typedef struct {
    mp_value v;
    char *intname;
  } mp_internal;
```

197. ⟨ MPlib internal header stuff 8 ⟩ +≡

```
#define internal_value(A) mp→internal[(A)].v.data.n
#define set_internal_from_number(A, B)
  do {
    number_clone(internal_value((A)), (B));
  } while (0)
#define internal_string(A) (mp_string) mp→internal[(A)].v.data.str
#define set_internal_string(A, B) mp→internal[(A)].v.data.str ← (B)
#define internal_name(A) mp→internal[(A)].intname
#define set_internal_name(A, B) mp→internal[(A)].intname ← (B)
#define internal_type(A) (mp_variable_type) mp→internal[(A)].v.type
#define set_internal_type(A, B) mp→internal[(A)].v.type ← (B)
#define set_internal_from_cur_exp(A)
  do {
    if (internal_type((A)) ≡ mp_string_type) {
      add_str_ref(cur_exp_str()); set_internal_string((A), cur_exp_str());
    }
    else {
      set_internal_from_number((A), cur_exp_value_number());
    }
  } while (0)
```

198. #define max_given_internal mp_gtroffmode

⟨ Global variables 18 ⟩ +≡

```
  mp_internal *internal;    ▷ the values of internal quantities ◁
  int int_ptr;    ▷ the maximum internal quantity defined so far ◁
  int max_internal;    ▷ current maximum number of internal quantities ◁
```

199. ⟨ Option variables 30 ⟩ +≡

```
  int troff_mode;
```

200. ⟨ Allocate or initialize variables 32 ⟩ +≡

```
mp→max_internal ← 2 * max_given_internal;
mp→internal ← xmalloc((mp→max_internal + 1), sizeof(mp_internal));
memset(mp→internal, 0, (size_t)(mp→max_internal + 1) * sizeof(mp_internal));
{
  int i;
  for (i ← 1; i ≤ mp→max_internal; i++) {
    new_number(mp→internal[i].v.data.n);
  }
  for (i ← 1; i ≤ max_given_internal; i++) {
    set_internal_type(i, mp_known);
  }
}
set_internal_type(mp_output_format, mp_string_type);
set_internal_type(mp_output_filename, mp_string_type);
set_internal_type(mp_output_format_options, mp_string_type);
set_internal_type(mp_output_template, mp_string_type);
set_internal_type(mp_number_system, mp_string_type); set_internal_type(mp_job_name, mp_string_type);
mp→troff_mode ← (opt→troff_mode > 0 ? true : false);
```

201. ⟨ Exported function headers 22 ⟩ +≡

```
int mp_troff_mode(MP mp);
```

202.

```
int mp_troff_mode(MP mp)
{
  return mp→troff_mode;
}
```

203. ⟨ Set initial values of key variables 42 ⟩ +≡

```
mp→int_ptr ← max_given_internal;
```

204. The symbolic names for internal quantities are put into METAPOST's hash table by using a routine called *primitive*, which will be defined later. Let us enter them now, so that we don't have to list all those names again anywhere else.

⟨ Put each of METAPOST's primitives into the hash table 204 ⟩ ≡

```
mp_primitive(mp, "tracingtitles", mp_internal_quantity, mp_tracing_titles);
mp_primitive(mp, "tracingequations", mp_internal_quantity, mp_tracing_equations);
mp_primitive(mp, "tracingcapsules", mp_internal_quantity, mp_tracing_capsules);
mp_primitive(mp, "tracingchoices", mp_internal_quantity, mp_tracing_choices);
mp_primitive(mp, "tracingspecs", mp_internal_quantity, mp_tracing_specs);
mp_primitive(mp, "tracingcommands", mp_internal_quantity, mp_tracing_commands);
mp_primitive(mp, "tracingrestores", mp_internal_quantity, mp_tracing_restores);
mp_primitive(mp, "tracingmacros", mp_internal_quantity, mp_tracing_macros);
mp_primitive(mp, "tracingoutput", mp_internal_quantity, mp_tracing_output);
mp_primitive(mp, "tracingstats", mp_internal_quantity, mp_tracing_stats);
mp_primitive(mp, "tracinglostchars", mp_internal_quantity, mp_tracing_lost_chars);
mp_primitive(mp, "tracingonline", mp_internal_quantity, mp_tracing_online);
mp_primitive(mp, "year", mp_internal_quantity, mp_year);
mp_primitive(mp, "month", mp_internal_quantity, mp_month);
mp_primitive(mp, "day", mp_internal_quantity, mp_day);
mp_primitive(mp, "time", mp_internal_quantity, mp_time);
mp_primitive(mp, "hour", mp_internal_quantity, mp_hour);
mp_primitive(mp, "minute", mp_internal_quantity, mp_minute);
mp_primitive(mp, "charcode", mp_internal_quantity, mp_char_code);
mp_primitive(mp, "charext", mp_internal_quantity, mp_char_ext);
mp_primitive(mp, "charwd", mp_internal_quantity, mp_char_wd);
mp_primitive(mp, "charht", mp_internal_quantity, mp_char_ht);
mp_primitive(mp, "chardp", mp_internal_quantity, mp_char_dp);
mp_primitive(mp, "charic", mp_internal_quantity, mp_char_ic);
mp_primitive(mp, "designsize", mp_internal_quantity, mp_design_size);
mp_primitive(mp, "pausing", mp_internal_quantity, mp_pausing);
mp_primitive(mp, "showstopping", mp_internal_quantity, mp_showstopping);
mp_primitive(mp, "fontmaking", mp_internal_quantity, mp_fontmaking);
mp_primitive(mp, "texscriptmode", mp_internal_quantity, mp_texscriptmode);
mp_primitive(mp, "linejoin", mp_internal_quantity, mp_linejoin);
mp_primitive(mp, "linecap", mp_internal_quantity, mp_linecap);
mp_primitive(mp, "miterlimit", mp_internal_quantity, mp_miterlimit);
mp_primitive(mp, "warningcheck", mp_internal_quantity, mp_warning_check);
mp_primitive(mp, "boundarychar", mp_internal_quantity, mp_boundary_char);
mp_primitive(mp, "prologues", mp_internal_quantity, mp_prologues);
mp_primitive(mp, "truecorners", mp_internal_quantity, mp_true_corners);
mp_primitive(mp, "mpprocset", mp_internal_quantity, mp_procset);
mp_primitive(mp, "troffmode", mp_internal_quantity, mp_gtroffmode);
mp_primitive(mp, "defaultcolormodel", mp_internal_quantity, mp_default_color_model);
mp_primitive(mp, "restoreclipcolor", mp_internal_quantity, mp_restore_clip_color);
mp_primitive(mp, "outputtemplate", mp_internal_quantity, mp_output_template);
mp_primitive(mp, "outputfilename", mp_internal_quantity, mp_output_filename);
mp_primitive(mp, "numbersystem", mp_internal_quantity, mp_number_system);
mp_primitive(mp, "numberprecision", mp_internal_quantity, mp_number_precision);
mp_primitive(mp, "outputformat", mp_internal_quantity, mp_output_format);
mp_primitive(mp, "outputformatoptions", mp_internal_quantity, mp_output_format_options);
mp_primitive(mp, "jobname", mp_internal_quantity, mp_job_name);
```

mp_primitive(*mp*, "hppp", *mp_internal_quantity*, *mp_hppp*);
mp_primitive(*mp*, "vppp", *mp_internal_quantity*, *mp_vppp*);

See also sections 238, 738, 748, 756, 762, 774, 816, 957, 1048, 1073, 1078, 1080, 1096, 1119, 1125, 1139, 1170, and 1180.
This code is used in section 1291.

205. Colors can be specified in four color models. In the special case of *no_model*, MetaPost does not output any color operator to the postscript output.

Note: these values are passed directly on to *with_option*. This only works because the other possible values passed to *with_option* are 8 and 10 respectively (from *with_pen* and *with_picture*).

There is a first state, that is only used for *gs_colormodel*. It flags the fact that there has not been any kind of color specification by the user so far in the game.

⟨ MPlib header stuff 205 ⟩ ≡
enum mp_color_model {
mp_no_model ← 1, *mp_grey_model* ← 3, *mp_rgb_model* ← 5, *mp_cmyk_model* ← 7,
mp_uninitialized_model ← 9
};

See also sections 305 and 461.
This code is used in section 3.

206. ⟨ Initialize table entries 186 ⟩ +≡
set_internal_from_number(*mp_default_color_model*, *unity_t*);
number_multiply_int(*internal_value*(*mp_default_color_model*), *mp_rgb_model*);
number_clone(*internal_value*(*mp_restore_clip_color*), *unity_t*);
number_clone(*internal_value*(*mp_hppp*), *unity_t*); *number_clone*(*internal_value*(*mp_vppp*), *unity_t*);
set_internal_string(*mp_output_template*, *mp_intern*(*mp*, "%j.%c"));
set_internal_string(*mp_output_filename*, *mp_intern*(*mp*, ""));
set_internal_string(*mp_output_format*, *mp_intern*(*mp*, "eps"));
set_internal_string(*mp_output_format_options*, *mp_intern*(*mp*, ""));
set_internal_string(*mp_number_system*, *mp_intern*(*mp*, "scaled"));
set_internal_from_number(*mp_number_precision*, *precision_default*);
set_internal_from_number(*mp_texscriptmode*, *unity_t*);
#if DEBUG
number_clone(*internal_value*(*mp_tracing_titles*), *three_t*);
number_clone(*internal_value*(*mp_tracing_equations*), *three_t*);
number_clone(*internal_value*(*mp_tracing_capsules*), *three_t*);
number_clone(*internal_value*(*mp_tracing_choices*), *three_t*);
number_clone(*internal_value*(*mp_tracing_specs*), *three_t*);
number_clone(*internal_value*(*mp_tracing_commands*), *three_t*);
number_clone(*internal_value*(*mp_tracing_restores*), *three_t*);
number_clone(*internal_value*(*mp_tracing_macros*), *three_t*);
number_clone(*internal_value*(*mp_tracing_output*), *three_t*);
number_clone(*internal_value*(*mp_tracing_stats*), *three_t*);
number_clone(*internal_value*(*mp_tracing_lost_chars*), *three_t*);
number_clone(*internal_value*(*mp_tracing_online*), *three_t*);
#endif

207. Well, we do have to list the names one more time, for use in symbolic printouts.

⟨ Initialize table entries 186 ⟩ +≡

set_internal_name(*mp_tracing_titles*, *xstrdup*("tracingtitles"));
set_internal_name(*mp_tracing_equations*, *xstrdup*("tracingequations"));
set_internal_name(*mp_tracing_capsules*, *xstrdup*("tracingcapsules"));
set_internal_name(*mp_tracing_choices*, *xstrdup*("tracingchoices"));
set_internal_name(*mp_tracing_specs*, *xstrdup*("tracingspecs"));
set_internal_name(*mp_tracing_commands*, *xstrdup*("tracingcommands"));
set_internal_name(*mp_tracing_restores*, *xstrdup*("tracingrestores"));
set_internal_name(*mp_tracing_macros*, *xstrdup*("tracingmacros"));
set_internal_name(*mp_tracing_output*, *xstrdup*("tracingoutput"));
set_internal_name(*mp_tracing_stats*, *xstrdup*("tracingstats"));
set_internal_name(*mp_tracing_lost_chars*, *xstrdup*("tracinglostchars"));
set_internal_name(*mp_tracing_online*, *xstrdup*("tracingonline"));
set_internal_name(*mp_year*, *xstrdup*("year")); *set_internal_name*(*mp_month*, *xstrdup*("month"));
set_internal_name(*mp_day*, *xstrdup*("day")); *set_internal_name*(*mp_time*, *xstrdup*("time"));
set_internal_name(*mp_hour*, *xstrdup*("hour")); *set_internal_name*(*mp_minute*, *xstrdup*("minute"));
set_internal_name(*mp_char_code*, *xstrdup*("charcode"));
set_internal_name(*mp_char_ext*, *xstrdup*("charext"));
set_internal_name(*mp_char_wd*, *xstrdup*("charwd")); *set_internal_name*(*mp_char_ht*, *xstrdup*("charht"));
set_internal_name(*mp_char_dp*, *xstrdup*("chardp")); *set_internal_name*(*mp_char_ic*, *xstrdup*("charic"));
set_internal_name(*mp_design_size*, *xstrdup*("designsize"));
set_internal_name(*mp_pausing*, *xstrdup*("pausing"));
set_internal_name(*mp_showstopping*, *xstrdup*("showstopping"));
set_internal_name(*mp_fontmaking*, *xstrdup*("fontmaking"));
set_internal_name(*mp_texscriptmode*, *xstrdup*("texscriptmode"));
set_internal_name(*mp_linejoin*, *xstrdup*("linejoin"));
set_internal_name(*mp_linecap*, *xstrdup*("linecap"));
set_internal_name(*mp_miterlimit*, *xstrdup*("miterlimit"));
set_internal_name(*mp_warning_check*, *xstrdup*("warningcheck"));
set_internal_name(*mp_boundary_char*, *xstrdup*("boundarychar"));
set_internal_name(*mp_prologues*, *xstrdup*("prologues"));
set_internal_name(*mp_true_corners*, *xstrdup*("truecorners"));
set_internal_name(*mp_default_color_model*, *xstrdup*("defaultcolormodel"));
set_internal_name(*mp_procset*, *xstrdup*("mpprocset"));
set_internal_name(*mp_gtroffmode*, *xstrdup*("troffmode"));
set_internal_name(*mp_restore_clip_color*, *xstrdup*("restoreclipcolor"));
set_internal_name(*mp_output_template*, *xstrdup*("outputtemplate"));
set_internal_name(*mp_output_filename*, *xstrdup*("outputfilename"));
set_internal_name(*mp_output_format*, *xstrdup*("outputformat"));
set_internal_name(*mp_output_format_options*, *xstrdup*("outputformatoptions"));
set_internal_name(*mp_job_name*, *xstrdup*("jobname"));
set_internal_name(*mp_number_system*, *xstrdup*("numbersystem"));
set_internal_name(*mp_number_precision*, *xstrdup*("numberprecision"));
set_internal_name(*mp_hppp*, *xstrdup*("hppp")); *set_internal_name*(*mp_vppp*, *xstrdup*("vppp"));

208. The following procedure, which is called just before METAPOST initializes its input and output, establishes the initial values of the date and time.

Note that the values are *scaled* integers. Hence METAPOST can no longer be used after the year 32767.

```
#if defined (_MSC_VER)
#define strtoull _strtoui64
#endif
  static void mp_fix_date_and_time(MP mp)
  {
    char *source_date_epoch;
    time_t epoch;
    char *endptr;
    struct tm *tmptr;
    source_date_epoch ← getenv("SOURCE_DATE_EPOCH");
    if (source_date_epoch) {
      errno ← 0;  epoch ← strtoull(source_date_epoch, &endptr, 10);
      if (*endptr ≠ '\0' ∨ errno ≠ 0) {
        FATAL1("invalid␣epoch-seconds-timezone␣value␣for␣environment␣variab\
            le␣$SOURCE_DATE_EPOCH:␣%s", source_date_epoch);
      }    ▷ there is a limit 3001.01.01:2059 for epoch in Microsoft C ◁
#if defined (_MSC_VER)
      if (epoch > 32535291599ULL) epoch ← 32535291599ULL;
#endif
      tmptr ← gmtime(&epoch);
    }
    else {
      epoch ← time((time_t *) 0);  tmptr ← localtime(&epoch);
    }
    set_internal_from_number(mp_time, unity_t);
    number_multiply_int(internal_value(mp_time), (tmptr→tm_hour * 60 + tmptr→tm_min));
    set_internal_from_number(mp_hour, unity_t);
    number_multiply_int(internal_value(mp_hour), (tmptr→tm_hour));
    set_internal_from_number(mp_minute, unity_t);
    number_multiply_int(internal_value(mp_minute), (tmptr→tm_min));
    set_internal_from_number(mp_day, unity_t);
    number_multiply_int(internal_value(mp_day), (tmptr→tm_mday));
    set_internal_from_number(mp_month, unity_t);
    number_multiply_int(internal_value(mp_month), (tmptr→tm_mon + 1));
    set_internal_from_number(mp_year, unity_t);
    number_multiply_int(internal_value(mp_year), (tmptr→tm_year + 1900));
  }
```

209. ⟨ Declarations 10 ⟩ +≡

```
  static void mp_fix_date_and_time(MP mp);
```

210. METAPOST is occasionally supposed to print diagnostic information that goes only into the transcript file, unless *mp_tracing_online* is positive. Now that we have defined *mp_tracing_online* we can define two routines that adjust the destination of print commands:

⟨ Declarations 10 ⟩ +≡

```
  static void mp_begin_diagnostic(MP mp);
  static void mp_end_diagnostic(MP mp, boolean blank_line);
  static void mp_print_diagnostic(MP mp, const char *s, const char *t, boolean nuline);
```

211. ⟨ Basic printing procedures 91 ⟩ +≡

```
void mp_begin_diagnostic(MP mp)
{   ▷ prepare to do some tracing ◁
  mp→old_setting ← mp→selector;
  if (number_nonpositive(internal_value(mp_tracing_online)) ∧ (mp→selector ≡ term_and_log)) {
    decr(mp→selector);
    if (mp→history ≡ mp_spotless) mp→history ← mp_warning_issued;
  }
}
void mp_end_diagnostic(MP mp, boolean blank_line)
{   ▷ restore proper conditions after tracing ◁
  mp_print_nl(mp, "");
  if (blank_line) mp_print_ln(mp);
  mp→selector ← mp→old_setting;
}
```

212. ⟨ Global variables 18 ⟩ +≡

```
unsigned int old_setting;
```

213. We will occasionally use *begin_diagnostic* in connection with line-number printing, as follows. (The parameter *s* is typically "Path" or "Cycle␣spec", etc.)

⟨ Basic printing procedures 91 ⟩ +≡

```
void mp_print_diagnostic(MP mp, const char *s, const char *t, boolean nuline)
{
  mp_begin_diagnostic(mp);
  if (nuline) mp_print_nl(mp, s);
  else mp_print(mp, s);
  mp_print(mp, "␣at␣line␣"); mp_print_int(mp, mp_true_line(mp)); mp_print(mp, t);
  mp_print_char(mp, xord(':'));
}
```

214. The 256 **ASCII_code** characters are grouped into classes by means of the *char_class* table. Individual class numbers have no semantic or syntactic significance, except in a few instances defined here. There's also *max_class*, which can be used as a basis for additional class numbers in nonstandard extensions of METAPOST.

```
#define digit_class 0   ▷ the class number of 0123456789 ◁
#define period_class 1   ▷ the class number of '.' ◁
#define space_class 2   ▷ the class number of spaces and nonstandard characters ◁
#define percent_class 3   ▷ the class number of '%' ◁
#define string_class 4   ▷ the class number of '"' ◁
#define right_paren_class 8   ▷ the class number of ')' ◁
#define isolated_classes 5: case 6: case 7: case 8   ▷ characters that make length-one tokens only ◁
#define letter_class 9   ▷ letters and the underline character ◁
#define mp_left_bracket_class 17   ▷ '[' ◁
#define mp_right_bracket_class 18   ▷ ']' ◁
#define invalid_class 20   ▷ bad character in the input ◁
#define max_class 20   ▷ the largest class number ◁
#define semicolon_class 6   ▷ the class number of ';' ◁
```

⟨ Global variables 18 ⟩ +≡

```
#define digit_class 0   ▷ the class number of 0123456789 ◁
  int char_class[256];   ▷ the class numbers ◁
```

215. If changes are made to accommodate non-ASCII character sets, they should follow the guidelines in Appendix C of *The METAFONT book*.

⟨Set initial values of key variables 42⟩ +≡

for ($k \leftarrow$ '0'; $k \leq$ '9'; k++) *mp→char_class*[k] ← *digit_class*;
mp→char_class['.'] ← *period_class*; *mp→char_class*['␣'] ← *space_class*;
mp→char_class['%'] ← *percent_class*; *mp→char_class*['"'] ← *string_class*; *mp→char_class*[','] ← 5;
mp→char_class[';'] ← 6; *mp→char_class*['('] ← 7; *mp→char_class*[')'] ← *right_paren_class*;
for ($k \leftarrow$ 'A'; $k \leq$ 'Z'; k++) *mp→char_class*[k] ← *letter_class*;
for ($k \leftarrow$ 'a'; $k \leq$ 'z'; k++) *mp→char_class*[k] ← *letter_class*;
mp→char_class['_'] ← *letter_class*; *mp→char_class*['<'] ← 10; *mp→char_class*['='] ← 10;
mp→char_class['>'] ← 10; *mp→char_class*[':'] ← 10; *mp→char_class*['|'] ← 10;
mp→char_class['`'] ← 11; *mp→char_class*['\''] ← 11; *mp→char_class*['+'] ← 12;
mp→char_class['-'] ← 12; *mp→char_class*['/'] ← 13; *mp→char_class*['*'] ← 13;
mp→char_class['\\'] ← 13; *mp→char_class*['!'] ← 14; *mp→char_class*['?'] ← 14;
mp→char_class['#'] ← 15; *mp→char_class*['&'] ← 15; *mp→char_class*['@'] ← 15;
mp→char_class['$'] ← 15; *mp→char_class*['^'] ← 16; *mp→char_class*['~'] ← 16;
mp→char_class['['] ← *mp_left_bracket_class*; *mp→char_class*[']'] ← *mp_right_bracket_class*;
mp→char_class['{'] ← 19; *mp→char_class*['}'] ← 19;
for ($k \leftarrow 0$; $k <$ '␣'; k++) *mp→char_class*[k] ← *invalid_class*;
mp→char_class['\t'] ← *space_class*; *mp→char_class*['\f'] ← *space_class*;
for ($i \leftarrow 127$; $i \leq 255$; i++) {
  mp→char_class[i] ← *mp→utf8_mode* ? *letter_class* : *invalid_class*;
}

216. The hash table.

Symbolic tokens are stored in and retrieved from an AVL tree. This is not as fast as an actual hash table, but it is easily extensible.

A symbolic token contains a pointer to the **mp_string** that contains the string representation of the symbol, a **halfword** that holds the current command value of the token, and an **mp_value** for the associated equivalent.

```
#define set_text(A)
        do {
          FUNCTION_TRACE3("set_text(%p,␣%p)\n", (A), (B)); (A)→text ← (B);
        } while (0)
#define set_eq_type(A, B)
        do {
          FUNCTION_TRACE3("set_eq_type(%p,␣%d)\n", (A), (B)); (A)→type ← (B);
        } while (0)
#define set_equiv(A, B)
        do {
          FUNCTION_TRACE3("set_equiv(%p,␣%d)\n", (A), (B)); (A)→v.data.node ← Λ;
          (A)→v.data.indep.serial ← (B);
        } while (0)
#define set_equiv_node(A, B)
        do {
          FUNCTION_TRACE3("set_equiv_node(%p,␣%p)\n", (A), (B)); (A)→v.data.node ← (B);
          (A)→v.data.indep.serial ← 0;
        } while (0)
#define set_equiv_sym(A, B)
        do {
          FUNCTION_TRACE3("set_equiv_sym(%p,␣%p)\n", (A), (B));
          (A)→v.data.node ← (mp_node)(B); (A)→v.data.indep.serial ← 0;
        } while (0)
```

217.

```
#if DEBUG
#define text(A) do_get_text(mp, (A))
#define eq_type(A) do_get_eq_type(mp, (A))
#define equiv(A) do_get_equiv(mp, (A))
#define equiv_node(A) do_get_equiv_node(mp, (A))
#define equiv_sym(A) do_get_equiv_sym(mp, (A))
  static mp_string do_get_text(MP mp, mp_sym A)
  {
    FUNCTION_TRACE3("%d = do_get_text(%p)\n", A->text, A); return A->text;
  }
  static halfword do_get_eq_type(MP mp, mp_sym A)
  {
    FUNCTION_TRACE3("%d = do_get_eq_type(%p)\n", A->type, A); return A->type;
  }
  static halfword do_get_equiv(MP mp, mp_sym A)
  {
    FUNCTION_TRACE3("%d = do_get_equiv(%p)\n", A->v.data.indep.serial, A);
    return A->v.data.indep.serial;
  }
  static mp_node do_get_equiv_node(MP mp, mp_sym A)
  {
    FUNCTION_TRACE3("%p = do_get_equiv_node(%p)\n", A->v.data.node, A); return A->v.data.node;
  }
  static mp_sym do_get_equiv_sym(MP mp, mp_sym A)
  {
    FUNCTION_TRACE3("%p = do_get_equiv_sym(%p)\n", A->v.data.node, A);
    return (mp_sym) A->v.data.node;
  }
#else
#define text(A) (A)->text
#define eq_type(A) (A)->type
#define equiv(A) (A)->v.data.indep.serial
#define equiv_node(A) (A)->v.data.node
#define equiv_sym(A) (mp_sym)(A)->v.data.node
#endif
```

218. ⟨ Declarations 10 ⟩ +≡

```
#if DEBUG
  static mp_string do_get_text(MP mp, mp_sym A);
  static halfword do_get_eq_type(MP mp, mp_sym A);
  static halfword do_get_equiv(MP mp, mp_sym A);
  static mp_node do_get_equiv_node(MP mp, mp_sym A);
  static mp_sym do_get_equiv_sym(MP mp, mp_sym A);
#endif
```

219. ⟨ Types in the outer block 37 ⟩ +≡

```
typedef struct mp_symbol_entry {
  halfword type;
  mp_value v;
  mp_string text;
  void *parent;
} mp_symbol_entry;
```

220. ⟨ Global variables 18 ⟩ +≡

```
integer st_count;     ▷ total number of known identifiers ◁
avl_tree symbols;     ▷ avl tree of symbolic tokens ◁
avl_tree frozen_symbols;     ▷ avl tree of frozen symbolic tokens ◁
mp_sym frozen_bad_vardef;
mp_sym frozen_colon;
mp_sym frozen_end_def;
mp_sym frozen_end_for;
mp_sym frozen_end_group;
mp_sym frozen_etex;
mp_sym frozen_fi;
mp_sym frozen_inaccessible;
mp_sym frozen_left_bracket;
mp_sym frozen_mpx_break;
mp_sym frozen_repeat_loop;
mp_sym frozen_right_delimiter;
mp_sym frozen_semicolon;
mp_sym frozen_slash;
mp_sym frozen_undefined;
mp_sym frozen_dump;
```

221. Here are the functions needed for the avl construction.

⟨ Declarations 10 ⟩ +≡

```
static int comp_symbols_entry(void *p, const void *pa, const void *pb);
static void *copy_symbols_entry(const void *p);
static void *delete_symbols_entry(void *p);
```

222. The avl comparison function is a straightword version of *strcmp*, except that checks for the string lengths first.

```
static int comp_symbols_entry(void *p, const void *pa, const void *pb)
{
  const mp_symbol_entry *a ← (const mp_symbol_entry *) pa;
  const mp_symbol_entry *b ← (const mp_symbol_entry *) pb;
  (void) p;
  if (a→text→len ≠ b→text→len) {
    return (a→text→len > b→text→len ? 1 : −1);
  }
  return strncmp((const char *) a→text→str, (const char *) b→text→str, a→text→len);
}
```

223. Copying a symbol happens when an item is inserted into an AVL tree. The *text* and **mp_number** needs to be deep copied, every thing else can be reassigned.

```
static void *copy_symbols_entry(const void *p)
{
  MP mp;
  mp_sym ff;
  const mp_symbol_entry *fp;
  fp ← (const mp_symbol_entry *) p; mp ← (MP) fp→parent;
  ff ← malloc(sizeof(mp_symbol_entry));
  if (ff ≡ Λ) return Λ;
  ff→text ← copy_strings_entry(fp→text);
  if (ff→text ≡ Λ) return Λ;
  ff→v ← fp→v; ff→type ← fp→type; ff→parent ← mp; new_number(ff→v.data.n);
  number_clone(ff→v.data.n, fp→v.data.n); return ff;
}
```

224. In the current implementation, symbols are not freed until the end of the run.

```
static void *delete_symbols_entry(void *p)
{
  MP mp;
  mp_sym ff ← (mp_sym) p;
  mp ← (MP) ff→parent; free_number(ff→v.data.n); mp_xfree(ff→text→str); mp_xfree(ff→text);
  mp_xfree(ff); return Λ;
}
```

225. ⟨ Allocate or initialize variables 32 ⟩ +≡

```
mp→symbols ← avl_create(comp_symbols_entry, copy_symbols_entry, delete_symbols_entry, malloc, free, Λ);
mp→frozen_symbols ← avl_create(comp_symbols_entry, copy_symbols_entry, delete_symbols_entry, malloc,
    free, Λ);
```

226. ⟨ Dealloc variables 31 ⟩ +≡

```
if (mp→symbols ≠ Λ) avl_destroy(mp→symbols);
if (mp→frozen_symbols ≠ Λ) avl_destroy(mp→frozen_symbols);
```

227. Actually creating symbols is done by *id_lookup*, but in order to do so it needs a way to create a new, empty symbol structure.

⟨ Declarations 10 ⟩ +≡

```
static mp_sym new_symbols_entry(MP mp, unsigned char *nam, size_t len);
```

228.

```
static mp_sym new_symbols_entry(MP mp, unsigned char *nam, size_t len)
{
  mp_sym ff;
  ff ← mp_xmalloc(mp, 1, sizeof(mp_symbol_entry)); memset(ff, 0, sizeof(mp_symbol_entry));
  ff→parent ← mp; ff→text ← mp_xmalloc(mp, 1, sizeof(mp_lstring)); ff→text→str ← nam;
  ff→text→len ← len; ff→type ← mp_tag_token; ff→v.type ← mp_known; new_number(ff→v.data.n);
  FUNCTION_TRACE4("%p␣=␣new_symbols_entry(\"%s\",%d)\n", ff, nam, (int) len); return ff;
}
```

229. There is one global variable so that *id_lookup* does not always have to create a new entry just for testing. This is not freed because it creates a double-free thanks to the Λ init.

⟨ Global variables 18 ⟩ +≡
mp_sym *id_lookup_test*;

230. ⟨ Initialize table entries 186 ⟩ +≡
mp→id_lookup_test ← *new_symbols_entry*(*mp*, Λ, 0);

231. Certain symbols are "frozen" and not redefinable, since they are used in error recovery.

⟨ Initialize table entries 186 ⟩ +≡
mp→st_count ← 0;
mp→frozen_bad_vardef ← *mp_frozen_primitive*(*mp*, "a␣bad␣variable", *mp_tag_token*, 0);
mp→frozen_right_delimiter ← *mp_frozen_primitive*(*mp*, ")", *mp_right_delimiter*, 0);
mp→frozen_inaccessible ← *mp_frozen_primitive*(*mp*, "␣INACCESSIBLE", *mp_tag_token*, 0);
mp→frozen_undefined ← *mp_frozen_primitive*(*mp*, "␣UNDEFINED", *mp_tag_token*, 0);

232. Here is the subroutine that searches the avl tree for an identifier that matches a given string of length l appearing in *buffer*$[j \mathinner{..} (j + l - 1)]$. If the identifier is not found, it is inserted if *insert_new* is *true*, and the corresponding symbol will be returned.

There are two variations on the lookup function: one for the normal symbol table, and one for the table of error recovery symbols.

#define *mp_id_lookup*(*A*, *B*, *C*, *D*) *mp_do_id_lookup*((*A*), *mp→symbols*, (*B*), (*C*), (*D*))

```
static mp_sym mp_do_id_lookup(MP mp, avl_tree symbols, char *j, size_t l, boolean insert_new)
{   ▷ search an avl tree ◁
  mp_sym str;
  mp→id_lookup_test→text→str ← (unsigned char *) j;  mp→id_lookup_test→text→len ← l;
  str ← (mp_sym) avl_find(mp→id_lookup_test, symbols);
  if (str ≡ Λ ∧ insert_new) {
    unsigned char *nam ← (unsigned char *) mp_xstrldup(mp, j, l);
    mp_sym s ← new_symbols_entry(mp, nam, l);
    mp→st_count++;  assert(avl_ins(s, symbols, avl_false) > 0);  str ← (mp_sym) avl_find(s, symbols);
    delete_symbols_entry(s);
  }
  return str;
}
static mp_sym mp_frozen_id_lookup(MP mp, char *j, size_t l, boolean insert_new)
{   ▷ search the error recovery symbol table ◁
  return mp_do_id_lookup(mp, mp→frozen_symbols, j, l, insert_new);
}   ▷ see mp_print_sym(mp_sym sym) ◁
```

233. Get a numeric value from METAPOST is not easy. We have to consider the macro and the loops, as also the internal type (this is a first attempt, and more work is needed). If we are inside a **for** loop, then the global *loop_ptr* is not null and the other loops eventually nested are available by mean of *loop_ptr→link*. The current numeric value is stored in *old_value*.

```
double mp_get_numeric_value(MP mp, const char *s, size_t l)
{
  char *ss ← mp_xstrdup(mp, s);
  if (ss) {
    mp_sym sym ← mp_id_lookup(mp, ss, l, false);
    if (sym ≠ Λ) {
      if (mp→loop_ptr ≠ Λ) {
        mp_loop_data *s;  s ← mp→loop_ptr;
        while (s ≠ Λ ∧ sym ≠ s→var) s ← s→link;
        if (s ≠ Λ ∧ sym ≡ s→var) {
          mp_xfree(ss); return number_to_double(s→old_value);
        }
      }
      if (mp_type(sym) ≡ mp_internal_quantity) {
        halfword qq ← equiv(sym);
        mp_xfree(ss);
        if (internal_type(qq) ≠ mp_string_type) return number_to_double(internal_value(qq));
        else return 0;
      }
      if (sym→v.data.node ≠ Λ ∧ mp_type(sym→v.data.node) ≡ mp_known) {
        mp_xfree(ss); return number_to_double(sym→v.data.node→data.n);
      }
    }
  }
  mp_xfree(ss); return 0;
}
int mp_get_boolean_value(MP mp, const char *s, size_t l)
{
  char *ss ← mp_xstrdup(mp, s);
  if (ss) {
    mp_sym sym ← mp_id_lookup(mp, ss, l, false);
    if (sym ≠ Λ) {
      if (mp_type(sym→v.data.node) ≡ mp_boolean_type) {
        if (number_to_boolean(sym→v.data.node→data.n) ≡ mp_true_code) {
          mp_xfree(ss); return 1;
        }
      }
    }
  }
  mp_xfree(ss); return 0;
}
char *mp_get_string_value(MP mp, const char *s, size_t l)
{
  char *ss ← mp_xstrdup(mp, s);
  if (ss) {
    mp_sym sym ← mp_id_lookup(mp, ss, l, false);
```

```
      if (sym ≠ Λ) {
        if (mp_type(sym→v.data.node) ≡ mp_string_type) {
          mp_xfree(ss); return (char *) sym→v.data.node→data.str→str;
        }
      }
    }
    mp_xfree(ss); return Λ;
  }
  mp_knot mp_get_path_value(MP mp, const char *s, size_t l)
  {
    char *ss ← mp_xstrdup(mp, s);
    if (ss) {
      mp_sym sym ← mp_id_lookup(mp, ss, l, false);
      if (sym ≠ Λ ∧ sym→v.data.node ≠ Λ) {
        if (mp_type(sym→v.data.node) ≡ mp_path_type) {
          mp_xfree(ss); return (mp_knot) sym→v.data.node→data.p;
        }
      }
    }
    mp_xfree(ss); return Λ;
  }
```

234. ⟨ Exported function headers 22 ⟩ +≡

```
  double mp_get_numeric_value(MP mp, const char *s, size_t l);
  int mp_get_boolean_value(MP mp, const char *s, size_t l);
  char *mp_get_string_value(MP mp, const char *s, size_t l);
  mp_knot mp_get_path_value(MP mp, const char *s, size_t l);
```

235. We need to put METAPOST's "primitive" symbolic tokens into the hash table, together with their command code (which will be the *eq_type*) and an operand (which will be the *equiv*). The *primitive* procedure does this, in a way that no METAPOST user can. The global value *cur_sym* contains the new *eqtb* pointer after *primitive* has acted.

```
  static void mp_primitive(MP mp, const char *ss, halfword c, halfword o)
  {
    char *s ← mp_xstrdup(mp, ss);
    set_cur_sym(mp_id_lookup(mp, s, strlen(s), true)); mp_xfree(s); set_eq_type(cur_sym(), c);
    set_equiv(cur_sym(), o);
  }
```

236. Some other symbolic tokens only exist for error recovery.

```
  static mp_sym mp_frozen_primitive(MP mp, const char *ss, halfword c, halfword o)
  {
    char *s ← mp_xstrdup(mp, ss);
    mp_sym str ← mp_frozen_id_lookup(mp, s, strlen(ss), true);
    mp_xfree(s); str→type ← c; str→v.data.indep.serial ← o; return str;
  }
```

237. This routine returns *true* if the argument is an un-redefinable symbol because it is one of the error recovery tokens (as explained elsewhere, *frozen_inaccessible* actually is redefinable).

```
static boolean mp_is_frozen(MP mp, mp_sym sym)
{
  mp_sym temp ← mp_frozen_id_lookup(mp, (char *) sym→text→str, sym→text→len, false);
  if (temp ≡ mp→frozen_inaccessible) return false;
  return (temp ≡ sym);
}
```

238. Many of METAPOST's primitives need no *equiv*, since they are identifiable by their *eq_type* alone. These primitives are loaded into the hash table as follows:

⟨Put each of METAPOST's primitives into the hash table 204⟩ +≡

```
mp_primitive(mp, "..", mp_path_join, 0); mp_primitive(mp, "[", mp_left_bracket, 0);
mp→frozen_left_bracket ← mp_frozen_primitive(mp, "[", mp_left_bracket, 0);
mp_primitive(mp, "]", mp_right_bracket, 0); mp_primitive(mp, "}", mp_right_brace, 0);
mp_primitive(mp, "{", mp_left_brace, 0); mp_primitive(mp, ":", mp_colon, 0);
mp→frozen_colon ← mp_frozen_primitive(mp, ":", mp_colon, 0);
mp_primitive(mp, "::", mp_double_colon, 0); mp_primitive(mp, "||:", mp_bchar_label, 0);
mp_primitive(mp, ":=", mp_assignment, 0); mp_primitive(mp, ",", mp_comma, 0);
mp_primitive(mp, ";", mp_semicolon, 0);
mp→frozen_semicolon ← mp_frozen_primitive(mp, ";", mp_semicolon, 0);
mp_primitive(mp, "\\", mp_relax, 0); mp_primitive(mp, "addto", mp_add_to_command, 0);
mp_primitive(mp, "atleast", mp_at_least, 0); mp_primitive(mp, "begingroup", mp_begin_group, 0);
mp→bg_loc ← cur_sym(); mp_primitive(mp, "controls", mp_controls, 0);
mp_primitive(mp, "curl", mp_curl_command, 0); mp_primitive(mp, "delimiters", mp_delimiters, 0);
mp_primitive(mp, "endgroup", mp_end_group, 0); mp→eg_loc ← cur_sym();
mp→frozen_end_group ← mp_frozen_primitive(mp, "endgroup", mp_end_group, 0);
mp_primitive(mp, "everyjob", mp_every_job_command, 0); mp_primitive(mp, "exitif", mp_exit_test, 0);
mp_primitive(mp, "expandafter", mp_expand_after, 0);
mp_primitive(mp, "interim", mp_interim_command, 0); mp_primitive(mp, "let", mp_let_command, 0);
mp_primitive(mp, "newinternal", mp_new_internal, 0); mp_primitive(mp, "of", mp_of_token, 0);
mp_primitive(mp, "randomseed", mp_random_seed, 0); mp_primitive(mp, "save", mp_save_command, 0);
mp_primitive(mp, "scantokens", mp_scan_tokens, 0); mp_primitive(mp, "runscript", mp_runscript, 0);
mp_primitive(mp, "maketext", mp_maketext, 0);
mp_primitive(mp, "shipout", mp_ship_out_command, 0); mp_primitive(mp, "skipto", mp_skip_to, 0);
mp_primitive(mp, "special", mp_special_command, 0);
mp_primitive(mp, "fontmapfile", mp_special_command, 1);
mp_primitive(mp, "fontmapline", mp_special_command, 2);
mp_primitive(mp, "step", mp_step_token, 0); mp_primitive(mp, "str", mp_str_op, 0);
mp_primitive(mp, "void", mp_void_op, 0); mp_primitive(mp, "tension", mp_tension, 0);
mp_primitive(mp, "to", mp_to_token, 0); mp_primitive(mp, "until", mp_until_token, 0);
mp_primitive(mp, "within", mp_within_token, 0); mp_primitive(mp, "write", mp_write_command, 0);
```

239. Each primitive has a corresponding inverse, so that it is possible to display the cryptic numeric contents of *eqtb* in symbolic form. Every call of *primitive* in this program is therefore accompanied by some straightforward code that forms part of the *print_cmd_mod* routine explained below.

⟨ Cases of *print_cmd_mod* for symbolic printing of primitives 239 ⟩ ≡

```
case mp_add_to_command: mp_print(mp, "addto"); break;
case mp_assignment: mp_print(mp, ":="); break;
case mp_at_least: mp_print(mp, "atleast"); break;
case mp_bchar_label: mp_print(mp, "||:"); break;
case mp_begin_group: mp_print(mp, "begingroup"); break;
case mp_colon: mp_print(mp, ":"); break;
case mp_comma: mp_print(mp, ","); break;
case mp_controls: mp_print(mp, "controls"); break;
case mp_curl_command: mp_print(mp, "curl"); break;
case mp_delimiters: mp_print(mp, "delimiters"); break;
case mp_double_colon: mp_print(mp, "::"); break;
case mp_end_group: mp_print(mp, "endgroup"); break;
case mp_every_job_command: mp_print(mp, "everyjob"); break;
case mp_exit_test: mp_print(mp, "exitif"); break;
case mp_expand_after: mp_print(mp, "expandafter"); break;
case mp_interim_command: mp_print(mp, "interim"); break;
case mp_left_brace: mp_print(mp, "{"); break;
case mp_left_bracket: mp_print(mp, "["); break;
case mp_let_command: mp_print(mp, "let"); break;
case mp_new_internal: mp_print(mp, "newinternal"); break;
case mp_of_token: mp_print(mp, "of"); break;
case mp_path_join: mp_print(mp, ".."); break;
case mp_random_seed: mp_print(mp, "randomseed"); break;
case mp_relax: mp_print_char(mp, xord('\\')); break;
case mp_right_brace: mp_print_char(mp, xord('}')); break;
case mp_right_bracket: mp_print_char(mp, xord(']')); break;
case mp_save_command: mp_print(mp, "save"); break;
case mp_scan_tokens: mp_print(mp, "scantokens"); break;
case mp_runscript: mp_print(mp, "runscript"); break;
case mp_maketext: mp_print(mp, "maketext"); break;
case mp_semicolon: mp_print_char(mp, xord(';')); break;
case mp_ship_out_command: mp_print(mp, "shipout"); break;
case mp_skip_to: mp_print(mp, "skipto"); break;
case mp_special_command:
  if (m ≡ 2) mp_print(mp, "fontmapline");
  else if (m ≡ 1) mp_print(mp, "fontmapfile");
  else mp_print(mp, "special");
  break;
case mp_step_token: mp_print(mp, "step"); break;
case mp_str_op: mp_print(mp, "str"); break;
case mp_void_op: mp_print(mp, "void"); break;
case mp_tension: mp_print(mp, "tension"); break;
case mp_to_token: mp_print(mp, "to"); break;
case mp_until_token: mp_print(mp, "until"); break;
case mp_within_token: mp_print(mp, "within"); break;
case mp_write_command: mp_print(mp, "write"); break;
```

See also sections 739, 749, 757, 763, 775, 817, 958, 1049, 1074, 1079, 1081, 1097, 1103, 1120, 1126, 1140, 1171, and 1181.

This code is used in section 674.

240. We will deal with the other primitives later, at some point in the program where their *eq_type* and *equiv* values are more meaningful. For example, the primitives for macro definitions will be loaded when we consider the routines that define macros. It is easy to find where each particular primitive was treated by looking in the index at the end; for example, the section where `"def"` entered *eqtb* is listed under '**def** primitive'.

241. Token lists.

A METAPOST token is either symbolic or numeric or a string, or it denotes a macro parameter or capsule or an internal; so there are six corresponding ways to encode it internally:

(1) A symbolic token for symbol p is represented by the pointer p, in the *sym_sym* field of a symbolic node in *mem*. The *type* field is *symbol_node*; and it has a *name_type* to differentiate various subtypes of symbolic tokens, which is usually *normal_sym*, but *macro_sym* for macro names.

(2) A numeric token whose *scaled* value is v is represented in a non-symbolic node of *mem*; the *type* field is *known*, the *name_type* field is *token*, and the *value* field holds v.

(3) A string token is also represented in a non-symbolic node; the *type* field is *mp_string_type*, the *name_type* field is *token*, and the *value* field holds the corresponding **mp_string**.

(4) Capsules have *name_type* ← *capsule*, and their *type* and *value* fields represent arbitrary values, with *type* different from *symbol_node* (in ways to be explained later).

(5) Macro parameters appear in *sym_info* fields of symbolic nodes. The *type* field is *symbol_node*; the kth parameter is represented by k in *sym_info*; and *expr_sym* in *name_type*, if it is of type **expr**, or *suffix_sym* if it is of type **suffix**, or by *text_sym* if it is of type **text**.

(6) The kth internal is also represented by k in *sym_info*; the *type* field is *symbol_node* as for the other symbolic tokens; and *internal_sym* is its *name_type*;

Actual values of the parameters and internals are kept in a separate stack, as we will see later.

Note that the '*type*' field of a node has nothing to do with "type" in a printer's sense. It's curious that the same word is used in such different ways.

```
#define token_node_size sizeof(mp_node_data)    ▷ the number of words in a large token node ◁
#define set_value_sym(A, B) do_set_value_sym(mp, (mp_token_node)(A), (B))
#define set_value_number(A, B) do_set_value_number(mp, (mp_token_node)(A), (B))
#define set_value_node(A, B) do_set_value_node(mp, (mp_token_node)(A), (B))
#define set_value_str(A, B) do_set_value_str(mp, (mp_token_node)(A), (B))
#define set_value_knot(A, B) do_set_value_knot(mp, (mp_token_node)A, (B))
#define value_sym_NEW(A) (mp_sym) mp_link(A)
#define set_value_sym_NEW(A, B) set_mp_link(A, (mp_node) B)
```

⟨ MPlib internal header stuff 8 ⟩ +≡

```
typedef struct mp_node_data *mp_token_node;
```

242.

```
#if DEBUG
#define value_sym(A) do_get_value_sym(mp, (mp_token_node)(A))
    ▷ #define value_number(A) do_get_value_number(mp, (mp_token_node)(A)) ◁
#define value_number(A) ((mp_token_node)(A))→data.n
#define value_node(A) do_get_value_node(mp, (mp_token_node)(A))
#define value_str(A) do_get_value_str(mp, (mp_token_node)(A))
#define value_knot(A) do_get_value_knot(mp, (mp_token_node)(A))
#else
#define value_sym(A) ((mp_token_node)(A))→data.sym
#define value_number(A) ((mp_token_node)(A))→data.n
#define value_node(A) ((mp_token_node)(A))→data.node
#define value_str(A) ((mp_token_node)(A))→data.str
#define value_knot(A) ((mp_token_node)(A))→data.p
#endif
  static void do_set_value_sym(MP mp, mp_token_node A, mp_sym B)
  {
    FUNCTION_TRACE3("set_value_sym(%p,%p)\n", (A), (B)); A→data.sym ← (B);
  }
  static void do_set_value_number(MP mp, mp_token_node A, mp_number B)
  {
    FUNCTION_TRACE3("set_value(%p,%s)\n", (A), number_tostring(B)); A→data.p ← Λ;
    A→data.str ← Λ; A→data.node ← Λ; number_clone(A→data.n, B);
  }
  static void do_set_value_str(MP mp, mp_token_node A, mp_string B)
  {
    FUNCTION_TRACE3("set_value_str(%p,%p)\n", (A), (B)); assert(A→type ≠ mp_structured);
    A→data.p ← Λ; A→data.str ← (B); add_str_ref((B)); A→data.node ← Λ;
    number_clone(A→data.n, zero_t);
  }
  static void do_set_value_node(MP mp, mp_token_node A, mp_node B)
  {    ▷ store the value in a large token node ◁
    FUNCTION_TRACE3("set_value_node(%p,%p)\n", A, B); assert(A→type ≠ mp_structured);
    A→data.p ← Λ; A→data.str ← Λ; A→data.node ← B; number_clone(A→data.n, zero_t);
  }
  static void do_set_value_knot(MP mp, mp_token_node A, mp_knot B)
  {
    FUNCTION_TRACE3("set_value_knot(%p,%p)\n", (A), (B)); assert(A→type ≠ mp_structured);
    A→data.p ← (B); A→data.str ← Λ; A→data.node ← Λ; number_clone(A→data.n, zero_t);
  }
```

243.

```
#if DEBUG
  static mp_sym do_get_value_sym(MP mp, mp_token_node A)
  {    /* A->type can be structured in this case */
    FUNCTION_TRACE3("%p = get_value_sym(%p)\n", A->data.sym, A);  return A->data.sym;
  }
  static mp_node do_get_value_node(MP mp, mp_token_node A)
  {
    assert(A->type != mp_structured);
    FUNCTION_TRACE3("%p = get_value_node(%p)\n", A->data.node, A);  return A->data.node;
  }
  static mp_string do_get_value_str(MP mp, mp_token_node A)
  {
    assert(A->type != mp_structured);  FUNCTION_TRACE3("%p = get_value_str(%p)\n", A->data.str, A);
    return A->data.str;
  }
  static mp_knot do_get_value_knot(MP mp, mp_token_node A)
  {
    assert(A->type != mp_structured);  FUNCTION_TRACE3("%p = get_value_knot(%p)\n", A->data.p, A);
    return A->data.p;
  }
  static mp_number do_get_value_number(MP mp, mp_token_node A)
  {
    assert(A->type != mp_structured);
    FUNCTION_TRACE3("%d = get_value_number(%p)\n", A->data.n.type, A);  return A->data.n;
  }
#endif
```

244. ⟨ Declarations 10 ⟩ +≡

```
#if DEBUG
  static mp_number do_get_value_number(MP mp, mp_token_node A);
  static mp_sym do_get_value_sym(MP mp, mp_token_node A);
  static mp_node do_get_value_node(MP mp, mp_token_node A);
  static mp_string do_get_value_str(MP mp, mp_token_node A);
  static mp_knot do_get_value_knot(MP mp, mp_token_node A);
#endif
  static void do_set_value_sym(MP mp, mp_token_node A, mp_sym B);
  static void do_set_value_number(MP mp, mp_token_node A, mp_number B);
  static void do_set_value_node(MP mp, mp_token_node A, mp_node B);
  static void do_set_value_str(MP mp, mp_token_node A, mp_string B);
  static void do_set_value_knot(MP mp, mp_token_node A, mp_knot B);
```

245. **static mp_node** *mp_get_token_node*(**MP** *mp*)

```
{
  mp_node p;
  if (mp→token_nodes) {
    p ← mp→token_nodes; mp→token_nodes ← p→link; mp→num_token_nodes −−; p→link ← Λ;
  }
  else {
    p ← malloc_node(token_node_size); new_number(p→data.n); p→has_number ← 1;
  }
  p→type ← mp_token_node_type; FUNCTION_TRACE2("%p␣=␣mp_get_token_node()\n", p);
  return (mp_node) p;
}
```

246. **static void** *mp_free_token_node*(**MP** *mp*, **mp_node** *p*)

```
{
  FUNCTION_TRACE2("mp_free_token_node(%p)\n", p);
  if (¬p) return;
  if (mp→num_token_nodes < max_num_token_nodes) {
    p→link ← mp→token_nodes; mp→token_nodes ← p; mp→num_token_nodes ++; return;
  }
  mp→var_used −= token_node_size;
  if (mp→math_mode > mp_math_double_mode) {
    free_number(((mp_value_node) p)→data.n);
  }
  xfree(p);
}
```

247. ⟨ Declarations 10 ⟩ +≡
static void *mp_free_token_node*(**MP** *mp*, **mp_node** *p*);

248. A numeric token is created by the following trivial routine.

static mp_node *mp_new_num_tok*(**MP** *mp*, **mp_number** *v*)

```
{
  mp_node p;    ▷ the new node ◁
  p ← mp_get_token_node(mp); set_value_number(p, v); p→type ← mp_known;
  p→name_type ← mp_token; FUNCTION_TRACE3("%p␣=␣mp_new_num_tok(%p)\n", p, v); return p;
}
```

249. A token list is a singly linked list of nodes in *mem*, where each node contains a token and a link. Here's a subroutine that gets rid of a token list when it is no longer needed.

```
static void mp_flush_token_list(MP mp, mp_node p)
{
  mp_node q;    ▷ the node being recycled ◁
  FUNCTION_TRACE2("mp_flush_token_list(%p)\n", p);
  while (p ≠ Λ) {
    q ← p; p ← mp_link(p);
    if (mp_type(q) ≡ mp_symbol_node) {
      mp_free_symbolic_node(mp, q);
    }
    else {
      switch (mp_type(q)) {
      case mp_vacuous: case mp_boolean_type: case mp_known: break;
      case mp_string_type: delete_str_ref(value_str(q)); break;
      case unknown_types: case mp_pen_type: case mp_path_type: case mp_picture_type:
        case mp_pair_type: case mp_color_type: case mp_cmykcolor_type: case mp_transform_type:
        case mp_dependent: case mp_proto_dependent: case mp_independent:
        mp_recycle_value(mp, q); break;
      default: mp_confusion(mp, "token");
      }
      mp_free_token_node(mp, q);
    }
  }
}
```

250. The procedure *show_token_list*, which prints a symbolic form of the token list that starts at a given node p, illustrates these conventions. The token list being displayed should not begin with a reference count.

An additional parameter q is also given; this parameter is either NULL or it points to a node in the token list where a certain magic computation takes place that will be explained later. (Basically, q is non-NULL when we are printing the two-line context information at the time of an error message; q marks the place corresponding to where the second line should begin.)

The generation will stop, and '` ETC.`' will be printed, if the length of printing exceeds a given limit l; the length of printing upon entry is assumed to be a given amount called *null_tally*. (Note that *show_token_list* sometimes uses itself recursively to print variable names within a capsule.)

Unusual entries are printed in the form of all-caps tokens preceded by a space, e.g., '` BAD`'.

⟨ Declarations 10 ⟩ +≡

```
static void mp_show_token_list(MP mp, mp_node p, mp_node q, integer l, integer null_tally);
```

251.
```
void mp_show_token_list(MP mp, mp_node p, mp_node q, integer l, integer null_tally)
{
  quarterword cclass, c;   ▷ the char_class of previous and new tokens ◁
  cclass ← percent_class; mp→tally ← null_tally;
  while ((p ≠ Λ) ∧ (mp→tally < l)) {
    if (p ≡ q) {
      set_trick_count( );
    }   ▷ Display token p and set c to its class; but return if there are problems ◁
    c ← letter_class;   ▷ the default ◁
    if (mp_type(p) ≠ mp_symbol_node) {   ▷ Display non-symbolic token ◁
      if (mp_name_type(p) ≡ mp_token) {
        if (mp_type(p) ≡ mp_known) {   ▷ Display a numeric token ◁
          if (cclass ≡ digit_class) mp_print_char(mp, xord('␣'));
          if (number_negative(value_number(p))) {
            if (cclass ≡ mp_left_bracket_class) mp_print_char(mp, xord('␣'));
            mp_print_char(mp, xord('[')); print_number(value_number(p));
            mp_print_char(mp, xord(']')); c ← mp_right_bracket_class;
          }
          else {
            print_number(value_number(p)); c ← digit_class;
          }
        }
        else if (mp_type(p) ≠ mp_string_type) {
          mp_print(mp, "␣BAD");
        }
        else {
          mp_print_char(mp, xord('"')); mp_print_str(mp, value_str(p));
          mp_print_char(mp, xord('"')); c ← string_class;
        }
      }
      else if ((mp_name_type(p) ≠ mp_capsule) ∨ (mp_type(p) < mp_vacuous) ∨ (mp_type(p) >
            mp_independent)) {
        mp_print(mp, "␣BAD");
      }
      else {
        mp_print_capsule(mp, p); c ← right_paren_class;
      }
    }
    else {
      if (mp_name_type(p) ≡ mp_expr_sym ∨ mp_name_type(p) ≡ mp_suffix_sym ∨ mp_name_type(p) ≡
            mp_text_sym) {
        integer r;   ▷ temporary register ◁
        r ← mp_sym_info(p);
        if (mp_name_type(p) ≡ mp_expr_sym) {
          mp_print(mp, "(EXPR");
        }
        else if (mp_name_type(p) ≡ mp_suffix_sym) {
          mp_print(mp, "(SUFFIX");
        }
        else {
          mp_print(mp, "(TEXT");
        }
```

```
        mp_print_int(mp, r);  mp_print_char(mp, xord(')'));  c ← right_paren_class;
      }
      else {
        mp_sym sr ← mp_sym_sym(p);
        if (sr ≡ collective_subscript) {    ▷ Display a collective subscript ◁
          if (cclass ≡ mp_left_bracket_class) mp_print_char(mp, xord('␣'));
          mp_print(mp, "[]");  c ← mp_right_bracket_class;
        }
        else {
          mp_string rr ← text(sr);
          if (rr ≡ Λ ∨ rr→str ≡ Λ) {
            mp_print(mp, "␣NONEXISTENT");
          }
          else {    ▷ Print string r as a symbolic token and set c to its class ◁
            c ← (quarterword) mp→char_class[(rr→str[0])];
            if (c ≡ cclass) {
              switch (c) {
              case letter_class: mp_print_char(mp, xord('.'));  break;
              case isolated_classes: break;
              default: mp_print_char(mp, xord('␣'));  break;
              }
            }
            mp_print_str(mp, rr);
          }
        }
      }
    }
    cclass ← c;  p ← mp_link(p);
  }
  if (p ≠ Λ) mp_print(mp, "␣ETC.");
  return;
}
```

252. ⟨ Declarations 10 ⟩ +≡

```
static void mp_print_capsule(MP mp, mp_node p);
```

253. ⟨ Declare miscellaneous procedures that were declared *forward* 253 ⟩ ≡

```
void mp_print_capsule(MP mp, mp_node p)
{
  mp_print_char(mp, xord('('));  mp_print_exp(mp, p, 0);  mp_print_char(mp, xord(')'));
}
```

This code is used in section 1280.

254. Macro definitions are kept in METAPOST's memory in the form of token lists that have a few extra symbolic nodes at the beginning.

The first node contains a reference count that is used to tell when the list is no longer needed. To emphasize the fact that a reference count is present, we shall refer to the *sym_info* field of this special node as the *ref_count* field.

The next node or nodes after the reference count serve to describe the formal parameters. They consist of zero or more parameter tokens followed by a code for the type of macro.

/* reference count preceding a macro definition or picture header */

```
#define ref_count(A) indep_value(A)
#define set_ref_count(A, B) set_indep_value(A, B)
#define add_mac_ref(A) set_ref_count((A), ref_count((A)) + 1)   ▷ make a new reference to a macro list ◁
#define decr_mac_ref(A) set_ref_count((A), ref_count((A)) − 1)   ▷ remove a reference to a macro list ◁
```

⟨Types in the outer block 37⟩ +≡

```
typedef enum {
  mp_general_macro,   ▷ preface to a macro defined with a parameter list ◁
  mp_primary_macro,   ▷ preface to a macro with a primary parameter ◁
  mp_secondary_macro,   ▷ preface to a macro with a secondary parameter ◁
  mp_tertiary_macro,   ▷ preface to a macro with a tertiary parameter ◁
  mp_expr_macro,   ▷ preface to a macro with an undelimited expr parameter ◁
  mp_of_macro,   ▷ preface to a macro with undelimited 'expr x of y' parameters ◁
  mp_suffix_macro,   ▷ preface to a macro with an undelimited suffix parameter ◁
  mp_text_macro,   ▷ preface to a macro with an undelimited text parameter ◁
  mp_expr_param,   ▷ used by expr primitive ◁
  mp_suffix_param,   ▷ used by suffix primitive ◁
  mp_text_param   ▷ used by text primitive ◁
} mp_macro_info;
```

255.

```
static void mp_delete_mac_ref(MP mp, mp_node p)
{   ▷ p points to the reference count of a macro list that is losing one reference ◁
  if (ref_count(p) ≡ 0) mp_flush_token_list(mp, p);
  else decr_mac_ref(p);
}
```

256. The following subroutine displays a macro, given a pointer to its reference count.

```
static void mp_show_macro(MP mp, mp_node p, mp_node q, integer l)
{
  mp_node r;    ▷ temporary storage ◁
  p ← mp_link(p);    ▷ bypass the reference count ◁
  while (mp_name_type(p) ≠ mp_macro_sym) {
    r ← mp_link(p); mp_link(p) ← Λ; mp_show_token_list(mp, p, Λ, l, 0); mp_link(p) ← r; p ← r;
    if (l > 0) l ← l − mp→tally;
    else return;
  }    ▷ control printing of 'ETC.' ◁
  mp→tally ← 0;
  switch (mp_sym_info(p)) {
  case mp_general_macro: mp_print(mp, "->"); break;
  case mp_primary_macro: case mp_secondary_macro: case mp_tertiary_macro:
    mp_print_char(mp, xord('<')); mp_print_cmd_mod(mp, mp_param_type, mp_sym_info(p));
    mp_print(mp, ">->"); break;
  case mp_expr_macro: mp_print(mp, "<expr>->"); break;
  case mp_of_macro: mp_print(mp, "<expr>of<primary>->"); break;
  case mp_suffix_macro: mp_print(mp, "<suffix>->"); break;
  case mp_text_macro: mp_print(mp, "<text>->"); break;
  }    ▷ there are no other cases ◁
  mp_show_token_list(mp, mp_link(p), q, l − mp→tally, 0);
}
```

257. Data structures for variables. The variables of METAPOST programs can be simple, like '`x`', or they can combine the structural properties of arrays and records, like '`x20a.b`'. A METAPOST user assigns a type to a variable like `x20a.b` by saying, for example, '`boolean x[]a.b`'. It's time for us to study how such things are represented inside of the computer.

Each variable value occupies two consecutive words, either in a non-symbolic node called a value node, or as a non-symbolic subfield of a larger node. One of those two words is called the *value* field; it is an integer, containing either a *scaled* numeric value or the representation of some other type of quantity. (It might also be subdivided into halfwords, in which case it is referred to by other names instead of *value*.) The other word is broken into subfields called *type*, *name_type*, and *link*. The *type* field is a quarterword that specifies the variable's type, and *name_type* is a quarterword from which METAPOST can reconstruct the variable's name (sometimes by using the *link* field as well). Thus, only 1.25 words are actually devoted to the value itself; the other three-quarters of a word are overhead, but they aren't wasted because they allow METAPOST to deal with sparse arrays and to provide meaningful diagnostics.

In this section we shall be concerned only with the structural aspects of variables, not their values. Later parts of the program will change the *type* and *value* fields, but we shall treat those fields as black boxes whose contents should not be touched.

However, if the *type* field is *mp_structured*, there is no *value* field, and the second word is broken into two pointer fields called *attr_head* and *subscr_head*. Those fields point to additional nodes that contain structural information, as we shall see.

TH Note: DEK and JDH had a nice theoretical split between *value*, *attr* and *subscr* nodes, as documented above and further below. However, all three types had a bad habit of transmuting into each other in practice while pointers to them still lived on elsewhere, so using three different C structures is simply not workable. All three are now represented as a single C structure called **mp_value_node**.

There is a potential union in this structure in the interest of space saving: *subscript_* and *hashloc_* are mutually exclusive.

Actually, so are *attr_head_* + *subscr_head_* on one side and and *value_* on the other, but because of all the access macros that are used in the code base to get at values, those cannot be folded into a union (yet); this would have required creating a similar union in **mp_token_node** where it would only serve to confuse things.

Finally, *parent_* only applies in *attr* nodes (the ones that have *hashloc_*), but creating an extra substructure inside the union just for that does not save space and the extra complication in the structure is not worth the minimal extra code clarification.

```
#define attr_head(A) do_get_attr_head(mp, (mp_value_node)(A))
#define set_attr_head(A, B) do_set_attr_head(mp, (mp_value_node)(A), (mp_node)(B))
#define subscr_head(A) do_get_subscr_head(mp, (mp_value_node)(A))
#define set_subscr_head(A, B) do_set_subscr_head(mp, (mp_value_node)(A), (mp_node)(B))
```

⟨MPlib internal header stuff 8⟩ +≡

```
typedef struct mp_value_node_data {
  NODE_BODY;
  mp_value_data data;
  mp_number subscript_;
  mp_sym hashloc_;
  mp_node parent_;
  mp_node attr_head_;
  mp_node subscr_head_;
} mp_value_node_data;
```

258. **static mp_node** *do_get_attr_head*(**MP** *mp*, **mp_value_node** *A*)
{
assert(*A*→*type* ≡ *mp_structured*); `FUNCTION_TRACE3("%p␣=␣get_attr_head(%p)\n"`, *A*→*attr_head_*, *A*);
return *A*→*attr_head_*;
}
static mp_node *do_get_subscr_head*(**MP** *mp*, **mp_value_node** *A*)
{
assert(*A*→*type* ≡ *mp_structured*);
`FUNCTION_TRACE3("%p␣=␣get_subscr_head(%p)\n"`, *A*→*subscr_head_*, *A*); **return** *A*→*subscr_head_*;
}
static void *do_set_attr_head*(**MP** *mp*, **mp_value_node** *A*, **mp_node** *d*)
{
`FUNCTION_TRACE4("set_attr_head(%p,%p)␣on␣line␣%d\n"`, (*A*), *d*, `__LINE__`);
assert(*A*→*type* ≡ *mp_structured*); *A*→*attr_head_* ← *d*;
}
static void *do_set_subscr_head*(**MP** *mp*, **mp_value_node** *A*, **mp_node** *d*)
{
`FUNCTION_TRACE4("set_subscr_head(%p,%p)␣on␣line␣%d\n"`, (*A*), *d*, `__LINE__`);
assert(*A*→*type* ≡ *mp_structured*); *A*→*subscr_head_* ← *d*;
}

259. ⟨ Declarations 10 ⟩ +≡
static mp_node *do_get_subscr_head*(**MP** *mp*, **mp_value_node** *A*);
static mp_node *do_get_attr_head*(**MP** *mp*, **mp_value_node** *A*);
static void *do_set_attr_head*(**MP** *mp*, **mp_value_node** *A*, **mp_node** *d*);
static void *do_set_subscr_head*(**MP** *mp*, **mp_value_node** *A*, **mp_node** *d*);

260. It would have been nicer to make *mp_get_value_node* return **mp_value_node** variables, but with *eqtb* as it stands that became messy: lots of typecasts. So, it returns a simple **mp_node** for now.

```
#define value_node_size sizeof(struct mp_value_node_data)
  static mp_node mp_get_value_node(MP mp)
  {
    mp_value_node p;
    if (mp→value_nodes) {
      p ← (mp_value_node) mp→value_nodes; mp→value_nodes ← p→link; mp→num_value_nodes −−;
      p→link ← Λ;
    }
    else {
      p ← malloc_node(value_node_size); new_number(p→data.n); new_number(p→subscript_);
      p→has_number ← 2;
    }
    mp_type(p) ← mp_value_node_type; FUNCTION_TRACE2("%p␣=␣mp_get_value_node()\n", p);
    return (mp_node) p;
  }
#if DEBUG > 1
  static void debug_dump_value_node(mp_node x)
  {
    mp_value_node qq ← (mp_value_node) x;
    fprintf(stdout, "\nnode␣%p:\n", qq); fprintf(stdout, "␣␣type=%s\n", mp_type_string(qq→type));
    fprintf(stdout, "␣␣name_type=%d\n", qq→name_type); fprintf(stdout, "␣␣link=%p\n", qq→link);
    fprintf(stdout, "␣␣data.n=%d\n", qq→data.n.type);
    if (is_number(qq→data.n)) {
      fprintf(stdout, "␣␣␣␣data.n.data.val=%d\n", qq→data.n.data.val);
      fprintf(stdout, "␣␣␣␣data.n.data.dval=%f\n", qq→data.n.data.dval);
    }
    fprintf(stdout, "␣␣data.str=%p\n", qq→data.str);
    if (qq→data.str ≠ Λ) {
      fprintf(stdout, "␣␣␣␣data.str->len=%d\n", (int) qq→data.str→len);
      fprintf(stdout, "␣␣␣␣data.str->str=%s\n", qq→data.str→str);
    }
    fprintf(stdout, "␣␣data.indep.serial=%d\n␣␣data.indep.scale=%d\n", qq→data.indep.serial,
        qq→data.indep.scale); fprintf(stdout, "␣␣data.sym=%p\n", qq→data.sym);
    fprintf(stdout, "␣␣data.p=%p\n", qq→data.p); fprintf(stdout, "␣␣data.node=%p\n", qq→data.node);
    fprintf(stdout, "␣␣subscript=%d\n", qq→subscript_.type);
    if (is_number(qq→subscript_)) {
      fprintf(stdout, "␣␣␣␣subscript_.data.val=%d\n", qq→subscript_.data.val);
      fprintf(stdout, "␣␣␣␣subscript_.data.dval=%f\n", qq→subscript_.data.dval);
    }
    fprintf(stdout, "␣␣hashloc=%p\n", qq→hashloc_); fprintf(stdout, "␣␣parent=%p\n", qq→parent_);
    fprintf(stdout, "␣␣attr_head=%p\n", qq→attr_head_);
    fprintf(stdout, "␣␣subscr_head=%p\n\n", qq→subscr_head_);
  }
#endif
```

261. ⟨ Declarations 10 ⟩ +≡

```
static mp_node mp_get_value_node(MP mp);
#if DEBUG > 1
static void debug_dump_value_node(mp_node x);
#endif
```

262. An attribute node is three words long. Two of these words contain *type* and *value* fields as described above, and the third word contains additional information: There is an *hashloc* field, which contains the hash address of the token that names this attribute; and there's also a *parent* field, which points to the value node of *mp_structured* type at the next higher level (i.e., at the level to which this attribute is subsidiary). The *name_type* in an attribute node is '*attr*'. The *link* field points to the next attribute with the same parent; these are arranged in increasing order, so that $hashloc(mp\_link(p)) > hashloc(p)$. The final attribute node links to the constant *end_attr*, whose *hashloc* field is greater than any legal hash address. The *attr_head* in the parent points to a node whose *name_type* is *mp_structured_root*; this node represents the NULL attribute, i.e., the variable that is relevant when no attributes are attached to the parent. The *attr_head* node has the fields of either a value node, a subscript node, or an attribute node, depending on what the parent would be if it were not structured; but the subscript and attribute fields are ignored, so it effectively contains only the data of a value node. The *link* field in this special node points to an attribute node whose *hashloc* field is zero; the latter node represents a collective subscript '`[]`' attached to the parent, and its *link* field points to the first non-special attribute node (or to *end_attr* if there are none).

A subscript node likewise occupies three words, with *type* and *value* fields plus extra information; its *name_type* is *subscr*. In this case the third word is called the *subscript* field, which is a *scaled* integer. The *link* field points to the subscript node with the next larger subscript, if any; otherwise the *link* points to the attribute node for collective subscripts at this level. We have seen that the latter node contains an upward pointer, so that the parent can be deduced.

The *name_type* in a parent-less value node is *root*, and the *link* is the hash address of the token that names this value.

In other words, variables have a hierarchical structure that includes enough threads running around so that the program is able to move easily between siblings, parents, and children. An example should be helpful: (The reader is advised to draw a picture while reading the following description, since that will help to firm up the ideas.) Suppose that '`x`' and '`x.a`' and '`x[]b`' and '`x5`' and '`x20b`' have been mentioned in a user's program, where `x[]b` has been declared to be of **boolean** type. Let $h(x)$, $h(a)$, and $h(b)$ be the hash addresses of `x`, `a`, and `b`. Then $eq\_type(h(x)) \leftarrow name$ and $equiv(h(x)) \leftarrow p$, where p is a non-symbolic value node with $mp\_name\_type(p) \leftarrow root$ and $mp\_link(p) \leftarrow h(x)$. We have $type(p) \leftarrow mp\_structured$, $attr\_head(p) \leftarrow q$, and $subscr\_head(p) \leftarrow r$, where q points to a value node and r to a subscript node. (Are you still following this? Use a pencil to draw a diagram.) The lone variable '`x`' is represented by $type(q)$ and $value(q)$; furthermore $mp\_name\_type(q) \leftarrow mp\_structured\_root$ and $mp\_link(q) \leftarrow q1$, where $q1$ points to an attribute node representing '`x[]`'. Thus $mp\_name\_type(q1) \leftarrow attr$, $hashloc(q1) \leftarrow collective\_subscript \leftarrow 0$, $parent(q1) \leftarrow p$, $type(q1) \leftarrow mp\_structured$, $attr\_head(q1) \leftarrow qq$, and $subscr\_head(q1) \leftarrow qq1$; qq is a three-word "attribute-as-value" node with $type(qq) \leftarrow numeric\_type$ (assuming that `x5` is numeric, because qq represents '`x[]`' with no further attributes), $mp\_name\_type(qq) \leftarrow structured\_root$, $hashloc(qq) \leftarrow 0$, $parent(qq) \leftarrow p$, and $mp\_link(qq) \leftarrow qq1$. (Now pay attention to the next part.) Node $qq1$ is an attribute node representing '`x[][]`', which has never yet occurred; its *type* field is *undefined*, and its *value* field is undefined. We have $mp\_name\_type(qq1) \leftarrow attr$, $hashloc(qq1) \leftarrow collective\_subscript$, $parent(qq1) \leftarrow q1$, and $mp\_link(qq1) \leftarrow qq2$. Since $qq2$ represents '`x[]b`', $type(qq2) \leftarrow mp\_unknown\_boolean$; also $hashloc(qq2) \leftarrow h(b)$, $parent(qq2) \leftarrow q1$, $mp\_name\_type(qq2) \leftarrow attr$, $mp\_link(qq2) \leftarrow end\_attr$. (Maybe colored lines will help untangle your picture.) Node r is a subscript node with *type* and *value* representing '`x5`'; $mp\_name\_type(r) \leftarrow subscr$, $subscript(r) \leftarrow 5.0$, and $mp\_link(r) \leftarrow r1$ is another subscript node. To complete the picture, see if you can guess what $mp\_link(r1)$ is; give up? It's $q1$. Furthermore $subscript(r1) \leftarrow 20.0$, $mp\_name\_type(r1) \leftarrow subscr$, $type(r1) \leftarrow mp\_structured$, $attr\_head(r1) \leftarrow qqq$, $subscr\_head(r1) \leftarrow qqq1$, and we finish things off with three more nodes qqq, $qqq1$, and $qqq2$ hung onto $r1$. (Perhaps you should start again with a larger sheet of paper.) The value of variable `x20b` appears in node $qqq2$, as you can well imagine.

If the example in the previous paragraph doesn't make things crystal clear, a glance at some of the simpler subroutines below will reveal how things work out in practice.

The only really unusual thing about these conventions is the use of collective subscript attributes. The idea is to avoid repeating a lot of type information when many elements of an array are identical macros (for which distinct values need not be stored) or when they don't have all of the possible attributes. Branches of the structure below collective subscript attributes do not carry actual values except for macro identifiers; branches of the structure below subscript nodes do not carry significant information in their collective subscript attributes.

```
#if DEBUG
#define hashloc(A) do_get_hashloc(mp, (mp_value_node)(A))
#define set_hashloc(A, B) do_set_hashloc(mp, (mp_value_node) A, B)
#define parent(A) do_get_parent(mp, A)
#define set_parent(A, B) do_set_parent(mp, (mp_value_node) A, B)
  static mp_sym do_get_hashloc(MP mp, mp_value_node A)
  {
    assert((A)→type ≡ mp_attr_node_type ∨ (A)→name_type ≡ mp_attr); return (A)→hashloc_;
  }
  static void do_set_hashloc(MP mp, mp_value_node A, mp_sym B)
  {
    FUNCTION_TRACE4("set_hashloc(%p,%p)␣on␣line␣%d\n", (A), (B), __LINE__);
    assert((A)→type ≡ mp_attr_node_type ∨ (A)→name_type ≡ mp_attr); A→hashloc_ ← B;
  }
  static mp_node do_get_parent(MP mp, mp_value_node A)
  {
    assert((A)→type ≡ mp_attr_node_type ∨ (A)→name_type ≡ mp_attr); return (A)→parent_;
      ▷ pointer to mp_structured variable ◁
  }
  static void do_set_parent(MP mp, mp_value_node A, mp_node d)
  {
    assert((A)→type ≡ mp_attr_node_type ∨ (A)→name_type ≡ mp_attr);
    FUNCTION_TRACE4("set_parent(%p,%p)␣on␣line␣%d\n", (A), d, __LINE__); A→parent_ ← d;
  }
#else
#define hashloc(A) ((mp_value_node)(A))→hashloc_
#define set_hashloc(A, B) ((mp_value_node)(A))→hashloc_ ← B
#define parent(A) ((mp_value_node)(A))→parent_
#define set_parent(A, B) ((mp_value_node)(A))→parent_ ← B
#endif
```

263.

```
#define mp_free_attr_node(a, b)
        do {
          assert((b)→type ≡ mp_attr_node_type ∨ (b)→name_type ≡ mp_attr); mp_free_value_node(a, b);
        } while (0)
  static mp_value_node mp_get_attr_node(MP mp)
  {
    mp_value_node p ← (mp_value_node) mp_get_value_node(mp);
    mp_type(p) ← mp_attr_node_type; return p;
  }
```

264. Setting the *hashloc* field of *end_attr* to a value greater than any legal hash address is done by assigning −1 typecasted to **mp_sym**, hopefully resulting in all bits being set. On systems that support negative pointer values or where typecasting −1 does not result in all bits in a pointer being set, something else needs to be done.

⟨Initialize table entries 186⟩ +≡
mp→end_attr ← (**mp_node**) *mp_get_attr_node*(*mp*); *set_hashloc*(*mp→end_attr*, (**mp_sym**) −1);
set_parent((**mp_value_node**) *mp→end_attr*, Λ);

265. ⟨Free table entries 187⟩ +≡
mp_free_attr_node(*mp*, *mp→end_attr*);

266. #**define** *collective_subscript* (**void** ∗) 0 ▷ code for the attribute '[]' ◁
#**define** *subscript*(*A*) ((**mp_value_node**)(*A*))→*subscript_*
#**define** *set_subscript*(*A*, *B*) *do_set_subscript*(*mp*, (**mp_value_node**)(*A*), *B*)

```
static void do_set_subscript(MP mp, mp_value_node A, mp_number B)
{
  FUNCTION_TRACE3("set_subscript(%p,%p)\n", (A), (B));
  assert((A)→type ≡ mp_subscr_node_type ∨ (A)→name_type ≡ mp_subscr);
  number_clone(A→subscript_, B);    ▷ subscript of this variable ◁
}
```

267.
```
static mp_value_node mp_get_subscr_node(MP mp)
{
  mp_value_node p ← (mp_value_node) mp_get_value_node(mp);
  mp_type(p) ← mp_subscr_node_type; return p;
}
```

268. Variables of type **pair** will have values that point to four-word nodes containing two numeric values. The first of these values has *name_type* ← *mp_x_part_sector* and the second has *name_type* ← *mp_y_part_sector*; the *link* in the first points back to the node whose *value* points to this four-word node.

#**define** *x_part*(*A*) ((*mp_pair_node*)(*A*))→*x_part_* ▷ where the **xpart** is found in a pair node ◁
#**define** *y_part*(*A*) ((*mp_pair_node*)(*A*))→*y_part_* ▷ where the **ypart** is found in a pair node ◁

⟨MPlib internal header stuff 8⟩ +≡
```
typedef struct mp_pair_node_data {
  NODE_BODY;
  mp_node x_part_;
  mp_node y_part_;
} mp_pair_node_data;
typedef struct mp_pair_node_data *mp_pair_node;
```

269. **#define** *pair_node_size* **sizeof**(**struct mp_pair_node_data**)
▷ the number of words in a subscript node ◁

```
static mp_node mp_get_pair_node(MP mp)
{
  mp_node p;
  if (mp→pair_nodes) {
    p ← mp→pair_nodes; mp→pair_nodes ← p→link; mp→num_pair_nodes −−; p→link ← Λ;
  }
  else {
    p ← malloc_node(pair_node_size);
  }
  mp_type(p) ← mp_pair_node_type; FUNCTION_TRACE2("get_pair_node():␣%p\n", p);
  return (mp_node) p;
}
```

270. ⟨ Declarations 10 ⟩ +≡

```
void mp_free_pair_node(MP mp, mp_node p);
```

271.

```
void mp_free_pair_node(MP mp, mp_node p)
{
  FUNCTION_TRACE2("mp_free_pair_node(%p)\n", p);
  if (¬p) return;
  if (mp→num_pair_nodes < max_num_pair_nodes) {
    p→link ← mp→pair_nodes; mp→pair_nodes ← p; mp→num_pair_nodes ++; return;
  }
  mp→var_used −= pair_node_size; xfree(p);
}
```

272. If *type*(*p*) ← *mp_pair_type* or if *value*(*p*) ← Λ, the procedure call *init_pair_node*(*p*) will allocate a pair node for *p*. The individual parts of such nodes are initially of type *mp_independent*.

```
static void mp_init_pair_node(MP mp, mp_node p)
{
  mp_node q;    ▷ the new node ◁
  mp_type(p) ← mp_pair_type; q ← mp_get_pair_node(mp); y_part(q) ← mp_get_value_node(mp);
  mp_new_indep(mp, y_part(q));    ▷ sets type(q) and value(q) ◁
  mp_name_type(y_part(q)) ← (quarterword)(mp_y_part_sector); mp_link(y_part(q)) ← p;
  x_part(q) ← mp_get_value_node(mp); mp_new_indep(mp, x_part(q));    ▷ sets type(q) and value(q) ◁
  mp_name_type(x_part(q)) ← (quarterword)(mp_x_part_sector); mp_link(x_part(q)) ← p;
  set_value_node(p, q);
}
```

273. Variables of type **transform** are similar, but in this case their *value* points to a 12-word node containing six values, identified by *x_part_sector*, *y_part_sector*, *mp_xx_part_sector*, *mp_xy_part_sector*, *mp_yx_part_sector*, and *mp_yy_part_sector*.

```
#define tx_part(A) ((mp_transform_node)(A))→tx_part_
        ▷ where the xpart is found in a transform node ◁
#define ty_part(A) ((mp_transform_node)(A))→ty_part_
        ▷ where the ypart is found in a transform node ◁
#define xx_part(A) ((mp_transform_node)(A))→xx_part_
        ▷ where the xxpart is found in a transform node ◁
#define xy_part(A) ((mp_transform_node)(A))→xy_part_
        ▷ where the xypart is found in a transform node ◁
#define yx_part(A) ((mp_transform_node)(A))→yx_part_
        ▷ where the yxpart is found in a transform node ◁
#define yy_part(A) ((mp_transform_node)(A))→yy_part_
        ▷ where the yypart is found in a transform node ◁
```

⟨MPlib internal header stuff 8⟩ +≡

```
typedef struct mp_transform_node_data {
  NODE_BODY;
  mp_node tx_part_;
  mp_node ty_part_;
  mp_node xx_part_;
  mp_node yx_part_;
  mp_node xy_part_;
  mp_node yy_part_;
} mp_transform_node_data;
typedef struct mp_transform_node_data *mp_transform_node;
```

274.

```
#define transform_node_size sizeof(struct mp_transform_node_data)
        ▷ the number of words in a subscript node ◁

static mp_node mp_get_transform_node(MP mp)
{
  mp_transform_node p ← (mp_transform_node) malloc_node(transform_node_size);
  mp_type(p) ← mp_transform_node_type; return (mp_node) p;
}
```

275. **static void** *mp_init_transform_node*(**MP** *mp*, **mp_node** *p*)
{
mp_node *q*; ▷ the new node ◁
mp_type(*p*) ← *mp_transform_type*; *q* ← *mp_get_transform_node*(*mp*); ▷ big node ◁
yy_part(*q*) ← *mp_get_value_node*(*mp*); *mp_new_indep*(*mp*, *yy_part*(*q*)); ▷ sets *type*(*q*) and *value*(*q*) ◁
mp_name_type(*yy_part*(*q*)) ← (**quarterword**)(*mp_yy_part_sector*); *mp_link*(*yy_part*(*q*)) ← *p*;
yx_part(*q*) ← *mp_get_value_node*(*mp*); *mp_new_indep*(*mp*, *yx_part*(*q*)); ▷ sets *type*(*q*) and *value*(*q*) ◁
mp_name_type(*yx_part*(*q*)) ← (**quarterword**)(*mp_yx_part_sector*); *mp_link*(*yx_part*(*q*)) ← *p*;
xy_part(*q*) ← *mp_get_value_node*(*mp*); *mp_new_indep*(*mp*, *xy_part*(*q*)); ▷ sets *type*(*q*) and *value*(*q*) ◁
mp_name_type(*xy_part*(*q*)) ← (**quarterword**)(*mp_xy_part_sector*); *mp_link*(*xy_part*(*q*)) ← *p*;
xx_part(*q*) ← *mp_get_value_node*(*mp*); *mp_new_indep*(*mp*, *xx_part*(*q*)); ▷ sets *type*(*q*) and *value*(*q*) ◁
mp_name_type(*xx_part*(*q*)) ← (**quarterword**)(*mp_xx_part_sector*); *mp_link*(*xx_part*(*q*)) ← *p*;
ty_part(*q*) ← *mp_get_value_node*(*mp*); *mp_new_indep*(*mp*, *ty_part*(*q*)); ▷ sets *type*(*q*) and *value*(*q*) ◁
mp_name_type(*ty_part*(*q*)) ← (**quarterword**)(*mp_y_part_sector*); *mp_link*(*ty_part*(*q*)) ← *p*;
tx_part(*q*) ← *mp_get_value_node*(*mp*); *mp_new_indep*(*mp*, *tx_part*(*q*)); ▷ sets *type*(*q*) and *value*(*q*) ◁
mp_name_type(*tx_part*(*q*)) ← (**quarterword**)(*mp_x_part_sector*); *mp_link*(*tx_part*(*q*)) ← *p*;
set_value_node(*p*, *q*);
}

276. Variables of type **color** have 3 values in 6 words identified by *mp_red_part_sector*, *mp_green_part_sector*, and *mp_blue_part_sector*.

#define *red_part*(*A*) ((*mp_color_node*)(*A*))→*red_part_* ▷ where the **redpart** is found in a color node ◁
#define *green_part*(*A*) ((*mp_color_node*)(*A*))→*green_part_*
▷ where the **greenpart** is found in a color node ◁
#define *blue_part*(*A*) ((*mp_color_node*)(*A*))→*blue_part_* ▷ where the **bluepart** is found in a color node ◁
#define *grey_part*(*A*) *red_part*(*A*) ▷ where the **greypart** is found in a color node ◁

⟨MPlib internal header stuff 8⟩ +≡
typedef struct mp_color_node_data {
NODE_BODY;
mp_node *red_part_*;
mp_node *green_part_*;
mp_node *blue_part_*;
} **mp_color_node_data**;
typedef struct mp_color_node_data ∗**mp_color_node**;

277. **#define** *color_node_size* **sizeof**(**struct mp_color_node_data**)
▷ the number of words in a subscript node ◁

static mp_node *mp_get_color_node*(**MP** *mp*)
{
mp_color_node *p* ← (**mp_color_node**) *malloc_node*(*color_node_size*);
mp_type(*p*) ← *mp_color_node_type*; *p*→*link* ← Λ; **return** (**mp_node**) *p*;
}

278. **static void** *mp_init_color_node*(**MP** *mp*, **mp_node** *p*)

```
{
  mp_node q;   ▷ the new node ◁
  mp_type(p) ← mp_color_type; q ← mp_get_color_node(mp);   ▷ big node ◁
  blue_part(q) ← mp_get_value_node(mp); mp_new_indep(mp, blue_part(q));
    ▷ sets type(q) and value(q) ◁
  mp_name_type(blue_part(q)) ← (quarterword)(mp_blue_part_sector); mp_link(blue_part(q)) ← p;
  green_part(q) ← mp_get_value_node(mp); mp_new_indep(mp, green_part(q));
    ▷ sets type(q) and value(q) ◁
  mp_name_type(y_part(q)) ← (quarterword)(mp_green_part_sector); mp_link(green_part(q)) ← p;
  red_part(q) ← mp_get_value_node(mp); mp_new_indep(mp, red_part(q));
    ▷ sets type(q) and value(q) ◁
  mp_name_type(red_part(q)) ← (quarterword)(mp_red_part_sector); mp_link(red_part(q)) ← p;
  set_value_node(p, q);
}
```

279. Finally, variables of type *cmykcolor*.

```
#define cyan_part(A) ((mp_cmykcolor_node)(A))→cyan_part_
    ▷ where the cyanpart is found in a color node ◁
#define magenta_part(A) ((mp_cmykcolor_node)(A))→magenta_part_
    ▷ where the magentapart is found in a color node ◁
#define yellow_part(A) ((mp_cmykcolor_node)(A))→yellow_part_
    ▷ where the yellowpart is found in a color node ◁
#define black_part(A) ((mp_cmykcolor_node)(A))→black_part_
    ▷ where the blackpart is found in a color node ◁
```

⟨ MPlib internal header stuff 8 ⟩ +≡

```
typedef struct mp_cmykcolor_node_data {
  NODE_BODY;
  mp_node cyan_part_;
  mp_node magenta_part_;
  mp_node yellow_part_;
  mp_node black_part_;
} mp_cmykcolor_node_data;
typedef struct mp_cmykcolor_node_data *mp_cmykcolor_node;
```

280. #**define** *cmykcolor_node_size* **sizeof**(**struct mp_cmykcolor_node_data**)
▷ the number of words in a subscript node ◁

```
static mp_node mp_get_cmykcolor_node(MP mp)
{
  mp_cmykcolor_node p ← (mp_cmykcolor_node) malloc_node(cmykcolor_node_size);
  mp_type(p) ← mp_cmykcolor_node_type; p→link ← Λ; return (mp_node) p;
}
```

281. **static void** *mp_init_cmykcolor_node*(**MP** *mp*, **mp_node** *p*)
{
mp_node *q*; ▷ the new node ◁
mp_type(*p*) ← *mp_cmykcolor_type*; *q* ← *mp_get_cmykcolor_node*(*mp*); ▷ big node ◁
black_part(*q*) ← *mp_get_value_node*(*mp*); *mp_new_indep*(*mp*, *black_part*(*q*));
▷ sets *type*(*q*) and *value*(*q*) ◁
mp_name_type(*black_part*(*q*)) ← (**quarterword**)(*mp_black_part_sector*); *mp_link*(*black_part*(*q*)) ← *p*;
yellow_part(*q*) ← *mp_get_value_node*(*mp*); *mp_new_indep*(*mp*, *yellow_part*(*q*));
▷ sets *type*(*q*) and *value*(*q*) ◁
mp_name_type(*yellow_part*(*q*)) ← (**quarterword**)(*mp_yellow_part_sector*);
mp_link(*yellow_part*(*q*)) ← *p*; *magenta_part*(*q*) ← *mp_get_value_node*(*mp*);
mp_new_indep(*mp*, *magenta_part*(*q*)); ▷ sets *type*(*q*) and *value*(*q*) ◁
mp_name_type(*magenta_part*(*q*)) ← (**quarterword**)(*mp_magenta_part_sector*);
mp_link(*magenta_part*(*q*)) ← *p*; *cyan_part*(*q*) ← *mp_get_value_node*(*mp*);
mp_new_indep(*mp*, *cyan_part*(*q*)); ▷ sets *type*(*q*) and *value*(*q*) ◁
mp_name_type(*cyan_part*(*q*)) ← (**quarterword**)(*mp_cyan_part_sector*); *mp_link*(*cyan_part*(*q*)) ← *p*;
set_value_node(*p*, *q*);
}

282. When an entire structured variable is saved, the *root* indication is temporarily replaced by *saved_root*.

Some variables have no name; they just are used for temporary storage while expressions are being evaluated. We call them *capsules*.

283. The *id_transform* function creates a capsule for the identity transformation.

static mp_node *mp_id_transform*(**MP** *mp*)
{
mp_node *p*, *q*; ▷ list manipulation registers ◁
p ← *mp_get_value_node*(*mp*); *mp_name_type*(*p*) ← *mp_capsule*; *set_value_number*(*p*, *zero_t*);
▷ TODO: this was Λ ◁
mp_init_transform_node(*mp*, *p*); *q* ← *value_node*(*p*); *mp_type*(*tx_part*(*q*)) ← *mp_known*;
set_value_number(*tx_part*(*q*), *zero_t*); *mp_type*(*ty_part*(*q*)) ← *mp_known*;
set_value_number(*ty_part*(*q*), *zero_t*); *mp_type*(*xy_part*(*q*)) ← *mp_known*;
set_value_number(*xy_part*(*q*), *zero_t*); *mp_type*(*yx_part*(*q*)) ← *mp_known*;
set_value_number(*yx_part*(*q*), *zero_t*); *mp_type*(*xx_part*(*q*)) ← *mp_known*;
set_value_number(*xx_part*(*q*), *unity_t*); *mp_type*(*yy_part*(*q*)) ← *mp_known*;
set_value_number(*yy_part*(*q*), *unity_t*); **return** *p*;
}

284. Tokens are of type *tag_token* when they first appear, but they point to Λ until they are first used as the root of a variable. The following subroutine establishes the root node on such grand occasions.

static void *mp_new_root*(**MP** *mp*, **mp_sym** *x*)
{
mp_node *p*; ▷ the new node ◁
p ← *mp_get_value_node*(*mp*); *mp_type*(*p*) ← *mp_undefined*; *mp_name_type*(*p*) ← *mp_root*;
set_value_sym(*p*, *x*); *set_equiv_node*(*x*, *p*);
}

285. These conventions for variable representation are illustrated by the *print_variable_name* routine, which displays the full name of a variable given only a pointer to its value.

⟨ Declarations 10 ⟩ +≡
static void *mp_print_variable_name*(**MP** *mp*, **mp_node** *p*);

286.
```
void mp_print_variable_name(MP mp, mp_node p)
{
  mp_node q;   ▷ a token list that will name the variable's suffix ◁
  mp_node r;   ▷ temporary for token list creation ◁
  while (mp_name_type(p) ≥ mp_x_part_sector) {
    switch (mp_name_type(p)) {
    case mp_x_part_sector: mp_print(mp, "xpart␣"); break;
    case mp_y_part_sector: mp_print(mp, "ypart␣"); break;
    case mp_xx_part_sector: mp_print(mp, "xxpart␣"); break;
    case mp_xy_part_sector: mp_print(mp, "xypart␣"); break;
    case mp_yx_part_sector: mp_print(mp, "yxpart␣"); break;
    case mp_yy_part_sector: mp_print(mp, "yypart␣"); break;
    case mp_red_part_sector: mp_print(mp, "redpart␣"); break;
    case mp_green_part_sector: mp_print(mp, "greenpart␣"); break;
    case mp_blue_part_sector: mp_print(mp, "bluepart␣"); break;
    case mp_cyan_part_sector: mp_print(mp, "cyanpart␣"); break;
    case mp_magenta_part_sector: mp_print(mp, "magentapart␣"); break;
    case mp_yellow_part_sector: mp_print(mp, "yellowpart␣"); break;
    case mp_black_part_sector: mp_print(mp, "blackpart␣"); break;
    case mp_grey_part_sector: mp_print(mp, "greypart␣"); break;
    case mp_capsule: mp_printf(mp, "%%CAPSULE%p", p); return; break;
    default:   ▷ this is to please the compiler: the remaining cases are operation codes ◁
      break;
    }
    p ← mp_link(p);
  }
  q ← Λ;
  while (mp_name_type(p) > mp_saved_root) {
      ▷ Ascend one level, pushing a token onto list q and replacing p by its parent ◁
    if (mp_name_type(p) ≡ mp_subscr) {
      r ← mp_new_num_tok(mp, subscript(p));
      do {
        p ← mp_link(p);
      } while (mp_name_type(p) ≠ mp_attr);
    }
    else if (mp_name_type(p) ≡ mp_structured_root) {
      p ← mp_link(p); goto FOUND;
    }
    else {
      if (mp_name_type(p) ≠ mp_attr) mp_confusion(mp, "var");
      r ← mp_get_symbolic_node(mp); set_mp_sym_sym(r, hashloc(p));   ▷ the hash address ◁
    }
    set_mp_link(r, q); q ← r;
  FOUND: p ← parent((mp_value_node) p);
  }   ▷ now link(p) is the hash address of p, and name_type(p) is either root or saved_root. Have to
        prepend a token to q for show_token_list. ◁
  r ← mp_get_symbolic_node(mp); set_mp_sym_sym(r, value_sym(p)); mp_link(r) ← q;
  if (mp_name_type(p) ≡ mp_saved_root) mp_print(mp, "(SAVED)");
  mp_show_token_list(mp, r, Λ, max_integer, mp→tally); mp_flush_token_list(mp, r);
}
```

287. The *interesting* function returns *true* if a given variable is not in a capsule, or if the user wants to trace capsules.

```
static boolean mp_interesting(MP mp, mp_node p)
{
  mp_name_type_type t;    ▷ a name_type ◁
  if (number_positive(internal_value(mp_tracing_capsules))) {
    return true;
  }
  else {
    t ← mp_name_type(p);
    if (t ≥ mp_x_part_sector ∧ t ≠ mp_capsule) {
      mp_node tt ← value_node(mp_link(p));
      switch (t) {
      case mp_x_part_sector: t ← mp_name_type(x_part(tt)); break;
      case mp_y_part_sector: t ← mp_name_type(y_part(tt)); break;
      case mp_xx_part_sector: t ← mp_name_type(xx_part(tt)); break;
      case mp_xy_part_sector: t ← mp_name_type(xy_part(tt)); break;
      case mp_yx_part_sector: t ← mp_name_type(yx_part(tt)); break;
      case mp_yy_part_sector: t ← mp_name_type(yy_part(tt)); break;
      case mp_red_part_sector: t ← mp_name_type(red_part(tt)); break;
      case mp_green_part_sector: t ← mp_name_type(green_part(tt)); break;
      case mp_blue_part_sector: t ← mp_name_type(blue_part(tt)); break;
      case mp_cyan_part_sector: t ← mp_name_type(cyan_part(tt)); break;
      case mp_magenta_part_sector: t ← mp_name_type(magenta_part(tt)); break;
      case mp_yellow_part_sector: t ← mp_name_type(yellow_part(tt)); break;
      case mp_black_part_sector: t ← mp_name_type(black_part(tt)); break;
      case mp_grey_part_sector: t ← mp_name_type(grey_part(tt)); break;
      default: break;
      }
    }
  }
  return (t ≠ mp_capsule);
}
```

288. Now here is a subroutine that converts an unstructured type into an equivalent structured type, by inserting a *mp_structured* node that is capable of growing. This operation is done only when *mp_name_type*$(p) \leftarrow$ *root*, *subscr*, or *attr*.

The procedure returns a pointer to the new node that has taken node p's place in the structure. Node p itself does not move, nor are its *value* or *type* fields changed in any way.

```
static mp_node mp_new_structure(MP mp, mp_node p)
{
  mp_node q, r ← Λ;    ▷ list manipulation registers ◁
  mp_sym qq ← Λ;
  switch (mp_name_type(p)) {
  case mp_root:
    {
      qq ← value_sym(p); r ← mp_get_value_node(mp); set_equiv_node(qq, r);
    }
    break;
  case mp_subscr:    ▷ Link a new subscript node r in place of node p ◁
    {
      mp_node q_new;
      q ← p;
      do {
        q ← mp_link(q);
      } while (mp_name_type(q) ≠ mp_attr);
      q ← parent((mp_value_node) q); r ← mp→temp_head; set_mp_link(r, subscr_head(q));
      do {
        q_new ← r; r ← mp_link(r);
      } while (r ≠ p);
      r ← (mp_node) mp_get_subscr_node(mp);
      if (q_new ≡ mp→temp_head) {
        set_subscr_head(q, r);
      }
      else {
        set_mp_link(q_new, r);
      }
      set_subscript(r, subscript(p));
    }
    break;
  case mp_attr:    ▷ Link a new attribute node r in place of node p ◁
      ▷ If the attribute is collective_subscript, there are two pointers to node p, so we must change both of
        them. ◁
    {
      mp_value_node rr;
      q ← parent((mp_value_node) p); r ← attr_head(q);
      do {
        q ← r; r ← mp_link(r);
      } while (r ≠ p);
      rr ← mp_get_attr_node(mp); r ← (mp_node) rr; set_mp_link(q, (mp_node) rr);
      set_hashloc(rr, hashloc(p)); set_parent(rr, parent((mp_value_node) p));
      if (hashloc(p) ≡ collective_subscript) {
        q ← mp→temp_head; set_mp_link(q, subscr_head(parent((mp_value_node) p)));
        while (mp_link(q) ≠ p) q ← mp_link(q);
        if (q ≡ mp→temp_head) set_subscr_head(parent((mp_value_node) p), (mp_node) rr);
```

```
        else set_mp_link(q, (mp_node) rr);
      }
    }
    break;
  default: mp_confusion(mp, "struct"); break;
  }
  set_mp_link(r, mp_link(p)); set_value_sym(r, value_sym(p)); mp_type(r) ← mp_structured;
  mp_name_type(r) ← mp_name_type(p); set_attr_head(r, p); mp_name_type(p) ← mp_structured_root;
  {
    mp_value_node qqr ← mp_get_attr_node(mp);
    set_mp_link(p, (mp_node) qqr); set_subscr_head(r, (mp_node) qqr); set_parent(qqr, r);
    mp_type(qqr) ← mp_undefined; mp_name_type(qqr) ← mp_attr; set_mp_link(qqr, mp→end_attr);
    set_hashloc(qqr, collective_subscript);
  }
  return r;
}
```

289. The *mp_find_variable* routine is given a pointer t to a nonempty token list of suffixes; it returns a pointer to the corresponding non-symbolic value. For example, if t points to token `x` followed by a numeric token containing the value 7, *find_variable* finds where the value of `x7` is stored in memory. This may seem a simple task, and it usually is, except when `x7` has never been referenced before. Indeed, `x` may never have even been subscripted before; complexities arise with respect to updating the collective subscript information.

If a macro type is detected anywhere along path t, or if the first item on t isn't a *tag_token*, the value Λ is returned. Otherwise p will be a non-NULL pointer to a node such that *undefined* < *type*(p) < *mp_structured*.

```
static mp_node mp_find_variable(MP mp, mp_node t)
{
  mp_node p, q, r, s;   ▷ nodes in the "value" line ◁
  mp_sym p_sym;
  mp_node pp, qq, rr, ss;   ▷ nodes in the "collective" line ◁
  p_sym ← mp_sym_sym(t); t ← mp_link(t);
  if ((eq_type(p_sym) % mp_outer_tag) ≠ mp_tag_token) return Λ;
  if (equiv_node(p_sym) ≡ Λ) mp_new_root(mp, p_sym);
  p ← equiv_node(p_sym); pp ← p;
  while (t ≠ Λ) {   ▷ Make sure that both nodes p and pp are of mp_structured type ◁
      ▷ Although pp and p begin together, they diverge when a subscript occurs; pp stays in the collective
        line while p goes through actual subscript values. ◁
    if (mp_type(pp) ≠ mp_structured) {
      if (mp_type(pp) > mp_structured) return Λ;
      ss ← mp_new_structure(mp, pp);
      if (p ≡ pp) p ← ss;
      pp ← ss;
    }   ▷ now type(pp) ← mp_structured ◁
    if (mp_type(p) ≠ mp_structured) {   ▷ it cannot be > mp_structured ◁
      p ← mp_new_structure(mp, p);   ▷ now type(p) ← mp_structured ◁
    }
    if (mp_type(t) ≠ mp_symbol_node) {   ▷ Descend one level for the subscript value(t) ◁
        ▷ We want this part of the program to be reasonably fast, in case there are lots of subscripts at the
          same level of the data structure. Therefore we store an "infinite" value in the word that appears
          at the end of the subscript list, even though that word isn't part of a subscript node. ◁
      mp_number nn, save_subscript;   ▷ temporary storage ◁
      new_number(nn); new_number(save_subscript); number_clone(nn, value_number(t));
      pp ← mp_link(attr_head(pp));   ▷ now hashloc(pp) ← collective_subscript ◁
      q ← mp_link(attr_head(p)); number_clone(save_subscript, subscript(q));
      set_number_to_inf(subscript(q)); s ← mp→temp_head; set_mp_link(s, subscr_head(p));
      do {
        r ← s; s ← mp_link(s);
      } while (number_greater(nn, subscript(s)));
      if (number_equal(nn, subscript(s))) {
        p ← s;
      }
      else {
        mp_value_node p1 ← mp_get_subscr_node(mp);
        if (r ≡ mp→temp_head) set_subscr_head(p, (mp_node) p1);
        else set_mp_link(r, (mp_node) p1);
        set_mp_link(p1, s); number_clone(subscript(p1), nn); mp_name_type(p1) ← mp_subscr;
        mp_type(p1) ← mp_undefined; p ← (mp_node) p1;
      }
```

$number\_clone(subscript(q), save\_subscript);$ $free\_number(save\_subscript);$ $free\_number(nn);$
}
else { ▷ Descend one level for the attribute $mp\_sym\_info(t)$ ◁
mp_sym $nn1 \leftarrow mp\_sym\_sym(t);$
$ss \leftarrow attr\_head(pp);$
do {
$rr \leftarrow ss;$ $ss \leftarrow mp\_link(ss);$
} **while** $(nn1 > hashloc(ss));$
if $(nn1 < hashloc(ss))$ {
$qq \leftarrow$ (**mp_node**) $mp\_get\_attr\_node(mp);$ $set\_mp\_link(rr, qq);$ $set\_mp\_link(qq, ss);$
$set\_hashloc(qq, nn1);$ $mp\_name\_type(qq) \leftarrow mp\_attr;$ $mp\_type(qq) \leftarrow mp\_undefined;$
$set\_parent(($**mp_value_node**$)\,qq, pp);$ $ss \leftarrow qq;$
}
if $(p \equiv pp)$ {
$p \leftarrow ss;$ $pp \leftarrow ss;$
}
else {
$pp \leftarrow ss;$ $s \leftarrow attr\_head(p);$
do {
$r \leftarrow s;$ $s \leftarrow mp\_link(s);$
} **while** $(nn1 > hashloc(s));$
if $(nn1 \equiv hashloc(s))$ {
$p \leftarrow s;$
}
else {
$q \leftarrow$ (**mp_node**) $mp\_get\_attr\_node(mp);$ $set\_mp\_link(r, q);$ $set\_mp\_link(q, s);$
$set\_hashloc(q, nn1);$ $mp\_name\_type(q) \leftarrow mp\_attr;$ $mp\_type(q) \leftarrow mp\_undefined;$
$set\_parent(($**mp_value_node**$)\,q, p);$ $p \leftarrow q;$
}
}
}
$t \leftarrow mp\_link(t);$
}
if $(mp\_type(pp) \geq mp\_structured)$ {
if $(mp\_type(pp) \equiv mp\_structured)$ $pp \leftarrow attr\_head(pp);$
else return Λ;
}
if $(mp\_type(p) \equiv mp\_structured)$ $p \leftarrow attr\_head(p);$
if $(mp\_type(p) \equiv mp\_undefined)$ {
if $(mp\_type(pp) \equiv mp\_undefined)$ {
$mp\_type(pp) \leftarrow mp\_numeric\_type;$ $set\_value\_number(pp, zero\_t);$
}
$mp\_type(p) \leftarrow mp\_type(pp);$ $set\_value\_number(p, zero\_t);$
}
return p;
}

290. Variables lose their former values when they appear in a type declaration, or when they are defined to be macros or **let** equal to something else. A subroutine will be defined later that recycles the storage associated with any particular *type* or *value*; our goal now is to study a higher level process called *flush_variable*, which selectively frees parts of a variable structure.

This routine has some complexity because of examples such as '`numeric x[]a[]b`' which recycles all variables of the form `x[i]a[j]b` (and no others), while '`vardef x[]a[]=...`' discards all variables of the form `x[i]a[j]` followed by an arbitrary suffix, except for the collective node `x[]a[]` itself. The obvious way to handle such examples is to use recursion; so that's what we do.

Parameter p points to the root information of the variable; parameter t points to a list of symbolic nodes that represent suffixes, with *info* ← *collective_subscript* for subscripts.

⟨ Declarations 10 ⟩ +≡
void *mp_flush_cur_exp*(**MP** *mp*, **mp_value** *v*);

291. **static void** *mp_flush_variable*(**MP** *mp*, **mp_node** *p*, **mp_node** *t*, **boolean** *discard_suffixes*)

```
{
  mp_node q, r ← Λ;   ▷ list manipulation ◁
  mp_sym n;   ▷ attribute to match ◁
  while (t ≠ Λ) {
    if (mp_type(p) ≠ mp_structured) {
      return;
    }
    n ← mp_sym_sym(t); t ← mp_link(t);
    if (n ≡ collective_subscript) {
      q ← subscr_head(p);
      while (mp_name_type(q) ≡ mp_subscr) {
        mp_flush_variable(mp, q, t, discard_suffixes);
        if (t ≡ Λ) {
          if (mp_type(q) ≡ mp_structured) {
            r ← q;
          }
          else {
            if (r ≡ Λ) set_subscr_head(p, mp_link(q));
            else set_mp_link(r, mp_link(q));
            mp_free_value_node(mp, q);
          }
        }
        else {
          r ← q;
        }
        q ← (r ≡ Λ ? subscr_head(p) : mp_link(r));
      }
    }
    p ← attr_head(p);
    do {
      p ← mp_link(p);
    } while (hashloc(p) < n);
    if (hashloc(p) ≠ n) {
      return;
    }
  }
  if (discard_suffixes) {
    mp_flush_below_variable(mp, p);
  }
  else {
    if (mp_type(p) ≡ mp_structured) {
      p ← attr_head(p);
    }
    mp_recycle_value(mp, p);
  }
}
```

292. The next procedure is simpler; it wipes out everything but p itself, which becomes undefined.

⟨ Declarations 10 ⟩ +≡

```
static void mp_flush_below_variable(MP mp, mp_node p);
```

293. **void** *mp_flush_below_variable*(**MP** *mp*, **mp_node** *p*)

```
{
  mp_node q, r;    ▷ list manipulation registers ◁
  FUNCTION_TRACE2("mp_flush_below_variable(%p)\n", p);
  if (mp_type(p) ≠ mp_structured) {
    mp_recycle_value(mp, p);    ▷ this sets type(p) ← undefined ◁
  }
  else {
    q ← subscr_head(p);
    while (mp_name_type(q) ≡ mp_subscr) {
      mp_flush_below_variable(mp, q); r ← q; q ← mp_link(q); mp_free_value_node(mp, r);
    }
    r ← attr_head(p); q ← mp_link(r); mp_recycle_value(mp, r); mp_free_value_node(mp, r);
    do {
      mp_flush_below_variable(mp, q); r ← q; q ← mp_link(q); mp_free_value_node(mp, r);
    } while (q ≠ mp→end_attr);
    mp_type(p) ← mp_undefined;
  }
}
```

294. Just before assigning a new value to a variable, we will recycle the old value and make the old value undefined. The *und_type* routine determines what type of undefined value should be given, based on the current type before recycling.

```
static quarterword mp_und_type(MP mp, mp_node p)
{
  (void) mp;
  switch (mp_type(p)) {
  case mp_vacuous: return mp_undefined;
  case mp_boolean_type: case mp_unknown_boolean: return mp_unknown_boolean;
  case mp_string_type: case mp_unknown_string: return mp_unknown_string;
  case mp_pen_type: case mp_unknown_pen: return mp_unknown_pen;
  case mp_path_type: case mp_unknown_path: return mp_unknown_path;
  case mp_picture_type: case mp_unknown_picture: return mp_unknown_picture;
  case mp_transform_type: case mp_color_type: case mp_cmykcolor_type: case mp_pair_type:
    case mp_numeric_type: return mp_type(p);
  case mp_known: case mp_dependent: case mp_proto_dependent: case mp_independent:
    return mp_numeric_type;
  default:    ▷ there are no other valid cases, but please the compiler ◁
    return 0;
  }
  return 0;
}
```

295. The *clear_symbol* routine is used when we want to redefine the equivalent of a symbolic token. It must remove any variable structure or macro definition that is currently attached to that symbol. If the *saving* parameter is true, a subsidiary structure is saved instead of destroyed.

```
static void mp_clear_symbol(MP mp, mp_sym p, boolean saving)
{
  mp_node q;   ▷ equiv(p) ◁
  FUNCTION_TRACE3("mp_clear_symbol(%p,%d)\n", p, saving);  q ← equiv_node(p);
  switch (eq_type(p) % mp_outer_tag) {
  case mp_defined_macro: case mp_secondary_primary_macro: case mp_tertiary_secondary_macro:
    case mp_expression_tertiary_macro:
    if (¬saving) mp_delete_mac_ref(mp, q);
    break;
  case mp_tag_token:
    if (q ≠ Λ) {
      if (saving) {
        mp_name_type(q) ← mp_saved_root;
      }
      else {
        mp_flush_below_variable(mp, q);  mp_free_value_node(mp, q);
      }
    }
    break;
  default: break;
  }
  set_equiv(p, mp→frozen_undefined→v.data.indep.serial);  set_eq_type(p, mp→frozen_undefined→type);
}
```

296. Saving and restoring equivalents. The nested structure given by **begingroup** and **endgroup** allows *eqtb* entries to be saved and restored, so that temporary changes can be made without difficulty. When the user requests a current value to be saved, METAPOST puts that value into its "save stack." An appearance of **endgroup** ultimately causes the old values to be removed from the save stack and put back in their former places.

The save stack is a linked list containing three kinds of entries, distinguished by their *type* fields. If p points to a saved item, then

p→type ← 0 stands for a group boundary; each **begingroup** contributes such an item to the save stack and each **endgroup** cuts back the stack until the most recent such entry has been removed.

p→type ← *mp_normal_sym* means that *p→value* holds the former contents of *eqtb*[q] (saved in the *knot* field of the value, which is otherwise unused for variables). Such save stack entries are generated by **save** commands.

p→type ← *mp_internal_sym* means that *p→value* is a **mp_internal** to be restored to internal parameter number q (saved in the *serial* field of the value, which is otherwise unused for internals). Such entries are generated by **interim** commands.

The global variable *save_ptr* points to the top item on the save stack.

⟨ Types in the outer block 37 ⟩ +≡
```
typedef struct mp_save_data {
  quarterword type;
  mp_internal value;
  struct mp_save_data *link;
} mp_save_data;
```

297. ⟨ Global variables 18 ⟩ +≡
```
mp_save_data *save_ptr;   ▷ the most recently saved item ◁
```

298. ⟨ Set initial values of key variables 42 ⟩ +≡
```
mp→save_ptr ← Λ;
```

299. Saving a boundary item
```
static void mp_save_boundary(MP mp)
{
  mp_save_data *p;   ▷ temporary register ◁
  FUNCTION_TRACE1("mp_save_boundary␣()\n"); p ← xmalloc(1, sizeof(mp_save_data));
  p→type ← 0; p→link ← mp→save_ptr; mp→save_ptr ← p;
}
```

300. The *save_variable* routine is given a hash address q; it salts this address in the save stack, together with its current equivalent, then makes token q behave as though it were brand new.

Nothing is stacked when $save\_ptr \leftarrow \Lambda$, however; there's no way to remove things from the stack when the program is not inside a group, so there's no point in wasting the space.

```
static void mp_save_variable(MP mp, mp_sym q)
{
  mp_save_data *p;   ▷ temporary register ◁
  FUNCTION_TRACE2("mp_save_variable␣(%p)\n", q);
  if (mp→save_ptr ≠ Λ) {
    p ← xmalloc(1, sizeof(mp_save_data)); p→type ← mp_normal_sym; p→link ← mp→save_ptr;
    p→value.v.data.indep.scale ← eq_type(q); p→value.v.data.indep.serial ← equiv(q);
    p→value.v.data.node ← equiv_node(q); p→value.v.data.p ← (mp_knot) q; mp→save_ptr ← p;
  }
  mp_clear_symbol(mp, q, (mp→save_ptr ≠ Λ));
}
static void mp_unsave_variable(MP mp)
{
  mp_sym q ← (mp_sym) mp→save_ptr→value.v.data.p;
  if (number_positive(internal_value(mp_tracing_restores))) {
    mp_begin_diagnostic(mp); mp_print_nl(mp, "{restoring␣"); mp_print_text(q);
    mp_print_char(mp, xord('}')); mp_end_diagnostic(mp, false);
  }
  mp_clear_symbol(mp, q, false); set_eq_type(q, mp→save_ptr→value.v.data.indep.scale);
  set_equiv(q, mp→save_ptr→value.v.data.indep.serial); q→v.data.node ← mp→save_ptr→value.v.data.node;
  if (eq_type(q) % mp_outer_tag ≡ mp_tag_token) {
    mp_node pp ← q→v.data.node;
    if (pp ≠ Λ) mp_name_type(pp) ← mp_root;
  }
}
```

301. Similarly, *save_internal* is given the location q of an internal quantity like *mp_tracing_pens*. It creates a save stack entry of the third kind.

```
static void mp_save_internal(MP mp, halfword q)
{
  mp_save_data *p;    ▷ new item for the save stack ◁
  FUNCTION_TRACE2("mp_save_internal␣(%d)\n", q);
  if (mp→save_ptr ≠ Λ) {
    p ← xmalloc(1, sizeof(mp_save_data)); p→type ← mp_internal_sym; p→link ← mp→save_ptr;
    p→value ← mp→internal[q]; p→value.v.data.indep.serial ← q; new_number(p→value.v.data.n);
    number_clone(p→value.v.data.n, mp→internal[q].v.data.n); mp→save_ptr ← p;
  }
}
static void mp_unsave_internal(MP mp)
{
  halfword q ← mp→save_ptr→value.v.data.indep.serial;
  mp_internal saved ← mp→save_ptr→value;
  if (number_positive(internal_value(mp_tracing_restores))) {
    mp_begin_diagnostic(mp); mp_print_nl(mp, "{restoring␣"); mp_print(mp, internal_name(q));
    mp_print_char(mp, xord('='));
    if (internal_type(q) ≡ mp_known) {
      print_number(saved.v.data.n);
    }
    else if (internal_type(q) ≡ mp_string_type) {
      char *s ← mp_str(mp, saved.v.data.str);
      mp_print(mp, s);
    }
    else {
      mp_confusion(mp, "internal_restore");
    }
    mp_print_char(mp, xord('}')); mp_end_diagnostic(mp, false);
  }
  free_number(mp→internal[q].v.data.n); mp→internal[q] ← saved;
}
```

302. At the end of a group, the *unsave* routine restores all of the saved equivalents in reverse order. This routine will be called only when there is at least one boundary item on the save stack.

```
static void mp_unsave(MP mp)
{
  mp_save_data *p;    ▷ saved item ◁
  FUNCTION_TRACE1("mp_unsave␣()\n");
  while (mp→save_ptr→type ≠ 0) {
    if (mp→save_ptr→type ≡ mp_internal_sym) {
      mp_unsave_internal(mp);
    }
    else {
      mp_unsave_variable(mp);
    }
    p ← mp→save_ptr→link; xfree(mp→save_ptr); mp→save_ptr ← p;
  }
  p ← mp→save_ptr→link; xfree(mp→save_ptr); mp→save_ptr ← p;
}
```

303. Data structures for paths. When a METAPOST user specifies a path, METAPOST will create a list of knots and control points for the associated cubic spline curves. If the knots are z_0, z_1, $\ldots$, z_n, there are control points z_k^+ and z_{k+1}^- such that the cubic splines between knots z_k and z_{k+1} are defined by Bézier's formula

$$\begin{aligned} z(t) &= B(z_k, z_k^+, z_{k+1}^-, z_{k+1}; t) \\ &= (1-t)^3 z_k + 3(1-t)^2 t z_k^+ + 3(1-t)t^2 z_{k+1}^- + t^3 z_{k+1} \end{aligned}$$

for $0 \le t \le 1$.

There is a 8-word node for each knot z_k, containing one word of control information and six words for the x and y coordinates of z_k^- and z_k and z_k^+. The control information appears in the *mp_left_type* and *mp_right_type* fields, which each occupy a quarter of the first word in the node; they specify properties of the curve as it enters and leaves the knot. There's also a halfword *link* field, which points to the following knot, and a final supplementary word (of which only a quarter is used).

If the path is a closed contour, knots 0 and n are identical; i.e., the *link* in knot $n-1$ points to knot 0. But if the path is not closed, the *mp_left_type* of knot 0 and the *mp_right_type* of knot n are equal to *endpoint*. In the latter case the *link* in knot n points to knot 0, and the control points z_0^- and z_n^+ are not used.

```
#define mp_next_knot(A) (A)→next   ▷ the next knot in this list ◁
#define mp_left_type(A) (A)→data.types.left_type   ▷ characterizes the path entering this knot ◁
#define mp_right_type(A) (A)→data.types.right_type   ▷ characterizes the path leaving this knot ◁
#define mp_prev_knot(A) (A)→data.prev   ▷ the previous knot in this list (only for pens) ◁
#define mp_knot_info(A) (A)→data.info   ▷ temporary info, used during splitting ◁

⟨ Exported types 19 ⟩ +≡
  typedef struct mp_knot_data *mp_knot;
  typedef struct mp_knot_data {
    mp_number x_coord;   ▷ the x coordinate of this knot ◁
    mp_number y_coord;   ▷ the y coordinate of this knot ◁
    mp_number left_x;   ▷ the x coordinate of previous control point ◁
    mp_number left_y;   ▷ the y coordinate of previous control point ◁
    mp_number right_x;   ▷ the x coordinate of next control point ◁
    mp_number right_y;   ▷ the y coordinate of next control point ◁
    mp_knot next;
    union {
      struct {
        unsigned short left_type;
        unsigned short right_type;
      } types;
      mp_knot prev;
      signed int info;
    } data;
    unsigned char originator;
  } mp_knot_data;
```

304. **#define** *mp_gr_next_knot*(*A*) (*A*)→*next* ▷ the next knot in this list ◁

⟨ Exported types 19 ⟩ +≡

```
typedef struct mp_gr_knot_data *mp_gr_knot;
typedef struct mp_gr_knot_data {
  double x_coord;
  double y_coord;
  double left_x;
  double left_y;
  double right_x;
  double right_y;
  mp_gr_knot next;
  union {
    struct {
      unsigned short left_type;
      unsigned short right_type;
    } types;
    mp_gr_knot prev;
    signed int info;
  } data;
  unsigned char originator;
} mp_gr_knot_data;
```

305. ⟨ MPlib header stuff 205 ⟩ +≡

```
enum mp_knot_type {
  mp_endpoint ← 0,   ▷ mp_left_type at path beginning and mp_right_type at path end ◁
  mp_explicit,   ▷ mp_left_type or mp_right_type when control points are known ◁
  mp_given,   ▷ mp_left_type or mp_right_type when a direction is given ◁
  mp_curl,   ▷ mp_left_type or mp_right_type when a curl is desired ◁
  mp_open,   ▷ mp_left_type or mp_right_type when METAPOST should choose the direction ◁
  mp_end_cycle
};
```

306. Before the Bézier control points have been calculated, the memory space they will ultimately occupy is taken up by information that can be used to compute them. There are four cases:

- If *mp_right_type* ← *mp_open*, the curve should leave the knot in the same direction it entered; METAPOST will figure out a suitable direction.
- If *mp_right_type* ← *mp_curl*, the curve should leave the knot in a direction depending on the angle at which it enters the next knot and on the curl parameter stored in *right_curl*.
- If *mp_right_type* ← *mp_given*, the curve should leave the knot in a nonzero direction stored as an *angle* in *right_given*.
- If *mp_right_type* ← *mp_explicit*, the Bézier control point for leaving this knot has already been computed; it is in the *mp_right_x* and *mp_right_y* fields.

The rules for *mp_left_type* are similar, but they refer to the curve entering the knot, and to *left* fields instead of *right* fields.

Non-*explicit* control points will be chosen based on "tension" parameters in the *left_tension*/*right_tension* fields. The '**atleast**' option is represented by negative tension values.

For example, the METAPOST path specification

```
z0..z1..tension atleast 1..{curl 2}z2..z3{-1,-2}..tension 3 and 4..p,
```

where `p` is the path '`z4..controls z45 and z54..z5`', will be represented by the six knots

mp_left_type	*left* info	*x_coord*, *y_coord*	*mp_right_type*	*right* info
endpoint	_, _	x_0, y_0	*curl*	$1.0, 1.0$
open	_, 1.0	x_1, y_1	*open*	_, −1.0
curl	$2.0, -1.0$	x_2, y_2	*curl*	$2.0, 1.0$
given	$d, 1.0$	x_3, y_3	*given*	$d, 3.0$
open	_, 4.0	x_4, y_4	*explicit*	x_{45}, y_{45}
explicit	x_{54}, y_{54}	x_5, y_5	*endpoint*	_, _

Here d is the *angle* obtained by calling $n\_arg(-unity, -two)$. Of course, this example is more complicated than anything a normal user would ever write.

These types must satisfy certain restrictions because of the form of METAPOST's path syntax: (i) *open* type never appears in the same node together with *endpoint*, *given*, or *curl*. (ii) The *mp_right_type* of a node is *explicit* if and only if the *mp_left_type* of the following node is *explicit*. (iii) *endpoint* types occur only at the ends, as mentioned above.

#**define** *left_curl* *left_x* ▷ curl information when entering this knot ◁
#**define** *left_given* *left_x* ▷ given direction when entering this knot ◁
#**define** *left_tension* *left_y* ▷ tension information when entering this knot ◁
#**define** *right_curl* *right_x* ▷ curl information when leaving this knot ◁
#**define** *right_given* *right_x* ▷ given direction when leaving this knot ◁
#**define** *right_tension* *right_y* ▷ tension information when leaving this knot ◁

307. Knots can be user-supplied, or they can be created by program code, like the *split_cubic* function, or *copy_path*. The distinction is needed for the cleanup routine that runs after *split_cubic*, because it should only delete knots it has previously inserted, and never anything that was user-supplied. In order to be able to differentiate one knot from another, we will set *originator*(*p*): ← *mp_metapost_user* when it appeared in the actual metapost program, and *originator*(*p*): ← *mp_program_code* in all other cases.

#define *mp_originator*(*A*) (*A*)→*originator* ▷ the creator of this knot ◁

⟨ Exported types 19 ⟩ +≡

```
enum mp_knot_originator {
  mp_program_code ← 0,   ▷ not created by a user ◁
  mp_metapost_user   ▷ created by a user ◁
};
```

308. Here is a routine that prints a given knot list in symbolic form. It illustrates the conventions discussed above, and checks for anomalies that might arise while METAPOST is being debugged.

⟨ Declarations 10 ⟩ +≡

```
static void mp_pr_path(MP mp, mp_knot h);
```

309.

```
void mp_pr_path(MP mp, mp_knot h)
{
  mp_knot p, q;   ▷ for list traversal ◁
  p ← h;
  do {
    q ← mp_next_knot(p);
    if ((p ≡ Λ) ∨ (q ≡ Λ)) {
      mp_print_nl(mp, "???"); return;   ▷ this won't happen ◁
    }
    ⟨ Print information for adjacent knots p and q 310 ⟩;
  DONE1: p ← q;
    if (p ∧ ((p ≠ h) ∨ (mp_left_type(h) ≠ mp_endpoint)))
      ⟨ Print two dots, followed by given or curl if present 311 ⟩
  } while (p ≠ h);
  if (mp_left_type(h) ≠ mp_endpoint) mp_print(mp, "cycle");
}
```

310. ⟨ Print information for adjacent knots p and q 310 ⟩ ≡
  mp_print_two(*mp*, *p*→*x_coord*, *p*→*y_coord*);
  switch (*mp_right_type*(*p*)) {
  case *mp_endpoint*:
    if (*mp_left_type*(*p*) ≡ *mp_open*) *mp_print*(*mp*, "{open?}"); ▷ can't happen ◁
    if ((*mp_left_type*(*q*) ≠ *mp_endpoint*) ∨ ($q \neq h$)) $q \leftarrow \Lambda$; ▷ force an error ◁
    goto DONE1; **break**;
  case *mp_explicit*: ⟨ Print control points between p and q, then **goto** *done1* 313 ⟩;
    break;
  case *mp_open*: ⟨ Print information for a curve that begins *open* 314 ⟩;
    break;
  case *mp_curl*: **case** *mp_given*: ⟨ Print information for a curve that begins *curl* or *given* 315 ⟩;
    break;
  default: *mp_print*(*mp*, "???"); ▷ can't happen ◁
    break;
  }
  if (*mp_left_type*(*q*) ≤ *mp_explicit*) {
    mp_print(*mp*, "..control?"); ▷ can't happen ◁
  }
  else if ((¬*number_equal*(*p*→*right_tension*, *unity_t*)) ∨ (¬*number_equal*(*q*→*left_tension*, *unity_t*)))
    ⟨ Print tension between p and q 312 ⟩

This code is used in section 309.

311. Since *n_sin_cos* produces *fraction* results, which we will print as if they were *scaled*, the magnitude of a *given* direction vector will be 4096.

⟨ Print two dots, followed by *given* or *curl* if present 311 ⟩ ≡
  {
    mp_number *n_sin*, *n_cos*;
    new_fraction(*n_sin*); *new_fraction*(*n_cos*); *mp_print_nl*(*mp*, "␣..");
    if (*mp_left_type*(*p*) ≡ *mp_given*) {
      n_sin_cos(*p*→*left_given*, *n_cos*, *n_sin*); *mp_print_char*(*mp*, *xord*('{')); *print_number*(*n_cos*);
      mp_print_char(*mp*, *xord*(',')); *print_number*(*n_sin*); *mp_print_char*(*mp*, *xord*('}'));
    }
    else if (*mp_left_type*(*p*) ≡ *mp_curl*) {
      mp_print(*mp*, "{curl␣"); *print_number*(*p*→*left_curl*); *mp_print_char*(*mp*, *xord*('}'));
    }
    free_number(*n_sin*); *free_number*(*n_cos*);
  }

This code is used in section 309.

312. ⟨ Print tension between p and q 312 ⟩ ≡

```
{
  mp_number v1;
  new_number(v1); mp_print(mp, "..tension␣");
  if (number_negative(p→right_tension)) mp_print(mp, "atleast");
  number_clone(v1, p→right_tension); number_abs(v1); print_number(v1);
  if (¬number_equal(p→right_tension, q→left_tension)) {
    mp_print(mp, "␣and␣");
    if (number_negative(q→left_tension)) mp_print(mp, "atleast");
    number_clone(v1, p→left_tension); number_abs(v1); print_number(v1);
  }
  free_number(v1);
}
```

This code is used in section 310.

313. ⟨ Print control points between p and q, then **goto** *done1* 313 ⟩ ≡

```
{
  mp_print(mp, "..controls␣"); mp_print_two(mp, p→right_x, p→right_y); mp_print(mp, "␣and␣");
  if (mp_left_type(q) ≠ mp_explicit) {
    mp_print(mp, "??");   ▷ can't happen ◁
  }
  else {
    mp_print_two(mp, q→left_x, q→left_y);
  }
  goto DONE1;
}
```

This code is used in section 310.

314. ⟨ Print information for a curve that begins *open* 314 ⟩ ≡

```
if ((mp_left_type(p) ≠ mp_explicit) ∧ (mp_left_type(p) ≠ mp_open)) {
  mp_print(mp, "{open?}");   ▷ can't happen ◁
}
```

This code is used in section 310.

315. A curl of 1 is shown explicitly, so that the user sees clearly that METAPOST's default curl is present.

⟨ Print information for a curve that begins *curl* or *given* 315 ⟩ ≡

```
{
  if (mp_left_type(p) ≡ mp_open) mp_print(mp, "??");   ▷ can't happen ◁
  if (mp_right_type(p) ≡ mp_curl) {
    mp_print(mp, "{curl␣"); print_number(p→right_curl);
  }
  else {
    mp_number n_sin, n_cos;
    new_fraction(n_sin); new_fraction(n_cos); n_sin_cos(p→right_given, n_cos, n_sin);
    mp_print_char(mp, xord('{')); print_number(n_cos); mp_print_char(mp, xord(','));
    print_number(n_sin); free_number(n_sin); free_number(n_cos);
  }
  mp_print_char(mp, xord('}'));
}
```

This code is used in section 310.

316. It is convenient to have another version of *pr_path* that prints the path as a diagnostic message.

⟨ Declarations 10 ⟩ +≡
```
static void mp_print_path(MP mp, mp_knot h, const char *s, boolean nuline);
```

317.
```
void mp_print_path(MP mp, mp_knot h, const char *s, boolean nuline)
{
  mp_print_diagnostic(mp, "Path", s, nuline); mp_print_ln(mp); mp_pr_path(mp, h);
  mp_end_diagnostic(mp, true);
}
```

318. ⟨ Declarations 10 ⟩ +≡
```
static mp_knot mp_new_knot(MP mp);
```

319.
```
static mp_knot mp_new_knot(MP mp)
{
  mp_knot q;
  if (mp→knot_nodes) {
    q ← mp→knot_nodes; mp→knot_nodes ← q→next; mp→num_knot_nodes −−;
  }
  else {
    q ← mp_xmalloc(mp, 1, sizeof(struct mp_knot_data));
  }
  memset(q, 0, sizeof(struct mp_knot_data)); new_number(q→x_coord); new_number(q→y_coord);
  new_number(q→left_x); new_number(q→left_y); new_number(q→right_x); new_number(q→right_y);
  return q;
}
```

320. ⟨ Declarations 10 ⟩ +≡
```
static mp_gr_knot mp_gr_new_knot(MP mp);
```

321.
```
static mp_gr_knot mp_gr_new_knot(MP mp)
{
  mp_gr_knot q ← mp_xmalloc(mp, 1, sizeof(struct mp_gr_knot_data));
  return q;
}
```

322. If we want to duplicate a knot node, we can say *copy_knot*:

```
static mp_knot mp_copy_knot(MP mp, mp_knot p)
{
  mp_knot q;
  if (mp→knot_nodes) {
    q ← mp→knot_nodes; mp→knot_nodes ← q→next; mp→num_knot_nodes−−;
  }
  else {
    q ← mp_xmalloc(mp, 1, sizeof(struct mp_knot_data));
  }
  memcpy(q, p, sizeof(struct mp_knot_data));
  if (mp→math_mode > mp_math_double_mode) {
    new_number(q→x_coord); new_number(q→y_coord); new_number(q→left_x); new_number(q→left_y);
    new_number(q→right_x); new_number(q→right_y); number_clone(q→x_coord, p→x_coord);
    number_clone(q→y_coord, p→y_coord); number_clone(q→left_x, p→left_x);
    number_clone(q→left_y, p→left_y); number_clone(q→right_x, p→right_x);
    number_clone(q→right_y, p→right_y);
  }
  mp_next_knot(q) ← Λ; return q;
}
```

323. If we want to export a knot node, we can say *export_knot*:

```
static mp_gr_knot mp_export_knot(MP mp, mp_knot p)
{
  mp_gr_knot q;    ▷ the copy ◁
  q ← mp_gr_new_knot(mp); q→x_coord ← number_to_double(p→x_coord);
  q→y_coord ← number_to_double(p→y_coord); q→left_x ← number_to_double(p→left_x);
  q→left_y ← number_to_double(p→left_y); q→right_x ← number_to_double(p→right_x);
  q→right_y ← number_to_double(p→right_y); q→data.types.left_type ← mp_left_type(p);
  q→data.types.right_type ← mp_left_type(p); q→data.info ← mp_knot_info(p); mp_gr_next_knot(q) ← Λ;
  return q;
}
```

324. The *copy_path* routine makes a clone of a given path.

```
static mp_knot mp_copy_path(MP mp, mp_knot p)
{
  mp_knot q, pp, qq;    ▷ for list manipulation ◁
  if (p ≡ Λ) return Λ;
  q ← mp_copy_knot(mp, p); qq ← q; pp ← mp_next_knot(p);
  while (pp ≠ p) {
    mp_next_knot(qq) ← mp_copy_knot(mp, pp); qq ← mp_next_knot(qq); pp ← mp_next_knot(pp);
  }
  mp_next_knot(qq) ← q; return q;
}
```

325. The *export_path* routine makes a clone of a given path and converts the *value*s therein to **double**s.

static mp_gr_knot *mp_export_path*(**MP** *mp*, **mp_knot** *p*)
{
  mp_knot *pp*; ▷ for list manipulation ◁
  mp_gr_knot *q*, *qq*;
  if $(p \equiv \Lambda)$ **return** Λ;
  $q \leftarrow mp\_export\_knot(mp, p)$; $qq \leftarrow q$; $pp \leftarrow mp\_next\_knot(p)$;
  while $(pp \neq p)$ {
    $mp\_gr\_next\_knot(qq) \leftarrow mp\_export\_knot(mp, pp)$; $qq \leftarrow mp\_gr\_next\_knot(qq)$;
    $pp \leftarrow mp\_next\_knot(pp)$;
  }
  $mp\_gr\_next\_knot(qq) \leftarrow q$; **return** *q*;
}

326. If we want to import a knot node, we can say *import_knot*:

static mp_knot *mp_import_knot*(**MP** *mp*, **mp_gr_knot** *p*)
{
  mp_knot *q*; ▷ the copy ◁
  $q \leftarrow mp\_new\_knot(mp)$; $set\_number\_from\_double(q\to x\_coord, p\to x\_coord)$;
  $set\_number\_from\_double(q\to y\_coord, p\to y\_coord)$; $set\_number\_from\_double(q\to left\_x, p\to left\_x)$;
  $set\_number\_from\_double(q\to left\_y, p\to left\_y)$; $set\_number\_from\_double(q\to right\_x, p\to right\_x)$;
  $set\_number\_from\_double(q\to right\_y, p\to right\_y)$; $mp\_left\_type(q) \leftarrow p\to data.types.left\_type$;
  $mp\_left\_type(q) \leftarrow p\to data.types.right\_type$; $mp\_knot\_info(q) \leftarrow p\to data.info$; $mp\_next\_knot(q) \leftarrow \Lambda$;
  return *q*;
}

327. The *import_path* routine makes a clone of a given path and converts the *value*s therein to *scaled*s.

static mp_knot *mp_import_path*(**MP** *mp*, **mp_gr_knot** *p*)
{
  mp_gr_knot *pp*; ▷ for list manipulation ◁
  mp_knot *q*, *qq*;
  if $(p \equiv \Lambda)$ **return** Λ;
  $q \leftarrow mp\_import\_knot(mp, p)$; $qq \leftarrow q$; $pp \leftarrow mp\_gr\_next\_knot(p)$;
  while $(pp \neq p)$ {
    $mp\_next\_knot(qq) \leftarrow mp\_import\_knot(mp, pp)$; $qq \leftarrow mp\_next\_knot(qq)$; $pp \leftarrow mp\_gr\_next\_knot(pp)$;
  }
  $mp\_next\_knot(qq) \leftarrow q$; **return** *q*;
}

328. Just before *ship_out*, knot lists are exported for printing.

329. The *export_knot_list* routine therefore also makes a clone of a given path.

```
static mp_gr_knot mp_export_knot_list(MP mp, mp_knot p)
{
  mp_gr_knot q;    ▷ the exported copy ◁
  if (p ≡ Λ) return Λ;
  q ← mp_export_path(mp, p); return q;
}
static mp_knot mp_import_knot_list(MP mp, mp_gr_knot q)
{
  mp_knot p;    ▷ the imported copy ◁
  if (q ≡ Λ) return Λ;
  p ← mp_import_path(mp, q); return p;
}
```

330. Similarly, there's a way to copy the *reverse* of a path. This procedure returns a pointer to the first node of the copy, if the path is a cycle, but to the final node of a non-cyclic copy. The global variable *path_tail* will point to the final node of the original path; this trick makes it easier to implement '**doublepath**'.

All node types are assumed to be *endpoint* or *explicit* only.

```
static mp_knot mp_htap_ypoc(MP mp, mp_knot p)
{
  mp_knot q, pp, qq, rr;    ▷ for list manipulation ◁
  q ← mp_new_knot(mp);    ▷ this will correspond to p ◁
  qq ← q; pp ← p;
  while (1) {
    mp_right_type(qq) ← mp_left_type(pp); mp_left_type(qq) ← mp_right_type(pp);
    number_clone(qq→x_coord, pp→x_coord); number_clone(qq→y_coord, pp→y_coord);
    number_clone(qq→right_x, pp→left_x); number_clone(qq→right_y, pp→left_y);
    number_clone(qq→left_x, pp→right_x); number_clone(qq→left_y, pp→right_y);
    mp_originator(qq) ← mp_originator(pp);
    if (mp_next_knot(pp) ≡ p) {
      mp_next_knot(q) ← qq; mp→path_tail ← pp; return q;
    }
    rr ← mp_new_knot(mp); mp_next_knot(rr) ← qq; qq ← rr; pp ← mp_next_knot(pp);
  }
}
```

331. ⟨ Global variables 18 ⟩ +≡

```
mp_knot path_tail;    ▷ the node that links to the beginning of a path ◁
```

332. When a cyclic list of knot nodes is no longer needed, it can be recycled by calling the following subroutine.

⟨ Declarations 10 ⟩ +≡

```
static void mp_toss_knot_list(MP mp, mp_knot p);
static void mp_toss_knot(MP mp, mp_knot p);
static void mp_free_knot(MP mp, mp_knot p);
```

333. **void** *mp_free_knot*(**MP** *mp*, **mp_knot** *q*)

```
{
  free_number(q→x_coord); free_number(q→y_coord); free_number(q→left_x); free_number(q→left_y);
  free_number(q→right_x); free_number(q→right_y); mp_xfree(q);
}
void mp_toss_knot(MP mp, mp_knot q)
{
  if (mp→num_knot_nodes < max_num_knot_nodes) {
    q→next ← mp→knot_nodes; mp→knot_nodes ← q; mp→num_knot_nodes++;
    if (mp→math_mode > mp_math_double_mode) {
      free_number(q→x_coord); free_number(q→y_coord); free_number(q→left_x); free_number(q→left_y);
      free_number(q→right_x); free_number(q→right_y);
    }
    return;
  }
  if (mp→math_mode > mp_math_double_mode) {
    mp_free_knot(mp, q);
  }
  else {
    mp_xfree(q);
  }
}
void mp_toss_knot_list(MP mp, mp_knot p)
{
  mp_knot q;    ▷ the node being freed ◁
  mp_knot r;    ▷ the next node ◁
  if (p ≡ Λ) return;
  q ← p;
  if (mp→math_mode > mp_math_double_mode) {
    do {
      r ← mp_next_knot(q); mp_toss_knot(mp, q); q ← r;
    } while (q ≠ p);
  }
  else {
    do {
      r ← mp_next_knot(q);
      if (mp→num_knot_nodes < max_num_knot_nodes) {
        q→next ← mp→knot_nodes; mp→knot_nodes ← q; mp→num_knot_nodes++;
      }
      else {
        mp_xfree(q);
      }
      q ← r;
    } while (q ≠ p);
  }
}
```

334. Choosing control points. Now we must actually delve into one of METAPOST's more difficult routines, the *make_choices* procedure that chooses angles and control points for the splines of a curve when the user has not specified them explicitly. The parameter to *make_choices* points to a list of knots and path information, as described above.

A path decomposes into independent segments at "breakpoint" knots, which are knots whose left and right angles are both prespecified in some way (i.e., their *mp_left_type* and *mp_right_type* aren't both open).

```
void mp_make_choices(MP mp, mp_knot knots)
{
  mp_knot h;    ▷ the first breakpoint ◁
  mp_knot p, q;    ▷ consecutive breakpoints being processed ◁
  ⟨Other local variables for make_choices 348⟩;
  FUNCTION_TRACE1("make_choices()\n"); check_arith();    ▷ make sure that arith_error ≡ false ◁
  if (number_positive(internal_value(mp_tracing_choices)))
    mp_print_path(mp, knots, ", before choices", true);
  ⟨If consecutive knots are equal, join them explicitly 337⟩;
  ⟨Find the first breakpoint, h, on the path; insert an artificial breakpoint if the path is an unbroken
      cycle 338⟩;
  p ← h;
  do {
    ⟨Fill in the control points between p and the next breakpoint, then advance p to that breakpoint 339⟩;
  } while (p ≠ h);
  if (number_positive(internal_value(mp_tracing_choices)))
    mp_print_path(mp, knots, ", after choices", true);
  if (mp→arith_error) ⟨Report an unexpected problem during the choice-making 336⟩
}
```

335. ⟨Internal library declarations 14⟩ +≡

```
void mp_make_choices(MP mp, mp_knot knots);
```

336. ⟨Report an unexpected problem during the choice-making 336⟩ ≡

```
{
  const char *hlp[] ← {"The path that I just computed is out of range.",
      "So it will probably look funny. Proceed, for a laugh.", Λ};
  mp_back_error(mp, "Some number got too big", hlp, true); mp_get_x_next(mp);
  mp→arith_error ← false;
}
```

This code is used in section 334.

337. Two knots in a row with the same coordinates will always be joined by an explicit "curve" whose control points are identical with the knots.

⟨ If consecutive knots are equal, join them explicitly 337 ⟩ ≡
$p \leftarrow knots$;
do {
$q \leftarrow mp\_next\_knot(p)$;
if $(number\_equal(p\rightarrow x\_coord, q\rightarrow x\_coord) \land number\_equal(p\rightarrow y\_coord, q\rightarrow y\_coord) \land mp\_right\_type(p) > mp\_explicit)$ {
$mp\_right\_type(p) \leftarrow mp\_explicit$;
if $(mp\_left\_type(p) \equiv mp\_open)$ {
$mp\_left\_type(p) \leftarrow mp\_curl$; $set\_number\_to\_unity(p\rightarrow left\_curl)$;
}
$mp\_left\_type(q) \leftarrow mp\_explicit$;
if $(mp\_right\_type(q) \equiv mp\_open)$ {
$mp\_right\_type(q) \leftarrow mp\_curl$; $set\_number\_to\_unity(q\rightarrow right\_curl)$;
}
$number\_clone(p\rightarrow right\_x, p\rightarrow x\_coord)$; $number\_clone(q\rightarrow left\_x, p\rightarrow x\_coord)$;
$number\_clone(p\rightarrow right\_y, p\rightarrow y\_coord)$; $number\_clone(q\rightarrow left\_y, p\rightarrow y\_coord)$;
}
$p \leftarrow q$;
} **while** $(p \neq knots)$

This code is used in section 334.

338. If there are no breakpoints, it is necessary to compute the direction angles around an entire cycle. In this case the *mp_left_type* of the first node is temporarily changed to *end_cycle*.

⟨ Find the first breakpoint, h, on the path; insert an artificial breakpoint if the path is an unbroken cycle 338 ⟩ ≡
$h \leftarrow knots$;
while (1) {
if $(mp\_left\_type(h) \neq mp\_open)$ **break**;
if $(mp\_right\_type(h) \neq mp\_open)$ **break**;
$h \leftarrow mp\_next\_knot(h)$;
if $(h \equiv knots)$ {
$mp\_left\_type(h) \leftarrow mp\_end\_cycle$; **break**;
}
}

This code is used in section 334.

339. If *mp_right_type*$(p) <$ *given* and $q \leftarrow$ *mp_link*(p), we must have *mp_right_type*$(p) \leftarrow$ *mp_left_type*$(q) \leftarrow$ *mp_explicit* or *endpoint*.

⟨ Fill in the control points between p and the next breakpoint, then advance p to that breakpoint 339 ⟩ ≡

  $q \leftarrow$ *mp_next_knot*(p);
  if (*mp_right_type*$(p) \geq$ *mp_given*) {
    while ((*mp_left_type*$(q) \equiv$ *mp_open*) $\wedge$ (*mp_right_type*$(q) \equiv$ *mp_open*)) {
      $q \leftarrow$ *mp_next_knot*(q);
    }
    ⟨ Fill in the control information between consecutive breakpoints p and q 345 ⟩;
  }
  else if (*mp_right_type*$(p) \equiv$ *mp_endpoint*)
    ⟨ Give reasonable values for the unused control points between p and q 340 ⟩
  $p \leftarrow q$

This code is used in section 334.

340. This step makes it possible to transform an explicitly computed path without checking the *mp_left_type* and *mp_right_type* fields.

⟨ Give reasonable values for the unused control points between p and q 340 ⟩ ≡

  {
    number_clone(*p→right_x*, *p→x_coord*); *number_clone*(*p→right_y*, *p→y_coord*);
    number_clone(*q→left_x*, *q→x_coord*); *number_clone*(*q→left_y*, *q→y_coord*);
  }

This code is used in section 339.

341. Before we can go further into the way choices are made, we need to consider the underlying theory. The basic ideas implemented in *make_choices* are due to John Hobby, who introduced the notion of "mock curvature" at a knot. Angles are chosen so that they preserve mock curvature when a knot is passed, and this has been found to produce excellent results.

It is convenient to introduce some notations that simplify the necessary formulas. Let $d_{k,k+1} = |z_{k+1} - z_k|$ be the (nonzero) distance between knots k and $k+1$; and let

$$\frac{z_{k+1} - z_k}{z_k - z_{k-1}} = \frac{d_{k,k+1}}{d_{k-1,k}} e^{i\psi_k}$$

so that a polygonal line from z_{k-1} to z_k to z_{k+1} turns left through an angle of ψ_k. We assume that $|\psi_k|$Ł180°. The control points for the spline from z_k to z_{k+1} will be denoted by

$$\begin{aligned} z_k^+ &= z_k + \tfrac{1}{3}\rho_k e^{i\theta_k}(z_{k+1} - z_k), \\ z_{k+1}^- &= z_{k+1} - \tfrac{1}{3}\sigma_{k+1} e^{-i\phi_{k+1}}(z_{k+1} - z_k), \end{aligned}$$

where ρ_k and σ_{k+1} are nonnegative "velocity ratios" at the beginning and end of the curve, while θ_k and ϕ_{k+1} are the corresponding "offset angles." These angles satisfy the condition

$$\theta_k + \phi_k + \psi_k = 0, \qquad (*)$$

whenever the curve leaves an intermediate knot k in the direction that it enters.

342. Let α_k and β_{k+1} be the reciprocals of the "tension" of the curve at its beginning and ending points. This means that $\rho_k = \alpha_k f(\theta_k, \phi_{k+1})$ and $\sigma_{k+1} = \beta_{k+1} f(\phi_{k+1}, \theta_k)$, where $f(\theta, \phi)$ is METAPOST's standard velocity function defined in the *velocity* subroutine. The cubic spline $B(z_k\,, z_k^+\,, z_{k+1}^-, z_{k+1}; t)$ has curvature

$$\frac{2\sigma_{k+1}\sin(\theta_k + \phi_{k+1}) - 6\sin\theta_k}{\rho_k^2 d_{k,k+1}} \qquad \text{and} \qquad \frac{2\rho_k\sin(\theta_k + \phi_{k+1}) - 6\sin\phi_{k+1}}{\sigma_{k+1}^2 d_{k,k+1}}$$

at $t \leftarrow 0$ and $t \leftarrow 1$, respectively. The mock curvature is the linear approximation to this true curvature that arises in the limit for small θ_k and ϕ_{k+1}, if second-order terms are discarded. The standard velocity function satisfies

$$f(\theta, \phi) = 1 + O(\theta^2 + \theta\phi + \phi^2);$$

hence the mock curvatures are respectively

$$\frac{2\beta_{k+1}(\theta_k + \phi_{k+1}) - 6\theta_k}{\alpha_k^2 d_{k,k+1}} \qquad \text{and} \qquad \frac{2\alpha_k(\theta_k + \phi_{k+1}) - 6\phi_{k+1}}{\beta_{k+1}^2 d_{k,k+1}}. \tag{$**$}$$

343. The turning angles ψ_k are given, and equation $(*)$ above determines ϕ_k when θ_k is known, so the task of angle selection is essentially to choose appropriate values for each θ_k. When equation $(*)$ is used to eliminate ϕ variables from $(**)$, we obtain a system of linear equations of the form

$$A_k\theta_{k-1} + (B_k + C_k)\theta_k + D_k\theta_{k+1} = -B_k\psi_k - D_k\psi_{k+1},$$

where

$$A_k = \frac{\alpha_{k-1}}{\beta_k^2 d_{k-1,k}}, \qquad B_k = \frac{3 - \alpha_{k-1}}{\beta_k^2 d_{k-1,k}}, \qquad C_k = \frac{3 - \beta_{k+1}}{\alpha_k^2 d_{k,k+1}}, \qquad D_k = \frac{\beta_{k+1}}{\alpha_k^2 d_{k,k+1}}.$$

The tensions are always $\frac{3}{4}$ or more, hence each α and β will be at most $\frac{4}{3}$. It follows that $B_k \ge \frac{5}{4}A_k$ and $C_k \ge \frac{5}{4}D_k$; hence the equations are diagonally dominant; hence they have a unique solution. Moreover, in most cases the tensions are equal to 1, so that $B_k = 2A_k$ and $C_k = 2D_k$. This makes the solution numerically stable, and there is an exponential damping effect: The data at knot $k \pm j$ affects the angle at knot k by a factor of $O(2^{-j})$.

344. However, we still must consider the angles at the starting and ending knots of a non-cyclic path. These angles might be given explicitly, or they might be specified implicitly in terms of an amount of "curl."

Let's assume that angles need to be determined for a non-cyclic path starting at z_0 and ending at z_n. Then equations of the form

$$A_k\theta_{k-1} + (B_k + C_k)\theta_k + D_k\theta_{k+1} = R_k$$

have been given for $0 < k < n$, and it will be convenient to introduce equations of the same form for $k = 0$ and $k = n$, where

$$A_0 = B_0 = C_n = D_n = 0.$$

If θ_0 is supposed to have a given value E_0, we simply define $C_0 = 1$, $D_0 = 0$, and $R_0 = E_0$. Otherwise a curl parameter, γ_0, has been specified at z_0; this means that the mock curvature at z_0 should be γ_0 times the mock curvature at z_1; i.e.,

$$\frac{2\beta_1(\theta_0+\phi_1)-6\theta_0}{\alpha_0^2 d_{01}} = \gamma_0 \frac{2\alpha_0(\theta_0+\phi_1)-6\phi_1}{\beta_1^2 d_{01}}.$$

This equation simplifies to

$$(\alpha_0\chi_0 + 3 - \beta_1)\theta_0 + \bigl((3-\alpha_0)\chi_0 + \beta_1\bigr)\theta_1 = -\bigl((3-\alpha_0)\chi_0 + \beta_1\bigr)\psi_1,$$

where $\chi_0 = \alpha_0^2\gamma_0/\beta_1^2$; so we can set $C_0 = \chi_0\alpha_0 + 3 - \beta_1$, $D_0 = (3-\alpha_0)\chi_0 + \beta_1$, $R_0 = -D_0\psi_1$. It can be shown that $C_0 > 0$ and $C_0B_1 - A_1D_0 > 0$ when $\gamma_0 \ge 0$, hence the linear equations remain nonsingular.

Similar considerations apply at the right end, when the final angle ϕ_n may or may not need to be determined. It is convenient to let $\psi_n = 0$, hence $\theta_n = -\phi_n$. We either have an explicit equation $\theta_n = E_n$, or we have

$$\bigl((3-\beta_n)\chi_n + \alpha_{n-1}\bigr)\theta_{n-1} + (\beta_n\chi_n + 3 - \alpha_{n-1})\theta_n = 0, \qquad \chi_n = \frac{\beta_n^2\gamma_n}{\alpha_{n-1}^2}.$$

When *make_choices* chooses angles, it must compute the coefficients of these linear equations, then solve the equations. To compute the coefficients, it is necessary to compute arctangents of the given turning angles ψ_k. When the equations are solved, the chosen directions θ_k are put back into the form of control points by essentially computing sines and cosines.

345. OK, we are ready to make the hard choices of *make_choices*. Most of the work is relegated to an auxiliary procedure called *solve_choices*, which has been introduced to keep *make_choices* from being extremely long.

⟨Fill in the control information between consecutive breakpoints p and q 345⟩ ≡
  ⟨Calculate the turning angles ψ_k and the distances $d_{k,k+1}$; set n to the length of the path 349⟩;
  ⟨Remove *open* types at the breakpoints 350⟩;
  mp_solve_choices(*mp*, *p*, *q*, *n*)

This code is used in section 339.

346. It's convenient to precompute quantities that will be needed several times later. The values of *delta_x*[k] and *delta_y*[k] will be the coordinates of $z_{k+1} - z_k$, and the magnitude of this vector will be *delta*[k] ← $d_{k,k+1}$. The path angle ψ_k between $z_k - z_{k-1}$ and $z_{k+1} - z_k$ will be stored in *psi*[k].

⟨Global variables 18⟩ +≡
  int *path_size*; ▷ maximum number of knots between breakpoints of a path ◁
  mp_number ∗*delta_x*;
  mp_number ∗*delta_y*;
  mp_number ∗*delta*; ▷ knot differences ◁
  mp_number ∗*psi*; ▷ turning angles ◁

347. ⟨ Dealloc variables 31 ⟩ +≡

```
{
  int k;
  for (k ← 0; k < mp→path_size; k++) {
    free_number(mp→delta_x[k]); free_number(mp→delta_y[k]); free_number(mp→delta[k]);
    free_number(mp→psi[k]);
  }
  xfree(mp→delta_x); xfree(mp→delta_y); xfree(mp→delta); xfree(mp→psi);
}
```

348. ⟨ Other local variables for *make_choices* 348 ⟩ ≡

```
int k, n;    ▷ current and final knot numbers ◁
mp_knot s, t;    ▷ registers for list traversal ◁
```

This code is used in section 334.

349. ⟨ Calculate the turning angles ψ_k and the distances $d_{k,k+1}$; set n to the length of the path 349 ⟩ ≡

```
{
  mp_number sine, cosine;    ▷ trig functions of various angles ◁
  new_fraction(sine); new_fraction(cosine);
RESTART: k ← 0; s ← p; n ← mp→path_size;
  do {
    t ← mp_next_knot(s); set_number_from_substraction(mp→delta_x[k], t→x_coord, s→x_coord);
    set_number_from_substraction(mp→delta_y[k], t→y_coord, s→y_coord);
    pyth_add(mp→delta[k], mp→delta_x[k], mp→delta_y[k]);
    if (k > 0) {
      mp_number arg1, arg2, r1, r2;
      new_number(arg1); new_number(arg2); new_fraction(r1); new_fraction(r2);
      make_fraction(r1, mp→delta_y[k − 1], mp→delta[k − 1]); number_clone(sine, r1);
      make_fraction(r2, mp→delta_x[k − 1], mp→delta[k − 1]); number_clone(cosine, r2);
      take_fraction(r1, mp→delta_x[k], cosine); take_fraction(r2, mp→delta_y[k], sine);
      set_number_from_addition(arg1, r1, r2); take_fraction(r1, mp→delta_y[k], cosine);
      take_fraction(r2, mp→delta_x[k], sine); set_number_from_substraction(arg2, r1, r2);
      n_arg(mp→psi[k], arg1, arg2); free_number(r1); free_number(r2); free_number(arg1);
      free_number(arg2);
    }
    incr(k); s ← t;
    if (k ≡ mp→path_size) {
      mp_reallocate_paths(mp, mp→path_size + (mp→path_size/4)); goto RESTART;
        ▷ retry, loop size has changed ◁
    }
    if (s ≡ q) n ← k;
  } while (¬((k ≥ n) ∧ (mp_left_type(s) ≠ mp_end_cycle)));
  if (k ≡ n) set_number_to_zero(mp→psi[k]);
  else number_clone(mp→psi[k], mp→psi[1]);
  free_number(sine); free_number(cosine);
}
```

This code is used in section 345.

350. When we get to this point of the code, *mp_right_type*(*p*) is either *given* or *curl* or *open*. If it is *open*, we must have *mp_left_type*(*p*) ← *mp_end_cycle* or *mp_left_type*(*p*) ← *mp_explicit*. In the latter case, the *open* type is converted to *given*; however, if the velocity coming into this knot is zero, the *open* type is converted to a *curl*, since we don't know the incoming direction.

Similarly, *mp_left_type*(*q*) is either *given* or *curl* or *open* or *mp_end_cycle*. The *open* possibility is reduced either to *given* or to *curl*.

⟨Remove *open* types at the breakpoints 350⟩ ≡

```
{
  mp_number delx, dely;    ▷ directions where open meets explicit ◁
  new_number(delx); new_number(dely);
  if (mp_left_type(q) ≡ mp_open) {
    set_number_from_substraction(delx, q→right_x, q→x_coord);
    set_number_from_substraction(dely, q→right_y, q→y_coord);
    if (number_zero(delx) ∧ number_zero(dely)) {
      mp_left_type(q) ← mp_curl; set_number_to_unity(q→left_curl);
    }
    else {
      mp_left_type(q) ← mp_given; n_arg(q→left_given, delx, dely);
    }
  }
  if ((mp_right_type(p) ≡ mp_open) ∧ (mp_left_type(p) ≡ mp_explicit)) {
    set_number_from_substraction(delx, p→x_coord, p→left_x);
    set_number_from_substraction(dely, p→y_coord, p→left_y);
    if (number_zero(delx) ∧ number_zero(dely)) {
      mp_right_type(p) ← mp_curl; set_number_to_unity(p→right_curl);
    }
    else {
      mp_right_type(p) ← mp_given; n_arg(p→right_given, delx, dely);
    }
  }
  free_number(delx); free_number(dely);
}
```

This code is used in section 345.

351. Linear equations need to be solved whenever $n > 1$; and also when $n \leftarrow 1$ and exactly one of the breakpoints involves a curl. The simplest case occurs when $n \leftarrow 1$ and there is a curl at both breakpoints; then we simply draw a straight line.

But before coding up the simple cases, we might as well face the general case, since we must deal with it sooner or later, and since the general case is likely to give some insight into the way simple cases can be handled best.

When there is no cycle, the linear equations to be solved form a tridiagonal system, and we can apply the standard technique of Gaussian elimination to convert that system to a sequence of equations of the form

$$\theta_0 + u_0\theta_1 = v_0, \quad \theta_1 + u_1\theta_2 = v_1, \quad \ldots, \quad \theta_{n-1} + u_{n-1}\theta_n = v_{n-1}, \quad \theta_n = v_n.$$

It is possible to do this diagonalization while generating the equations. Once θ_n is known, it is easy to determine $\theta_{n-1}, \ldots, \theta_1, \theta_0$; thus, the equations will be solved.

The procedure is slightly more complex when there is a cycle, but the basic idea will be nearly the same. In the cyclic case the right-hand sides will be $v_k + w_k\theta_0$ instead of simply v_k, and we will start the process off with $u_0 = v_0 = 0$, $w_0 = 1$. The final equation will be not $\theta_n = v_n$ but $\theta_n + u_n\theta_1 = v_n + w_n\theta_0$; an appropriate ending routine will take account of the fact that $\theta_n = \theta_0$ and eliminate the w's from the system, after which the solution can be obtained as before.

When u_k, v_k, and w_k are being computed, the three pointer variables r, s, t will point respectively to knots $k-1$, k, and $k+1$. The u's and w's are scaled by 2^{28}, i.e., they are of type *fraction*; the θ's and v's are of type *angle*.

⟨ Global variables 18 ⟩ +≡
```
mp_number *theta;   ▷ values of θ_k ◁
mp_number *uu;   ▷ values of u_k ◁
mp_number *vv;   ▷ values of v_k ◁
mp_number *ww;   ▷ values of w_k ◁
```

352. ⟨ Dealloc variables 31 ⟩ +≡
```
{
  int k;
  for (k ← 0; k < mp→path_size; k++) {
    free_number(mp→theta[k]); free_number(mp→uu[k]); free_number(mp→vv[k]);
    free_number(mp→ww[k]);
  }
  xfree(mp→theta); xfree(mp→uu); xfree(mp→vv); xfree(mp→ww);
}
```

353. ⟨ Declarations 10 ⟩ +≡
```
static void mp_reallocate_paths(MP mp, int l);
```

354. **void** *mp_reallocate_paths*(**MP** *mp*, **int** *l*)

```
{
  int k;
  XREALLOC(mp→delta_x, l, mp_number); XREALLOC(mp→delta_y, l, mp_number);
  XREALLOC(mp→delta, l, mp_number); XREALLOC(mp→psi, l, mp_number);
  XREALLOC(mp→theta, l, mp_number); XREALLOC(mp→uu, l, mp_number);
  XREALLOC(mp→vv, l, mp_number); XREALLOC(mp→ww, l, mp_number);
  for (k ← mp→path_size; k < l; k++) {
    new_number(mp→delta_x[k]); new_number(mp→delta_y[k]); new_number(mp→delta[k]);
    new_angle(mp→psi[k]); new_angle(mp→theta[k]); new_fraction(mp→uu[k]); new_angle(mp→vv[k]);
    new_fraction(mp→ww[k]);
  }
  mp→path_size ← l;
}
```

355. Our immediate problem is to get the ball rolling by setting up the first equation or by realizing that no equations are needed, and to fit this initialization into a framework suitable for the overall computation.

⟨ Declarations 10 ⟩ +≡
static void *mp_solve_choices*(**MP** *mp*, **mp_knot** *p*, **mp_knot** *q*, **halfword** *n*);

356. **void** *mp_solve_choices*(**MP** *mp*, **mp_knot** *p*, **mp_knot** *q*, **halfword** *n*)

```
{
  int k;    ▷ current knot number ◁
  mp_knot r, s, t;    ▷ registers for list traversal ◁
  mp_number ff;
  new_fraction(ff); FUNCTION_TRACE2("solve_choices(%d)\n", n); k ← 0; s ← p; r ← 0;
  while (1) {
    t ← mp_next_knot(s);
    if (k ≡ 0) ⟨ Get the linear equations started; or return with the control points in place, if linear
          equations needn't be solved 357 ⟩
    else {
      switch (mp_left_type(s)) {
      case mp_end_cycle: case mp_open: ⟨ Set up equation to match mock curvatures at z_k; then goto
            found with θ_n adjusted to equal θ_0, if a cycle has ended 358 ⟩;
        break;
      case mp_curl: ⟨ Set up equation for a curl at θ_n and goto found 368 ⟩;
        break;
      case mp_given: ⟨ Calculate the given value of θ_n and goto found 365 ⟩;
        break;
      }    ▷ there are no other cases ◁
    }
    r ← s; s ← t; incr(k);
  }
FOUND: ⟨ Finish choosing angles and assigning control points 371 ⟩;
  free_number(ff);
}
```

357. On the first time through the loop, we have $k \leftarrow 0$ and r is not yet defined. The first linear equation, if any, will have $A_0 = B_0 = 0$.

⟨Get the linear equations started; or **return** with the control points in place, if linear equations needn't be solved 357⟩ ≡

```
{
  switch (mp_right_type(s)) {
  case mp_given:
    if (mp_left_type(t) ≡ mp_given) ⟨Reduce to simple case of two givens and return 378⟩
    else ⟨Set up the equation for a given value of θ0 366⟩
    break;
  case mp_curl:
    if (mp_left_type(t) ≡ mp_curl) ⟨Reduce to simple case of straight line and return 379⟩
    else ⟨Set up the equation for a curl at θ0 367⟩
    break;
  case mp_open: set_number_to_zero(mp→uu[0]); set_number_to_zero(mp→vv[0]);
    number_clone(mp→ww[0], fraction_one_t);    ▷ this begins a cycle ◁
    break;
  }    ▷ there are no other cases ◁
}
```

This code is used in section 356.

358. The general equation that specifies equality of mock curvature at z_k is

$$A_k\theta_{k-1} + (B_k + C_k)\theta_k + D_k\theta_{k+1} = -B_k\psi_k - D_k\psi_{k+1},$$

as derived above. We want to combine this with the already-derived equation $\theta_{k-1} + u_{k-1}\theta_k = v_{k-1} + w_{k-1}\theta_0$ in order to obtain a new equation $\theta_k + u_k\theta_{k+1} = v_k + w_k\theta_0$. This can be done by dividing the equation

$$(B_k - u_{k-1}A_k + C_k)\theta_k + D_k\theta_{k+1} = -B_k\psi_k - D_k\psi_{k+1} - A_kv_{k-1} - A_kw_{k-1}\theta_0$$

by $B_k - u_{k-1}A_k + C_k$. The trick is to do this carefully with fixed-point arithmetic, avoiding the chance of overflow while retaining suitable precision.

The calculations will be performed in several registers that provide temporary storage for intermediate quantities.

⟨Set up equation to match mock curvatures at z_k; then **goto** *found* with θ_n adjusted to equal θ_0, if a cycle has ended 358⟩ ≡

```
{
  mp_number aa, bb, cc, acc;    ▷ temporary registers ◁
  mp_number dd, ee;    ▷ likewise, but scaled ◁
  new_fraction(aa); new_fraction(bb); new_fraction(cc); new_fraction(acc); new_number(dd);
  new_number(ee);
  ⟨Calculate the values aa = A_k/B_k, bb = D_k/C_k, dd = (3 − α_{k−1})d_{k,k+1}, ee = (3 − β_{k+1})d_{k−1,k}, and
      cc = (B_k − u_{k−1}A_k)/B_k 359⟩;
  ⟨Calculate the ratio ff = C_k/(C_k + B_k − u_{k−1}A_k) 360⟩;
  take_fraction(mp→uu[k], ff, bb); ⟨Calculate the values of v_k and w_k 361⟩;
  if (mp_left_type(s) ≡ mp_end_cycle) ⟨Adjust θ_n to equal θ0 and goto found 362⟩
  free_number(aa); free_number(bb); free_number(cc); free_number(acc); free_number(dd);
  free_number(ee);
}
```

This code is used in section 356.

359. Since tension values are never less than 3/4, the values aa and bb computed here are never more than 4/5.

⟨ Calculate the values $aa = A_k/B_k$, $bb = D_k/C_k$, $dd = (3-\alpha_{k-1})d_{k,k+1}$, $ee = (3-\beta_{k+1})d_{k-1,k}$, and $cc = (B_k - u_{k-1}A_k)/B_k$ 359 ⟩ ≡

```
{
  mp_number absval;
  new_number(absval); number_clone(absval, r→right_tension); number_abs(absval);
  if (number_equal(absval, unity_t)) {
    number_clone(aa, fraction_half_t); number_clone(dd, mp→delta[k]); number_double(dd);
  }
  else {
    mp_number arg1, arg2, ret;
    new_number(arg2); new_number(arg1); number_clone(arg2, r→right_tension); number_abs(arg2);
    number_multiply_int(arg2, 3); number_substract(arg2, unity_t); make_fraction(aa, unity_t, arg2);
    number_clone(arg2, r→right_tension); number_abs(arg2); new_fraction(ret);
    make_fraction(ret, unity_t, arg2); set_number_from_substraction(arg1, fraction_three_t, ret);
    take_fraction(arg2, mp→delta[k], arg1); number_clone(dd, arg2); free_number(ret);
    free_number(arg1); free_number(arg2);
  }
  number_clone(absval, t→left_tension); number_abs(absval);
  if (number_equal(absval, unity_t)) {
    number_clone(bb, fraction_half_t); number_clone(ee, mp→delta[k − 1]); number_double(ee);
  }
  else {
    mp_number arg1, arg2, ret;
    new_number(arg1); new_number(arg2); number_clone(arg2, t→left_tension); number_abs(arg2);
    number_multiply_int(arg2, 3); number_substract(arg2, unity_t); make_fraction(bb, unity_t, arg2);
    number_clone(arg2, t→left_tension); number_abs(arg2); new_fraction(ret);
    make_fraction(ret, unity_t, arg2); set_number_from_substraction(arg1, fraction_three_t, ret);
    take_fraction(ee, mp→delta[k − 1], arg1); free_number(ret); free_number(arg1); free_number(arg2);
  }
  free_number(absval);
}
{
  mp_number r1;
  new_number(r1); take_fraction(r1, mp→uu[k − 1], aa);
  set_number_from_substraction(cc, fraction_one_t, r1); free_number(r1);
}
```

This code is used in section 358.

360. The ratio to be calculated in this step can be written in the form

$$\frac{\beta_k^2 \cdot ee}{\beta_k^2 \cdot ee + \alpha_k^2 \cdot cc \cdot dd},$$

because of the quantities just calculated. The values of dd and ee will not be needed after this step has been performed.

$\langle$ Calculate the ratio $ff = C_k/(C_k + B_k - u_{k-1}A_k)$ 360 $\rangle \equiv$

```
{
  mp_number rt, lt;
  mp_number arg2;
  new_number(arg2); number_clone(arg2, dd); take_fraction(dd, arg2, cc); new_number(lt);
  new_number(rt); number_clone(lt, s→left_tension); number_abs(lt); number_clone(rt, s→right_tension);
  number_abs(rt);
  if (¬number_equal(lt, rt)) {    ▷ β_k^{-1} ≠ α_k^{-1} ◁
    mp_number r1;
    new_number(r1);
    if (number_less(lt, rt)) {
      make_fraction(r1, lt, rt);    ▷ α_k^2/β_k^2 ◁
      take_fraction(ff, r1, r1); number_clone(r1, dd); take_fraction(dd, r1, ff);
    }
    else {
      make_fraction(r1, rt, lt);    ▷ β_k^2/α_k^2 ◁
      take_fraction(ff, r1, r1); number_clone(r1, ee); take_fraction(ee, r1, ff);
    }
    free_number(r1);
  }
  free_number(rt); free_number(lt); set_number_from_addition(arg2, dd, ee);
  make_fraction(ff, ee, arg2); free_number(arg2);
}
```

This code is used in section 358.

361. The value of u_{k-1} will be ≤ 1 except when $k = 1$ and the previous equation was specified by a curl. In that case we must use a special method of computation to prevent overflow.

Fortunately, the calculations turn out to be even simpler in this "hard" case. The curl equation makes $w_0 = 0$ and $v_0 = -u_0\psi_1$, hence $-B_1\psi_1 - A_1v_0 = -(B_1 - u_0A_1)\psi_1 = -cc \cdot B_1\psi_1$.

⟨ Calculate the values of v_k and w_k 361 ⟩ ≡

```
take_fraction(acc, mp→psi[k + 1], mp→uu[k]); number_negate(acc);
if (mp_right_type(r) ≡ mp_curl) {
   mp_number r1, arg2;
   new_fraction(r1); new_number(arg2); set_number_from_substraction(arg2, fraction_one_t, ff);
   take_fraction(r1, mp→psi[1], arg2); set_number_to_zero(mp→ww[k]);
   set_number_from_substraction(mp→vv[k], acc, r1); free_number(r1); free_number(arg2);
}
else {
   mp_number arg1, r1;
   new_fraction(r1); new_number(arg1); set_number_from_substraction(arg1, fraction_one_t, ff);
   make_fraction(ff, arg1, cc);    ▷ this is B_k/(C_k + B_k − u_{k−1}A_k) < 5 ◁
   free_number(arg1); take_fraction(r1, mp→psi[k], ff); number_substract(acc, r1); number_clone(r1, ff);
   take_fraction(ff, r1, aa);    ▷ this is A_k/(C_k + B_k − u_{k−1}A_k) ◁
   take_fraction(r1, mp→vv[k − 1], ff); set_number_from_substraction(mp→vv[k], acc, r1);
   if (number_zero(mp→ww[k − 1])) {
      set_number_to_zero(mp→ww[k]);
   }
   else {
      take_fraction(mp→ww[k], mp→ww[k − 1], ff); number_negate(mp→ww[k]);
   }
   free_number(r1);
}
```

This code is used in section 358.

362. When a complete cycle has been traversed, we have $\theta_k + u_k\theta_{k+1} = v_k + w_k\theta_0$, for $1 \le k \le n$. We would like to determine the value of θ_n and reduce the system to the form $\theta_k + u_k\theta_{k+1} = v_k$ for $0 \le k < n$, so that the cyclic case can be finished up just as if there were no cycle.

The idea in the following code is to observe that

$$\begin{aligned}\theta_n &= v_n + w_n\theta_0 - u_n\theta_1 = \cdots \\ &= v_n + w_n\theta_0 - u_n\bigl(v_1 + w_1\theta_0 - u_1(v_2 + \cdots - u_{n-2}(v_{n-1} + w_{n-1}\theta_0 - u_{n-1}\theta_0))\bigr),\end{aligned}$$

so we can solve for $\theta_n = \theta_0$.

⟨ Adjust θ_n to equal θ_0 and **goto** *found* 362 ⟩ ≡

```
{
  mp_number arg2, r1;
  new_number(arg2); new_number(r1); set_number_to_zero(aa); number_clone(bb, fraction_one_t);
    ▷ we have k ≡ n ◁
  do {
    decr(k);
    if (k ≡ 0) k ← n;
    take_fraction(r1, aa, mp→uu[k]); set_number_from_substraction(aa, mp→vv[k], r1);
    take_fraction(r1, bb, mp→uu[k]); set_number_from_substraction(bb, mp→ww[k], r1);
  } while (k ≠ n);   ▷ now θn = aa + bb · θn ◁
  set_number_from_substraction(arg2, fraction_one_t, bb); make_fraction(r1, aa, arg2);
  number_clone(aa, r1); number_clone(mp→theta[n], aa); number_clone(mp→vv[0], aa);
  for (k ← 1; k < n; k++) {
    take_fraction(r1, aa, mp→ww[k]); number_add(mp→vv[k], r1);
  }
  free_number(arg2); free_number(r1); free_number(aa); free_number(bb); free_number(cc);
  free_number(acc); free_number(dd); free_number(ee); goto FOUND;
}
```

This code is used in section 358.

363. **void** *mp_reduce_angle*(**MP** *mp*, **mp_number** ∗*a*)

```
{
  mp_number abs_a;
  FUNCTION_TRACE2("reduce_angle(%f)\n", number_to_double(*a)); new_number(abs_a);
  number_clone(abs_a, *a); number_abs(abs_a);
  if (number_greater(abs_a, one_eighty_deg_t)) {
    if (number_positive(*a)) {
      number_substract(*a, three_sixty_deg_t);
    }
    else {
      number_add(*a, three_sixty_deg_t);
    }
  }
  free_number(abs_a);
}
```

364. ⟨ Declarations 10 ⟩ +≡

```
void mp_reduce_angle(MP mp, mp_number *a);
```

365. ⟨ Calculate the given value of θ_n and **goto** *found* 365 ⟩ ≡

```
{
  mp_number narg;
  new_angle(narg); n_arg(narg, mp→delta_x[n − 1], mp→delta_y[n − 1]);
  set_number_from_substraction(mp→theta[n], s→left_given, narg); free_number(narg);
  mp_reduce_angle(mp, &mp→theta[n]); goto FOUND;
}
```

This code is used in section 356.

366. ⟨ Set up the equation for a given value of θ_0 366 ⟩ ≡

```
{
  mp_number narg;
  new_angle(narg); n_arg(narg, mp→delta_x[0], mp→delta_y[0]);
  set_number_from_substraction(mp→vv[0], s→right_given, narg); free_number(narg);
  mp_reduce_angle(mp, &mp→vv[0]); set_number_to_zero(mp→uu[0]); set_number_to_zero(mp→ww[0]);
}
```

This code is used in section 357.

367. ⟨ Set up the equation for a curl at θ_0 367 ⟩ ≡

```
{
  mp_number lt, rt, cc;   ▷ tension values ◁
  new_number(lt); new_number(rt); new_number(cc); number_clone(cc, s→right_curl);
  number_clone(lt, t→left_tension); number_abs(lt); number_clone(rt, s→right_tension); number_abs(rt);
  if (number_unity(rt) ∧ number_unity(lt)) {
    mp_number arg1, arg2;
    new_number(arg1); new_number(arg2); number_clone(arg1, cc); number_double(arg1);
    number_add(arg1, unity_t); number_clone(arg2, cc); number_add(arg2, two_t);
    make_fraction(mp→uu[0], arg1, arg2); free_number(arg1); free_number(arg2);
  }
  else {
    mp_curl_ratio(mp, &mp→uu[0], cc, rt, lt);
  }
  take_fraction(mp→vv[0], mp→psi[1], mp→uu[0]); number_negate(mp→vv[0]);
  set_number_to_zero(mp→ww[0]); free_number(rt); free_number(lt); free_number(cc);
}
```

This code is used in section 357.

368. ⟨ Set up equation for a curl at θ_n and **goto** *found* 368 ⟩ ≡

```
{
  mp_number lt, rt, cc;   ▷ tension values ◁
  new_number(lt); new_number(rt); new_number(cc); number_clone(cc, s→left_curl);
  number_clone(lt, s→left_tension); number_abs(lt); number_clone(rt, r→right_tension); number_abs(rt);
  if (number_unity(rt) ∧ number_unity(lt)) {
    mp_number arg1, arg2;
    new_number(arg1); new_number(arg2); number_clone(arg1, cc); number_double(arg1);
    number_add(arg1, unity_t); number_clone(arg2, cc); number_add(arg2, two_t);
    make_fraction(ff, arg1, arg2); free_number(arg1); free_number(arg2);
  }
  else {
    mp_curl_ratio(mp, &ff, cc, lt, rt);
  }
  {
    mp_number arg1, arg2, r1;
    new_fraction(r1); new_fraction(arg1); new_number(arg2); take_fraction(arg1, mp→vv[n − 1], ff);
    take_fraction(r1, ff, mp→uu[n − 1]); set_number_from_substraction(arg2, fraction_one_t, r1);
    make_fraction(mp→theta[n], arg1, arg2); number_negate(mp→theta[n]); free_number(r1);
    free_number(arg1); free_number(arg2);
  }
  free_number(rt); free_number(lt); free_number(cc); goto FOUND;
}
```

This code is used in section 356.

369. The *curl_ratio* subroutine has three arguments, which our previous notation encourages us to call γ, α^{-1}, and β^{-1}. It is a somewhat tedious program to calculate

$$\frac{(3-\alpha)\alpha^2\gamma+\beta^3}{\alpha^3\gamma+(3-\beta)\beta^2},$$

with the result reduced to 4 if it exceeds 4. (This reduction of curl is necessary only if the curl and tension are both large.) The values of α and β will be at most 4/3.

⟨ Declarations 10 ⟩ +≡

```
static void mp_curl_ratio(MP mp, mp_number *ret, mp_number gamma, mp_number
    a_tension, mp_number b_tension);
```

370. **void** *mp_curl_ratio*(**MP** *mp*, **mp_number** **ret*, **mp_number** *gamma_orig*, **mp_number** *a_tension*, **mp_number** *b_tension*)

```
{
  mp_number alpha, beta, gamma, num, denom, ff;    ▷ registers ◁
  mp_number arg1;
  new_number(arg1); new_fraction(alpha); new_fraction(beta); new_fraction(gamma); new_fraction(ff);
  new_fraction(denom); new_fraction(num); make_fraction(alpha, unity_t, a_tension);
  make_fraction(beta, unity_t, b_tension); number_clone(gamma, gamma_orig);
  if (number_lessequal(alpha, beta)) {
    make_fraction(ff, alpha, beta); number_clone(arg1, ff); take_fraction(ff, arg1, arg1);
    number_clone(arg1, gamma); take_fraction(gamma, arg1, ff); convert_fraction_to_scaled(beta);
    take_fraction(denom, gamma, alpha); number_add(denom, three_t);
  }
  else {
    make_fraction(ff, beta, alpha); number_clone(arg1, ff); take_fraction(ff, arg1, arg1);
    take_fraction(arg1, beta, ff); convert_fraction_to_scaled(arg1); number_clone(beta, arg1);
    take_fraction(denom, gamma, alpha); set_number_from_div(arg1, ff, twelvebits_3);
    number_add(denom, arg1);
  }
  number_substract(denom, beta); set_number_from_substraction(arg1, fraction_three_t, alpha);
  take_fraction(num, gamma, arg1); number_add(num, beta); number_clone(arg1, denom);
  number_double(arg1); number_double(arg1);    ▷ arg1 = 4*denom ◁
  if (number_greaterequal(num, arg1)) {
    number_clone(*ret, fraction_four_t);
  }
  else {
    make_fraction(*ret, num, denom);
  }
  free_number(alpha); free_number(beta); free_number(gamma); free_number(num);
  free_number(denom); free_number(ff); free_number(arg1);
}
```

371. We're in the home stretch now.

⟨ Finish choosing angles and assigning control points 371 ⟩ ≡
{
  mp_number *r1*;
  new_number(*r1*);
  for ($k \leftarrow n - 1$; $k \geq 0$; k−−) {
    take_fraction(*r1*, *mp→theta*[$k+1$], *mp→uu*[k]);
    set_number_from_substraction(*mp→theta*[k], *mp→vv*[k], *r1*);
  }
  free_number(*r1*);
}
$s \leftarrow p$; $k \leftarrow 0$;
{
  mp_number *arg*;
  new_number(*arg*);
  do {
    $t \leftarrow$ *mp_next_knot*(s); *n_sin_cos*(*mp→theta*[k], *mp→ct*, *mp→st*); *number_clone*(*arg*, *mp→psi*[$k+1$]);
    number_negate(*arg*); *number_substract*(*arg*, *mp→theta*[$k+1$]); *n_sin_cos*(*arg*, *mp→cf*, *mp→sf*);
    mp_set_controls(*mp*, s, t, k); *incr*(k); $s \leftarrow t$;
  } **while** ($k \neq n$);
  free_number(*arg*);
}

This code is used in section 356.

372. The *set_controls* routine actually puts the control points into a pair of consecutive nodes p and q. Global variables are used to record the values of $\sin\theta$, $\cos\theta$, $\sin\phi$, and $\cos\phi$ needed in this calculation.

⟨ Global variables 18 ⟩ +≡
  mp_number *st*;
  mp_number *ct*;
  mp_number *sf*;
  mp_number *cf*; ▷ sines and cosines ◁

373. ⟨ Initialize table entries 186 ⟩ +≡
  new_fraction(*mp→st*); *new_fraction*(*mp→ct*); *new_fraction*(*mp→sf*); *new_fraction*(*mp→cf*);

374. ⟨ Dealloc variables 31 ⟩ +≡
  free_number(*mp→st*); *free_number*(*mp→ct*); *free_number*(*mp→sf*); *free_number*(*mp→cf*);

375. ⟨ Declarations 10 ⟩ +≡
  static void *mp_set_controls*(**MP** *mp*, **mp_knot** *p*, **mp_knot** *q*, **integer** *k*);

376. **void** *mp_set_controls*(**MP** *mp*, **mp_knot** *p*, **mp_knot** *q*, **integer** *k*)
{
  mp_number *rr*, *ss*; ▷ velocities, divided by thrice the tension ◁
  mp_number *lt*, *rt*; ▷ tensions ◁
  mp_number *sine*; ▷ $\sin(\theta+\phi)$ ◁
  mp_number *tmp*;
  mp_number *r1*, *r2*;
  new_number(*tmp*); *new_number*(*lt*); *new_number*(*rt*); *new_number*(*r1*); *new_number*(*r2*);
  number_clone(*lt*, *q→left_tension*); *number_abs*(*lt*); *number_clone*(*rt*, *p→right_tension*); *number_abs*(*rt*);
  new_fraction(*sine*); *new_fraction*(*rr*); *new_fraction*(*ss*); *velocity*(*rr*, *mp→st*, *mp→ct*, *mp→sf*, *mp→cf*, *rt*);
  velocity(*ss*, *mp→sf*, *mp→cf*, *mp→st*, *mp→ct*, *lt*);
  if (*number_negative*(*p→right_tension*) ∨ *number_negative*(*q→left_tension*))
    ⟨ Decrease the velocities, if necessary, to stay inside the bounding triangle 377 ⟩
  take_fraction(*r1*, *mp→delta_x*[*k*], *mp→ct*); *take_fraction*(*r2*, *mp→delta_y*[*k*], *mp→st*);
  number_substract(*r1*, *r2*); *take_fraction*(*tmp*, *r1*, *rr*);
  set_number_from_addition(*p→right_x*, *p→x_coord*, *tmp*); *take_fraction*(*r1*, *mp→delta_y*[*k*], *mp→ct*);
  take_fraction(*r2*, *mp→delta_x*[*k*], *mp→st*); *number_add*(*r1*, *r2*); *take_fraction*(*tmp*, *r1*, *rr*);
  set_number_from_addition(*p→right_y*, *p→y_coord*, *tmp*); *take_fraction*(*r1*, *mp→delta_x*[*k*], *mp→cf*);
  take_fraction(*r2*, *mp→delta_y*[*k*], *mp→sf*); *number_add*(*r1*, *r2*); *take_fraction*(*tmp*, *r1*, *ss*);
  set_number_from_substraction(*q→left_x*, *q→x_coord*, *tmp*); *take_fraction*(*r1*, *mp→delta_y*[*k*], *mp→cf*);
  take_fraction(*r2*, *mp→delta_x*[*k*], *mp→sf*); *number_substract*(*r1*, *r2*); *take_fraction*(*tmp*, *r1*, *ss*);
  set_number_from_substraction(*q→left_y*, *q→y_coord*, *tmp*); *mp_right_type*(*p*) ← *mp_explicit*;
  mp_left_type(*q*) ← *mp_explicit*; *free_number*(*tmp*); *free_number*(*r1*); *free_number*(*r2*);
  free_number(*lt*); *free_number*(*rt*); *free_number*(*rr*); *free_number*(*ss*); *free_number*(*sine*);
}

377. The boundedness conditions $rr \L \sin\phi\,/\sin(\theta+\phi)$ and $ss \L \sin\theta\,/\sin(\theta+\phi)$ are to be enforced if $\sin\theta$, $\sin\phi$, and $\sin(\theta+\phi)$ all have the same sign. Otherwise there is no "bounding triangle."

⟨Decrease the velocities, if necessary, to stay inside the bounding triangle 377⟩ ≡

```
if ((number_nonnegative(mp→st) ∧ number_nonnegative(mp→sf)) ∨ (number_nonpositive(mp→st) ∧
      number_nonpositive(mp→sf))) {
   mp_number r1, r2, arg1;
   mp_number ab_vs_cd;
   new_number(ab_vs_cd); new_fraction(r1); new_fraction(r2); new_number(arg1);
   number_clone(arg1, mp→st); number_abs(arg1); take_fraction(r1, arg1, mp→cf);
   number_clone(arg1, mp→sf); number_abs(arg1); take_fraction(r2, arg1, mp→ct);
   set_number_from_addition(sine, r1, r2);
   if (number_positive(sine)) {
      set_number_from_addition(arg1, fraction_one_t, unity_t);    ▷ safety factor ◁
      number_clone(r1, sine); take_fraction(sine, r1, arg1);
      if (number_negative(p→right_tension)) {
         number_clone(arg1, mp→sf); number_abs(arg1); ab_vs_cd(ab_vs_cd, arg1, fraction_one_t, rr, sine);
         if (number_negative(ab_vs_cd)) {
            number_clone(arg1, mp→sf); number_abs(arg1); make_fraction(rr, arg1, sine);
         }
      }
      if (number_negative(q→left_tension)) {
         number_clone(arg1, mp→st); number_abs(arg1); ab_vs_cd(ab_vs_cd, arg1, fraction_one_t, ss, sine);
         if (number_negative(ab_vs_cd)) {
            number_clone(arg1, mp→st); number_abs(arg1); make_fraction(ss, arg1, sine);
         }
      }
   }
   free_number(arg1); free_number(r1); free_number(r2); free_number(ab_vs_cd);
}
```

This code is used in section 376.

378. Only the simple cases remain to be handled.

⟨Reduce to simple case of two givens and **return** 378⟩ ≡

```
{
   mp_number arg1;
   mp_number narg;
   new_angle(narg); n_arg(narg, mp→delta_x[0], mp→delta_y[0]); new_number(arg1);
   set_number_from_substraction(arg1, p→right_given, narg); n_sin_cos(arg1, mp→ct, mp→st);
   set_number_from_substraction(arg1, q→left_given, narg); n_sin_cos(arg1, mp→cf, mp→sf);
   number_negate(mp→sf); mp_set_controls(mp, p, q, 0); free_number(narg); free_number(arg1);
   free_number(ff); return;
}
```

This code is used in section 357.

379. ⟨Reduce to simple case of straight line and **return** 379⟩ ≡

```
{
  mp_number lt, rt;    ▷ tension values ◁
  mp_right_type(p) ← mp_explicit; mp_left_type(q) ← mp_explicit; new_number(lt); new_number(rt);
  number_clone(lt, q→left_tension); number_abs(lt); number_clone(rt, p→right_tension); number_abs(rt);
  if (number_unity(rt)) {
    mp_number arg2;
    new_number(arg2);
    if (number_nonnegative(mp→delta_x[0])) {
      set_number_from_addition(arg2, mp→delta_x[0], epsilon_t);
    }
    else {
      set_number_from_substraction(arg2, mp→delta_x[0], epsilon_t);
    }
    number_int_div(arg2, 3); set_number_from_addition(p→right_x, p→x_coord, arg2);
    if (number_nonnegative(mp→delta_y[0])) {
      set_number_from_addition(arg2, mp→delta_y[0], epsilon_t);
    }
    else {
      set_number_from_substraction(arg2, mp→delta_y[0], epsilon_t);
    }
    number_int_div(arg2, 3); set_number_from_addition(p→right_y, p→y_coord, arg2); free_number(arg2);
  }
  else {
    mp_number arg2, r1;
    new_fraction(r1); new_number(arg2); number_clone(arg2, rt); number_multiply_int(arg2, 3);
    make_fraction(ff, unity_t, arg2);    ▷ α/3 ◁
    free_number(arg2); take_fraction(r1, mp→delta_x[0], ff);
    set_number_from_addition(p→right_x, p→x_coord, r1); take_fraction(r1, mp→delta_y[0], ff);
    set_number_from_addition(p→right_y, p→y_coord, r1);
  }
  if (number_unity(lt)) {
    mp_number arg2;
    new_number(arg2);
    if (number_nonnegative(mp→delta_x[0])) {
      set_number_from_addition(arg2, mp→delta_x[0], epsilon_t);
    }
    else {
      set_number_from_substraction(arg2, mp→delta_x[0], epsilon_t);
    }
    number_int_div(arg2, 3); set_number_from_substraction(q→left_x, q→x_coord, arg2);
    if (number_nonnegative(mp→delta_y[0])) {
      set_number_from_addition(arg2, mp→delta_y[0], epsilon_t);
    }
    else {
      set_number_from_substraction(arg2, mp→delta_y[0], epsilon_t);
    }
    number_int_div(arg2, 3); set_number_from_substraction(q→left_y, q→y_coord, arg2);
    free_number(arg2);
  }
  else {
```

```
    mp_number arg2, r1;
    new_fraction(r1); new_number(arg2); number_clone(arg2, lt); number_multiply_int(arg2, 3);
    make_fraction(ff, unity_t, arg2);    ▷ β/3 ◁
    free_number(arg2); take_fraction(r1, mp→delta_x[0], ff);
    set_number_from_substraction(q→left_x, q→x_coord, r1); take_fraction(r1, mp→delta_y[0], ff);
    set_number_from_substraction(q→left_y, q→y_coord, r1); free_number(r1);
  }
  free_number(ff); free_number(lt); free_number(rt); return;
}
```

This code is used in section 357.

380. Various subroutines that are useful for the new (1.770) exported api for solving path choices

```
#define TOO_LARGE(a) (fabs((a)) > 4096.0)
#define PI 3.1415926535897932384626433832795028841971
  static int out_of_range(MP mp, double a)
  {
    mp_number t;
    new_number(t); set_number_from_double(t, fabs(a));
    if (number_greaterequal(t, inf_t)) {
      free_number(t); return 1;
    }
    free_number(t); return 0;
  }
  static int mp_link_knotpair(MP mp, mp_knot p, mp_knot q)
  {
    if (p ≡ Λ ∨ q ≡ Λ) return 0;
    p→next ← q; set_number_from_double(p→right_tension, 1.0);
    if (mp_right_type(p) ≡ mp_endpoint) {
      mp_right_type(p) ← mp_open;
    }
    set_number_from_double(q→left_tension, 1.0);
    if (mp_left_type(q) ≡ mp_endpoint) {
      mp_left_type(q) ← mp_open;
    }
    return 1;
  }
  int mp_close_path_cycle(MP mp, mp_knot p, mp_knot q)
  {
    return mp_link_knotpair(mp, p, q);
  }
  int mp_close_path(MP mp, mp_knot q, mp_knot first)
  {
    if (q ≡ Λ ∨ first ≡ Λ) return 0;
    q→next ← first; mp_right_type(q) ← mp_endpoint; set_number_from_double(q→right_tension, 1.0);
    mp_left_type(first) ← mp_endpoint; set_number_from_double(first→left_tension, 1.0); return 1;
  }
  mp_knot mp_create_knot(MP mp)
  {
    mp_knot q ← mp_new_knot(mp);
    mp_left_type(q) ← mp_endpoint; mp_right_type(q) ← mp_endpoint; return q;
  }
  int mp_set_knot(MP mp, mp_knot p, double x, double y)
  {
    if (out_of_range(mp, x)) return 0;
    if (out_of_range(mp, y)) return 0;
    if (p ≡ Λ) return 0;
    set_number_from_double(p→x_coord, x); set_number_from_double(p→y_coord, y); return 1;
  }
  mp_knot mp_append_knot(MP mp, mp_knot p, double x, double y)
  {
    mp_knot q ← mp_create_knot(mp);
```

```
  if (q ≡ Λ) return Λ;
  if (¬mp_set_knot(mp, q, x, y)) {
    free(q); return Λ;
  }
  if (p ≡ Λ) return q;
  if (¬mp_link_knotpair(mp, p, q)) {
    free(q); return Λ;
  }
  return q;
}
int mp_set_knot_curl(MP mp, mp_knot q, double value)
{
  if (q ≡ Λ) return 0;
  if (TOO_LARGE(value)) return 0;
  mp_right_type(q) ← mp_curl; set_number_from_double(q→right_curl, value);
  if (mp_left_type(q) ≡ mp_open) {
    mp_left_type(q) ← mp_curl; set_number_from_double(q→left_curl, value);
  }
  return 1;
}
int mp_set_knot_left_curl(MP mp, mp_knot q, double value)
{
  if (q ≡ Λ) return 0;
  if (TOO_LARGE(value)) return 0;
  mp_left_type(q) ← mp_curl; set_number_from_double(q→left_curl, value);
  if (mp_right_type(q) ≡ mp_open) {
    mp_right_type(q) ← mp_curl; set_number_from_double(q→right_curl, value);
  }
  return 1;
}
int mp_set_knot_right_curl(MP mp, mp_knot q, double value)
{
  if (q ≡ Λ) return 0;
  if (TOO_LARGE(value)) return 0;
  mp_right_type(q) ← mp_curl; set_number_from_double(q→right_curl, value);
  if (mp_left_type(q) ≡ mp_open) {
    mp_left_type(q) ← mp_curl; set_number_from_double(q→left_curl, value);
  }
  return 1;
}
int mp_set_knotpair_curls(MP mp, mp_knot p, mp_knot q, double t1, double t2)
{
  if (p ≡ Λ ∨ q ≡ Λ) return 0;
  if (mp_set_knot_curl(mp, p, t1)) return mp_set_knot_curl(mp, q, t2);
  return 0;
}
int mp_set_knotpair_tensions(MP mp, mp_knot p, mp_knot q, double t1, double t2)
{
  if (p ≡ Λ ∨ q ≡ Λ) return 0;
  if (TOO_LARGE(t1)) return 0;
  if (TOO_LARGE(t2)) return 0;
```

```
  if ((fabs(t1) < 0.75)) return 0;
  if ((fabs(t2) < 0.75)) return 0;
  set_number_from_double(p→right_tension, t1); set_number_from_double(q→left_tension, t2); return 1;
}
int mp_set_knot_left_tension(MP mp, mp_knot p, double t1)
{
  if (p ≡ Λ) return 0;
  if (TOO_LARGE(t1)) return 0;
  if ((fabs(t1) < 0.75)) return 0;
  set_number_from_double(p→left_tension, t1); return 1;
}
int mp_set_knot_right_tension(MP mp, mp_knot p, double t1)
{
  if (p ≡ Λ) return 0;
  if (TOO_LARGE(t1)) return 0;
  if ((fabs(t1) < 0.75)) return 0;
  set_number_from_double(p→right_tension, t1); return 1;
}
int mp_set_knotpair_controls(MP mp, mp_knot p, mp_knot q, double x1, double y1, double
      x2, double y2)
{
  if (p ≡ Λ ∨ q ≡ Λ) return 0;
  if (out_of_range(mp, x1)) return 0;
  if (out_of_range(mp, y1)) return 0;
  if (out_of_range(mp, x2)) return 0;
  if (out_of_range(mp, y2)) return 0;
  mp_right_type(p) ← mp_explicit; set_number_from_double(p→right_x, x1);
  set_number_from_double(p→right_y, y1); mp_left_type(q) ← mp_explicit;
  set_number_from_double(q→left_x, x2); set_number_from_double(q→left_y, y2); return 1;
}
int mp_set_knot_left_control(MP mp, mp_knot p, double x1, double y1)
{
  if (p ≡ Λ) return 0;
  if (out_of_range(mp, x1)) return 0;
  if (out_of_range(mp, y1)) return 0;
  mp_left_type(p) ← mp_explicit; set_number_from_double(p→left_x, x1);
  set_number_from_double(p→left_y, y1); return 1;
}
int mp_set_knot_right_control(MP mp, mp_knot p, double x1, double y1)
{
  if (p ≡ Λ) return 0;
  if (out_of_range(mp, x1)) return 0;
  if (out_of_range(mp, y1)) return 0;
  mp_right_type(p) ← mp_explicit; set_number_from_double(p→right_x, x1);
  set_number_from_double(p→right_y, y1); return 1;
}
int mp_set_knot_direction(MP mp, mp_knot q, double x, double y)
{
  double value ← 0;
  if (q ≡ Λ) return 0;
```

```
    if (TOO_LARGE(x)) return 0;
    if (TOO_LARGE(y)) return 0;
    if (¬(x ≡ 0 ∧ y ≡ 0)) value ← atan2(y, x) ∗ (180.0/PI) ∗ 16.0;
    mp_right_type(q) ← mp_given; set_number_from_double(q→right_curl, value);
    if (mp_left_type(q) ≡ mp_open) {
      mp_left_type(q) ← mp_given; set_number_from_double(q→left_curl, value);
    }
    return 1;
  }
  int mp_set_knotpair_directions(MP mp, mp_knot p, mp_knot q, double x1, double y1, double
          x2, double y2)
  {
    if (p ≡ Λ ∨ q ≡ Λ) return 0;
    if (mp_set_knot_direction(mp, p, x1, y1)) return mp_set_knot_direction(mp, q, x2, y2);
    return 0;
  }
```

381.

```
static int path_needs_fixing(mp_knot source)
  {
    mp_knot sourcehead ← source;
    do {
      source ← source→next;
    } while (source ∧ source ≠ sourcehead);
    if (¬source) {
      return 1;
    }
    return 0;
  }
  int mp_solve_path(MP mp, mp_knot first)
  {
    int saved_arith_error ← mp→arith_error;
    jmp_buf ∗saved_jump_buf ← mp→jump_buf;
    int retval ← 1;
    if (first ≡ Λ) return 0;
    if (path_needs_fixing(first)) return 0;
    mp→jump_buf ← malloc(sizeof(jmp_buf));
    if (mp→jump_buf ≡ Λ ∨ setjmp(∗(mp→jump_buf)) ≠ 0) {
      return 0;
    }
    mp→arith_error ← 0; mp_make_choices(mp, first);
    if (mp→arith_error) retval ← 0;
    mp→arith_error ← saved_arith_error; free(mp→jump_buf); mp→jump_buf ← saved_jump_buf;
    return retval;
  }
  void mp_free_path(MP mp, mp_knot p)
  {
    mp_toss_knot_list(mp, p);
  }
```

382. ⟨Exported function headers 22⟩ +≡

int *mp_close_path_cycle*(**MP** *mp*, **mp_knot** *p*, **mp_knot** *q*);
int *mp_close_path*(**MP** *mp*, **mp_knot** *q*, **mp_knot** *first*);
mp_knot *mp_create_knot*(**MP** *mp*);
int *mp_set_knot*(**MP** *mp*, **mp_knot** *p*, **double** *x*, **double** *y*);
mp_knot *mp_append_knot*(**MP** *mp*, **mp_knot** *p*, **double** *x*, **double** *y*);
int *mp_set_knot_curl*(**MP** *mp*, **mp_knot** *q*, **double** *value*);
int *mp_set_knot_left_curl*(**MP** *mp*, **mp_knot** *q*, **double** *value*);
int *mp_set_knot_right_curl*(**MP** *mp*, **mp_knot** *q*, **double** *value*);
int *mp_set_knotpair_curls*(**MP** *mp*, **mp_knot** *p*, **mp_knot** *q*, **double** *t1*, **double** *t2*);
int *mp_set_knotpair_tensions*(**MP** *mp*, **mp_knot** *p*, **mp_knot** *q*, **double** *t1*, **double** *t2*);
int *mp_set_knot_left_tension*(**MP** *mp*, **mp_knot** *p*, **double** *t1*);
int *mp_set_knot_right_tension*(**MP** *mp*, **mp_knot** *p*, **double** *t1*);
int *mp_set_knot_left_control*(**MP** *mp*, **mp_knot** *p*, **double** *t1*, **double** *t2*);
int *mp_set_knot_right_control*(**MP** *mp*, **mp_knot** *p*, **double** *t1*, **double** *t2*);
int *mp_set_knotpair_controls*(**MP** *mp*, **mp_knot** *p*, **mp_knot** *q*, **double** *x1*, **double** *y1*, **double** *x2*, **double** *y2*);
int *mp_set_knot_direction*(**MP** *mp*, **mp_knot** *q*, **double** *x*, **double** *y*);
int *mp_set_knotpair_directions*(**MP** *mp*, **mp_knot** *p*, **mp_knot** *q*, **double** *x1*, **double** *y1*, **double** *x2*, **double** *y2*);
int *mp_solve_path*(**MP** *mp*, **mp_knot** *first*);
void *mp_free_path*(**MP** *mp*, **mp_knot** *p*);

383. Simple accessors for **mp_knot**.

```
mp_number mp_knot_x_coord(MP mp, mp_knot p)
{
  return p->x_coord;
}
mp_number mp_knot_y_coord(MP mp, mp_knot p)
{
  return p->y_coord;
}
mp_number mp_knot_left_x(MP mp, mp_knot p)
{
  return p->left_x;
}
mp_number mp_knot_left_y(MP mp, mp_knot p)
{
  return p->left_y;
}
mp_number mp_knot_right_x(MP mp, mp_knot p)
{
  return p->right_x;
}
mp_number mp_knot_right_y(MP mp, mp_knot p)
{
  return p->right_y;
}
int mp_knot_right_type(MP mp, mp_knot p)
{
  return mp_right_type(p);
}
int mp_knot_left_type(MP mp, mp_knot p)
{
  return mp_left_type(p);
}
mp_knot mp_knot_next(MP mp, mp_knot p)
{
  return p->next;
}
double mp_number_as_double(MP mp, mp_number n)
{
  return number_to_double(n);
}
```

384. ⟨ Exported function headers 22 ⟩ +≡

```
#define mp_knot_left_curl mp_knot_left_x
#define mp_knot_left_given mp_knot_left_x
#define mp_knot_left_tension mp_knot_left_y
#define mp_knot_right_curl mp_knot_right_x
#define mp_knot_right_given mp_knot_right_x
#define mp_knot_right_tension mp_knot_right_y
  mp_number mp_knot_x_coord(MP mp, mp_knot p);
  mp_number mp_knot_y_coord(MP mp, mp_knot p);
  mp_number mp_knot_left_x(MP mp, mp_knot p);
  mp_number mp_knot_left_y(MP mp, mp_knot p);
  mp_number mp_knot_right_x(MP mp, mp_knot p);
  mp_number mp_knot_right_y(MP mp, mp_knot p);
  int mp_knot_right_type(MP mp, mp_knot p);
  int mp_knot_left_type(MP mp, mp_knot p);
  mp_knot mp_knot_next(MP mp, mp_knot p);
  double mp_number_as_double(MP mp, mp_number n);
```

385. Measuring paths. METAPOST's **llcorner**, **lrcorner**, **ulcorner**, and **urcorner** operators allow the user to measure the bounding box of anything that can go into a picture. It's easy to get rough bounds on the x and y extent of a path by just finding the bounding box of the knots and the control points. We need a more accurate version of the bounding box, but we can still use the easy estimate to save time by focusing on the interesting parts of the path.

386. Computing an accurate bounding box involves a theme that will come up again and again. Given a Bernshteĭn polynomial

$$B(z_0, z_1, \ldots, z_n; t) = \sum_k \binom{n}{k} t^k (1-t)^{n-k} z_k,$$

we can conveniently bisect its range as follows:

1) Let $z_k^{(0)} = z_k$, for $0 \le k \le n$.

2) Let $z_k^{(j+1)} = \frac{1}{2}(z_k^{(j)} + z_{k+1}^{(j)})$, for $0 \le k < n - j$, for $0 \le j < n$.

Then

$$B(z_0, z_1, \ldots, z_n; t) = B(z_0^{(0)}, z_0^{(1)}, \ldots, z_0^{(n)}; 2t) = B(z_0^{(n)}, z_1^{(n-1)}, \ldots, z_n^{(0)}; 2t - 1).$$

This formula gives us the coefficients of polynomials to use over the ranges 0ŁtŁ$\frac{1}{2}$ and $\frac{1}{2}$ŁtŁ1.

387. Here is a routine that computes the x or y coordinate of the point on a cubic corresponding to the *fraction* value t.

```
static void mp_eval_cubic(MP mp, mp_number *r, mp_knot p, mp_knot q, quarterword
        c, mp_number t)
{
  mp_number x1, x2, x3;    ▷ intermediate values ◁
  new_number(x1); new_number(x2); new_number(x3);
  if (c ≡ mp_x_code) {
    set_number_from_of_the_way(x1, t, p→x_coord, p→right_x);
    set_number_from_of_the_way(x2, t, p→right_x, q→left_x);
    set_number_from_of_the_way(x3, t, q→left_x, q→x_coord);
  }
  else {
    set_number_from_of_the_way(x1, t, p→y_coord, p→right_y);
    set_number_from_of_the_way(x2, t, p→right_y, q→left_y);
    set_number_from_of_the_way(x3, t, q→left_y, q→y_coord);
  }
  set_number_from_of_the_way(x1, t, x1, x2); set_number_from_of_the_way(x2, t, x2, x3);
  set_number_from_of_the_way(*r, t, x1, x2); free_number(x1); free_number(x2); free_number(x3);
}
```

388. The actual bounding box information is stored in global variables. Since it is convenient to address the x and y information separately, we define arrays indexed by *x_code* .. *y_code* and use macros to give them more convenient names.

```
⟨ Types in the outer block 37 ⟩ +≡
  enum mp_bb_code {
    mp_x_code ← 0,    ▷ index for minx and maxx ◁
    mp_y_code    ▷ index for miny and maxy ◁
  };
```

389.

```
#define mp_minx mp→bbmin[mp_x_code]
#define mp_maxx mp→bbmax[mp_x_code]
#define mp_miny mp→bbmin[mp_y_code]
#define mp_maxy mp→bbmax[mp_y_code]
⟨ Global variables 18 ⟩ +≡
  mp_number bbmin[mp_y_code + 1];
  mp_number bbmax[mp_y_code + 1];
    ▷ the result of procedures that compute bounding box information ◁
```

390. ⟨ Initialize table entries 186 ⟩ +≡

```
  {
    int i;
    for (i ← 0; i ≤ mp_y_code; i++) {
      new_number(mp→bbmin[i]); new_number(mp→bbmax[i]);
    }
  }
```

391. ⟨ Dealloc variables 31 ⟩ +≡

```
  {
    int i;
    for (i ← 0; i ≤ mp_y_code; i++) {
      free_number(mp→bbmin[i]); free_number(mp→bbmax[i]);
    }
  }
```

392. Now we're ready for the key part of the bounding box computation. The *bound_cubic* procedure updates *bbmin*[*c*] and *bbmax*[*c*] based on

$$B(knot\_coord(p), right\_coord(p), left\_coord(q), knot\_coord(q); t)$$

for $0 < t \le 1$. In other words, the procedure adjusts the bounds to accommodate *knot_coord*(*q*) and any extremes over the range $0 < t < 1$. The *c* parameter is *x_code* or *y_code*.

```
static void mp_bound_cubic(MP mp, mp_knot p, mp_knot q, quarterword c)
{
  boolean wavy;    ▷ whether we need to look for extremes ◁
  mp_number del1, del2, del3, del, dmax;
    ▷ proportional to the control points of a quadratic derived from a cubic ◁
  mp_number t, tt;    ▷ where a quadratic crosses zero ◁
  mp_number x;    ▷ a value that bbmin[c] and bbmax[c] must accommodate ◁
  new_number(x); new_fraction(t); new_fraction(tt);
  if (c ≡ mp_x_code) {
    number_clone(x, q→x_coord);
  }
  else {
    number_clone(x, q→y_coord);
  }
  new_number(del1); new_number(del2); new_number(del3); new_number(del); new_number(dmax);
  ⟨Adjust bbmin[c] and bbmax[c] to accommodate x 393⟩;
  ⟨Check the control points against the bounding box and set wavy: ← true if any of them lie
      outside 394⟩;
  if (wavy) {
    if (c ≡ mp_x_code) {
      set_number_from_substraction(del1, p→right_x, p→x_coord);
      set_number_from_substraction(del2, q→left_x, p→right_x);
      set_number_from_substraction(del3, q→x_coord, q→left_x);
    }
    else {
      set_number_from_substraction(del1, p→right_y, p→y_coord);
      set_number_from_substraction(del2, q→left_y, p→right_y);
      set_number_from_substraction(del3, q→y_coord, q→left_y);
    }
    ⟨Scale up del1, del2, and del3 for greater accuracy; also set del to the first nonzero element of
        (del1, del2, del3) 395⟩;
    if (number_negative(del)) {
      number_negate(del1); number_negate(del2); number_negate(del3);
    }
    crossing_point(t, del1, del2, del3);
    if (number_less(t, fraction_one_t)) ⟨Test the extremes of the cubic against the bounding box 396⟩
  }
  free_number(del3); free_number(del2); free_number(del1); free_number(del); free_number(dmax);
  free_number(x); free_number(t); free_number(tt);
}
```

393. ⟨Adjust *bbmin*[*c*] and *bbmax*[*c*] to accommodate *x* 393⟩ ≡

```
  if (number_less(x, mp→bbmin[c])) number_clone(mp→bbmin[c], x);
  if (number_greater(x, mp→bbmax[c])) number_clone(mp→bbmax[c], x)
```

This code is used in sections 392, 396, and 397.

394. ⟨ Check the control points against the bounding box and set *wavy*: ← *true* if any of them lie outside 394 ⟩ ≡

```
wavy ← true;
if (c ≡ mp_x_code) {
  if (number_lessequal(mp→bbmin[c], p→right_x))
    if (number_lessequal(p→right_x, mp→bbmax[c]))
      if (number_lessequal(mp→bbmin[c], q→left_x))
        if (number_lessequal(q→left_x, mp→bbmax[c])) wavy ← false;
}
else {
  if (number_lessequal(mp→bbmin[c], p→right_y))
    if (number_lessequal(p→right_y, mp→bbmax[c]))
      if (number_lessequal(mp→bbmin[c], q→left_y))
        if (number_lessequal(q→left_y, mp→bbmax[c])) wavy ← false;
}
```

This code is used in section 392.

395. If *del1* ← *del2* ← *del3* ← 0, it's impossible to obey the title of this section. We just set *del* ← 0 in that case.

⟨ Scale up *del1*, *del2*, and *del3* for greater accuracy; also set *del* to the first nonzero element of (*del1*, *del2*, *del3*) 395 ⟩ ≡

```
if (number_nonzero(del1)) {
  number_clone(del, del1);
}
else if (number_nonzero(del2)) {
  number_clone(del, del2);
}
else {
  number_clone(del, del3);
}
if (number_nonzero(del)) {
  mp_number absval1;
  new_number(absval1); number_clone(dmax, del1); number_abs(dmax); number_clone(absval1, del2);
  number_abs(absval1);
  if (number_greater(absval1, dmax)) {
    number_clone(dmax, absval1);
  }
  number_clone(absval1, del3); number_abs(absval1);
  if (number_greater(absval1, dmax)) {
    number_clone(dmax, absval1);
  }
  while (number_less(dmax, fraction_half_t)) {
    number_double(dmax); number_double(del1); number_double(del2); number_double(del3);
  }
  free_number(absval1);
}
```

This code is used in section 392.

396. Since *crossing_point* has tried to choose t so that $B(del1, del2, del3; \tau)$ crosses zero at $\tau = t$ with negative slope, the value of *del2* computed below should not be positive. But rounding error could make it slightly positive in which case we must cut it to zero to avoid confusion.

⟨ Test the extremes of the cubic against the bounding box 396 ⟩ ≡

```
{
  mp_eval_cubic(mp, &x, p, q, c, t);  ⟨ Adjust bbmin[c] and bbmax[c] to accommodate x 393 ⟩;
  set_number_from_of_the_way(del2, t, del2, del3);
    ▷ now 0, del2, del3 represent the derivative on the remaining interval ◁
  if (number_positive(del2)) set_number_to_zero(del2);
  {
    mp_number arg2, arg3;
    new_number(arg2);  new_number(arg3);  number_clone(arg2, del2);  number_negate(arg2);
    number_clone(arg3, del3);  number_negate(arg3);  crossing_point(tt, zero_t, arg2, arg3);
    free_number(arg2);  free_number(arg3);
  }
  if (number_less(tt, fraction_one_t)) ⟨ Test the second extreme against the bounding box 397 ⟩
}
```

This code is used in section 392.

397. ⟨ Test the second extreme against the bounding box 397 ⟩ ≡

```
{
  mp_number arg;
  new_number(arg);  set_number_from_of_the_way(arg, t, tt, fraction_one_t);
  mp_eval_cubic(mp, &x, p, q, c, arg);  free_number(arg);
  ⟨ Adjust bbmin[c] and bbmax[c] to accommodate x 393 ⟩;
}
```

This code is used in section 396.

398. Finding the bounding box of a path is basically a matter of applying *bound_cubic* twice for each pair of adjacent knots.

```
static void mp_path_bbox(MP mp, mp_knot h)
{
  mp_knot p, q;    ▷ a pair of adjacent knots ◁
  number_clone(mp_minx, h→x_coord);  number_clone(mp_miny, h→y_coord);
  number_clone(mp_maxx, mp_minx);  number_clone(mp_maxy, mp_miny);  p ← h;
  do {
    if (mp_right_type(p) ≡ mp_endpoint) return;
    q ← mp_next_knot(p);  mp_bound_cubic(mp, p, q, mp_x_code);  mp_bound_cubic(mp, p, q, mp_y_code);
    p ← q;
  } while (p ≠ h);
}
```

399. Another important way to measure a path is to find its arc length. This is best done by using the general bisection algorithm to subdivide the path until obtaining "well behaved" subpaths whose arc lengths can be approximated by simple means.

Since the arc length is the integral with respect to time of the magnitude of the velocity, it is natural to use Simpson's rule for the approximation. If $\dot{B}(t)$ is the spline velocity, Simpson's rule gives

$$\frac{|\dot{B}(0)| + 4|\dot{B}(\frac{1}{2})| + |\dot{B}(1)|}{6}$$

for the arc length of a path of length 1. For a cubic spline $B(z_0, z_1, z_2, z_3; t)$, the time derivative $\dot{B}(t)$ is $3B(dz_0, dz_1, dz_2; t)$, where $dz_i = z_{i+1} - z_i$. Hence the arc length approximation is

$$\frac{|dz_0|}{2} + 2|dz_{02}| + \frac{|dz_2|}{2},$$

where

$$dz_{02} = \frac{1}{2}\left(\frac{dz_0 + dz_1}{2} + \frac{dz_1 + dz_2}{2}\right)$$

is the result of the bisection algorithm.

400. The remaining problem is how to decide when a subpath is "well behaved." This could be done via the theoretical error bound for Simpson's rule, but this is impractical because it requires an estimate of the fourth derivative of the quantity being integrated. It is much easier to just perform a bisection step and see how much the arc length estimate changes. Since the error for Simpson's rule is proportional to the fourth power of the sample spacing, the remaining error is typically about $\frac{1}{16}$ of the amount of the change. We say "typically" because the error has a pseudo-random behavior that could cause the two estimates to agree when each contain large errors.

To protect against disasters such as undetected cusps, the bisection process should always continue until all the dz_i vectors belong to a single 90° sector. This ensures that no point on the spline can have velocity less than 70% of the minimum of $|dz_0|$, $|dz_1|$ and $|dz_2|$. If such a spline happens to produce an erroneous arc length estimate that is little changed by bisection, the amount of the error is likely to be fairly small. We will try to arrange things so that freak accidents of this type do not destroy the inverse relationship between the **arclength** and **arctime** operations.

401. The **arclength** and **arctime** operations are both based on a recursive function that finds the arc length of a cubic spline given dz_0, dz_1, dz_2. This *arc_test* routine also takes an arc length goal *a_goal* and returns the time when the arc length reaches *a_goal* if there is such a time. Thus the return value is either an arc length less than *a_goal* or, if the arc length would be at least *a_goal*, it returns a time value decreased by *two*. This allows the caller to use the sign of the result to distinguish between arc lengths and time values. On certain types of overflow, it is possible for *a_goal* and the result of *arc_test* both to be `EL_GORDO`. Otherwise, the result is always less than *a_goal*.

Rather than halving the control point coordinates on each recursive call to *arc_test*, it is better to keep them proportional to velocity on the original curve and halve the results instead. This means that recursive calls can potentially use larger error tolerances in their arc length estimates. How much larger depends on to what extent the errors behave as though they are independent of each other. To save computing time, we use optimistic assumptions and increase the tolerance by a factor of about $\sqrt{2}$ for each recursive call.

In addition to the tolerance parameter, *arc_test* should also have parameters for $\frac{1}{3}|\dot{B}(0)|$, $\frac{2}{3}|\dot{B}(\frac{1}{2})|$, and $\frac{1}{3}|\dot{B}(1)|$. These quantities are relatively expensive to compute and they are needed in different instances of *arc_test*.

```
static void mp_arc_test(MP mp, mp_number *ret, mp_number dx0, mp_number dy0, mp_number
        dx1, mp_number dy1, mp_number dx2, mp_number dy2, mp_number v0, mp_number
        v02, mp_number v2, mp_number a_goal, mp_number tol_orig)
{
  boolean simple;    ▷ are the control points confined to a 90° sector? ◁
  mp_number dx01, dy01, dx12, dy12, dx02, dy02;    ▷ bisection results ◁
  mp_number v002, v022;    ▷ twice the velocity magnitudes at t = 1/4 and t = 3/4 ◁
  mp_number arc;    ▷ best arc length estimate before recursion ◁
  mp_number arc1;    ▷ arc length estimate for the first half ◁
  mp_number simply;
  mp_number tol;

  new_number(arc); new_number(arc1); new_number(dx01); new_number(dy01); new_number(dx12);
  new_number(dy12); new_number(dx02); new_number(dy02); new_number(v002); new_number(v022);
  new_number(simply); new_number(tol); number_clone(tol, tol_orig);
  ⟨Bisect the Bézier quadratic given by dx0, dy0, dx1, dy1, dx2, dy2 405⟩;
  ⟨Initialize v002, v022, and the arc length estimate arc; if it overflows set arc_test and return 406⟩;
  ⟨Test if the control points are confined to one quadrant or rotating them 45° would put them in one
      quadrant. Then set simple appropriately 407⟩;
  set_number_from_addition(simply, v0, v2); number_halfp(simply); number_negate(simply);
  number_add(simply, arc); number_substract(simply, v02); number_abs(simply);
  if (simple ∧ number_lessequal(simply, tol)) {
    if (number_less(arc, a_goal)) {
      number_clone(*ret, arc);
    }
    else ⟨Estimate when the arc length reaches a_goal and set arc_test to that time minus two 408⟩
  }
  else ⟨Use one or two recursive calls to compute the arc_test function 402⟩
DONE: free_number(arc); free_number(arc1); free_number(dx01); free_number(dy01);
  free_number(dx12); free_number(dy12); free_number(dx02); free_number(dy02); free_number(v002);
  free_number(v022); free_number(simply); free_number(tol);
}
```

402. The *tol* value should by multiplied by $\sqrt{2}$ before making recursive calls, but 1.5 is an adequate approximation. It is best to avoid using *make_fraction* in this inner loop.

⟨ Use one or two recursive calls to compute the *arc_test* function 402 ⟩ ≡

```
{
  mp_number a_new, a_aux;   ▷ the sum of these gives the a_goal ◁
  mp_number a, b;   ▷ results of recursive calls ◁
  mp_number half_v02;   ▷ halfp(v02), a recursion argument ◁
  new_number(a_new); new_number(a_aux); new_number(half_v02);
  ⟨ Set a_new and a_aux so their sum is 2 * a_goal and a_new is as large as possible 403 ⟩;
  {
    mp_number halfp_tol;
    new_number(halfp_tol); number_clone(halfp_tol, tol); number_halfp(halfp_tol);
    number_add(tol, halfp_tol); free_number(halfp_tol);
  }
  number_clone(half_v02, v02); number_halfp(half_v02); new_number(a);
  mp_arc_test(mp, &a, dx0, dy0, dx01, dy01, dx02, dy02, v0, v002, half_v02, a_new, tol);
  if (number_negative(a)) {
    set_number_to_unity(*ret);   ▷ 1 ◁
    number_double(*ret);   ▷ 2 ◁
    number_substract(*ret, a);   ▷ 2 − a ◁
    number_halfp(*ret); number_negate(*ret);   ▷ −halfp(2 − a) ◁
  }
  else {
    ⟨ Update a_new to reduce a_new + a_aux by a 404 ⟩;
    new_number(b);
    mp_arc_test(mp, &b, dx02, dy02, dx12, dy12, dx2, dy2, half_v02, v022, v2, a_new, tol);
    if (number_negative(b)) {
      mp_number tmp;
      new_number(tmp); number_clone(tmp, b); number_negate(tmp); number_halfp(tmp);
      number_negate(tmp); number_clone(*ret, tmp); set_number_to_unity(tmp); number_halfp(tmp);
      number_substract(*ret, tmp);   ▷ −(halfp(−b)) − 1/2 ◁
      free_number(tmp);
    }
    else {
      set_number_from_substraction(*ret, b, a); number_half(*ret);
      set_number_from_addition(*ret, a, *ret);   ▷ a + half(b − a) ◁
    }
    free_number(b);
  }
  free_number(half_v02); free_number(a_aux); free_number(a_new); free_number(a); goto DONE;
}
```

This code is used in section 401.

403. ⟨ Set *a_new* and *a_aux* so their sum is $2 * a\_goal$ and *a_new* is as large as possible 403 ⟩ ≡

```
set_number_to_inf(a_aux); number_substract(a_aux, a_goal);
if (number_greater(a_goal, a_aux)) {
  set_number_from_substraction(a_aux, a_goal, a_aux); set_number_to_inf(a_new);
}
else {
  set_number_from_addition(a_new, a_goal, a_goal); set_number_to_zero(a_aux);
}
```

This code is used in section 402.

404. There is no need to maintain *a_aux* at this point so we use it as a temporary to force the additions and subtractions to be done in an order that avoids overflow.

⟨ Update *a_new* to reduce *a_new* + *a_aux* by *a* 404 ⟩ ≡

```
if (number_greater(a, a_aux)) {
  number_substract(a_aux, a); number_add(a_new, a_aux);
}
```

This code is used in section 402.

405. This code assumes all *dx* and *dy* variables have magnitude less than *fraction_four*. To simplify the rest of the *arc_test* routine, we strengthen this assumption by requiring the norm of each (dx, dy) pair to obey this bound. Note that recursive calls will maintain this invariant.

⟨ Bisect the Bézier quadratic given by *dx0*, *dy0*, *dx1*, *dy1*, *dx2*, *dy2* 405 ⟩ ≡

```
set_number_from_addition(dx01, dx0, dx1); number_half(dx01);
set_number_from_addition(dx12, dx1, dx2); number_half(dx12);
set_number_from_addition(dx02, dx01, dx12); number_half(dx02);
set_number_from_addition(dy01, dy0, dy1); number_half(dy01);
set_number_from_addition(dy12, dy1, dy2); number_half(dy12);
set_number_from_addition(dy02, dy01, dy12); number_half(dy02);
```

This code is used in section 401.

406. We should be careful to keep $arc <$ `EL_GORDO` so that calling *arc_test* with *a_goal* ← `EL_GORDO` is guaranteed to yield the arc length.

⟨ Initialize *v002*, *v022*, and the arc length estimate *arc*; if it overflows set *arc_test* and **return** 406 ⟩ ≡

```
{
  mp_number tmp, arg1, arg2;
  new_number(tmp); new_number(arg1); new_number(arg2);
  set_number_from_addition(arg1, dx0, dx02); number_half(arg1); number_add(arg1, dx01);
  set_number_from_addition(arg2, dy0, dy02); number_half(arg2); number_add(arg2, dy01);
  pyth_add(v002, arg1, arg2); set_number_from_addition(arg1, dx02, dx2); number_half(arg1);
  number_add(arg1, dx12); set_number_from_addition(arg2, dy02, dy2); number_half(arg2);
  number_add(arg2, dy12); pyth_add(v022, arg1, arg2); free_number(arg1); free_number(arg2);
  number_clone(tmp, v02); number_add_scaled(tmp, 2); number_halfp(tmp);
  set_number_from_addition(arc1, v0, tmp); number_halfp(arc1); number_substract(arc1, v002);
  number_half(arc1); set_number_from_addition(arc1, v002, arc1);
  set_number_from_addition(arc, v2, tmp); number_halfp(arc); number_substract(arc, v022);
  number_half(arc); set_number_from_addition(arc, v022, arc); set_number_to_inf(tmp);
    ▷ reuse tmp for the next if test ◁
  number_substract(tmp, arc1);
  if (number_less(arc, tmp)) {
    free_number(tmp); number_add(arc, arc1);
  }
  else {
    free_number(tmp); mp→arith_error ← true;
    if (number_infinite(a_goal)) {
      set_number_to_inf(*ret);
    }
    else {
      set_number_to_unity(*ret); number_double(*ret); number_negate(*ret);    ▷ −2 ◁
    }
    goto DONE;
  }
}
```

This code is used in section 401.

407. ⟨ Test if the control points are confined to one quadrant or rotating them 45° would put them in one quadrant. Then set *simple* appropriately 407 ⟩ ≡

$simple \leftarrow ((number\_nonnegative(dx0) \wedge number\_nonnegative(dx1) \wedge number\_nonnegative(dx2)) \vee (number\_nonpositive(dx0) \wedge number\_nonpositive(dx1) \wedge number\_nonpositive(dx2)));$

if $(simple)$ {
  $simple \leftarrow (number\_nonnegative(dy0) \wedge number\_nonnegative(dy1) \wedge number\_nonnegative(dy2)) \vee (number\_nonpositive(dy0) \wedge number\_nonpositive(dy1) \wedge number\_nonpositive(dy2));$
}
if $(\neg simple)$ {
  $simple \leftarrow (number\_greaterequal(dx0, dy0) \wedge number\_greaterequal(dx1, dy1) \wedge number\_greaterequal(dx2, dy2)) \vee (number\_lessequal(dx0, dy0) \wedge number\_lessequal(dx1, dy1) \wedge number\_lessequal(dx2, dy2));$
  if $(simple)$ {
    mp_number *neg_dx0, neg_dx1, neg_dx2*;
    $new\_number(neg\_dx0);$ $new\_number(neg\_dx1);$ $new\_number(neg\_dx2);$ $number\_clone(neg\_dx0, dx0);$ $number\_clone(neg\_dx1, dx1);$ $number\_clone(neg\_dx2, dx2);$ $number\_negate(neg\_dx0);$ $number\_negate(neg\_dx1);$ $number\_negate(neg\_dx2);$
    $simple \leftarrow (number\_greaterequal(neg\_dx0, dy0) \wedge number\_greaterequal(neg\_dx1, dy1) \wedge number\_greaterequal(neg\_dx2, dy2)) \vee (number\_lessequal(neg\_dx0, dy0) \wedge number\_lessequal(neg\_dx1, dy1) \wedge number\_lessequal(neg\_dx2, dy2));$
    $free\_number(neg\_dx0);$ $free\_number(neg\_dx1);$ $free\_number(neg\_dx2);$
  }
}

This code is used in section 401.

408. Since Simpson's rule is based on approximating the integrand by a parabola, it is appropriate to use the same approximation to decide when the integral reaches the intermediate value *a_goal*. At this point

$$\frac{|\dot B(0)|}{3} = v0\,, \qquad \frac{|\dot B(\frac14)|}{3} = \frac{v002}{2}, \qquad \frac{|\dot B(\frac12)|}{3} = \frac{v02}{2},$$
$$\frac{|\dot B(\frac34)|}{3} = \frac{v022}{2}, \qquad \frac{|\dot B(1)|}{3} = v2$$

and

$$\frac{|\dot B(t)|}{3} \approx \begin{cases} B\left(v0\,, v002 - \frac12 v0 - \frac14 v02\,, \frac12 v02\,; 2t\right) & \text{if } t \le \frac12 \\ B\left(\frac12 v02\,, v022 - \frac14 v02 - \frac12 v2\,, v2\,; 2t-1\right) & \text{if } t \ge \frac12. \end{cases} \tag{$*$}$$

We can integrate $|\dot B(t)|$ by using

$$\int 3B(a,b,c;\tau)\,dt = \frac{B(0,a,a+b,a+b+c;\tau) + \text{constant}}{\frac{d\tau}{dt}}.$$

This construction allows us to find the time when the arc length reaches *a_goal* by solving a cubic equation of the form

$$B(0,a,a+b,a+b+c;\tau) = x,$$

where τ is $2t$ or $2t+1$, x is *a_goal* or *a_goal* − *arc1*, and a, b, and c are the Bernshteĭn coefficients from ($*$) divided by $\frac{d\tau}{dt}$. We shall define a function *solve_rising_cubic* that finds τ given a, b, c, and x.

⟨ Estimate when the arc length reaches *a_goal* and set *arc_test* to that time minus *two* 408 ⟩ ≡

```
{
  mp_number tmp;
  mp_number tmp2;
  mp_number tmp3;
  mp_number tmp4;
  mp_number tmp5;
  new_number(tmp); new_number(tmp2); new_number(tmp3); new_number(tmp4);
  new_number(tmp5); number_clone(tmp, v02); number_add_scaled(tmp, 2); number_half(tmp);
  number_half(tmp);    ▷ (v02 + 2)/4 ◁
  if (number_lessequal(a_goal, arc1)) {
    number_clone(tmp2, v0); number_halfp(tmp2); set_number_from_substraction(tmp3, arc1, tmp2);
    number_substract(tmp3, tmp); mp_solve_rising_cubic(mp, &tmp5, tmp2, tmp3, tmp, a_goal);
    number_halfp(tmp5); set_number_to_unity(tmp3); number_substract(tmp5, tmp3);
    number_substract(tmp5, tmp3); number_clone(*ret, tmp5);
  }
  else {
    number_clone(tmp2, v2); number_halfp(tmp2); set_number_from_substraction(tmp3, arc, arc1);
    number_substract(tmp3, tmp); number_substract(tmp3, tmp2);
    set_number_from_substraction(tmp4, a_goal, arc1);
    mp_solve_rising_cubic(mp, &tmp5, tmp, tmp3, tmp2, tmp4); number_halfp(tmp5);
    set_number_to_unity(tmp2); set_number_to_unity(tmp3); number_half(tmp2);
    number_substract(tmp2, tmp3); number_substract(tmp2, tmp3);
    set_number_from_addition(*ret, tmp2, tmp5);
  }
  free_number(tmp); free_number(tmp2); free_number(tmp3); free_number(tmp4); free_number(tmp5);
  goto DONE;
}
```

This code is used in section 401.

409. Here is the *solve_rising_cubic* routine that finds the time t when

$$B(0, a, a + b, a + b + c; t) = x.$$

This routine is based on *crossing_point* but is simplified by the assumptions that $B(a, b, c; t) \ge 0$ for $0 \le t \le 1$ and that $0 \le x \le a + b + c$. If rounding error causes this condition to be violated slightly, we just ignore it and proceed with binary search. This finds a time when the function value reaches x and the slope is positive.

⟨Declarations 10⟩ +≡
```
static void mp_solve_rising_cubic(MP mp, mp_number *ret, mp_number a, mp_number
    b, mp_number c, mp_number x);
```

410.
```
void mp_solve_rising_cubic(MP mp, mp_number *ret, mp_number a_orig, mp_number
      b_orig, mp_number c_orig, mp_number x_orig)
{
  mp_number abc;
  mp_number a, b, c, x;    ▷ local versions of arguments ◁
  mp_number ab, bc, ac;    ▷ bisection results ◁
  mp_number t;    ▷ 2^k + q where unscaled answer is in [q2^{-k}, (q + 1)2^{-k}) ◁
  mp_number xx;    ▷ temporary for updating x ◁
  mp_number neg_x;    ▷ temporary for an if ◁
  if (number_negative(a_orig) ∨ number_negative(c_orig)) mp_confusion(mp, "rising?");
  new_number(t); new_number(abc); new_number(a); new_number(b); new_number(c); new_number(x);
  number_clone(a, a_orig); number_clone(b, b_orig); number_clone(c, c_orig); number_clone(x, x_orig);
  new_number(ab); new_number(bc); new_number(ac); new_number(xx); new_number(neg_x);
  set_number_from_addition(abc, a, b); number_add(abc, c);
  if (number_nonpositive(x)) {
    set_number_to_zero(*ret);
  }
  else if (number_greaterequal(x, abc)) {
    set_number_to_unity(*ret);
  }
  else {
    number_clone(t, epsilon_t);
    ⟨Rescale if necessary to make sure a, b, and c are all less than EL_GORDO div 3 412⟩;
    do {
      number_add(t, t); ⟨Subdivide the Bézier quadratic defined by a, b, c 411⟩;
      number_clone(xx, x); number_substract(xx, a); number_substract(xx, ab);
      number_substract(xx, ac); number_clone(neg_x, x); number_negate(neg_x);
      if (number_less(xx, neg_x)) {
        number_double(x); number_clone(b, ab); number_clone(c, ac);
      }
      else {
        number_add(x, xx); number_clone(a, ac); number_clone(b, bc); number_add(t, epsilon_t);
      }
    } while (number_less(t, unity_t));
    set_number_from_substraction(*ret, t, unity_t);
  }
  free_number(abc); free_number(t); free_number(a); free_number(b); free_number(c); free_number(ab);
  free_number(bc); free_number(ac); free_number(xx); free_number(x); free_number(neg_x);
}
```

411. ⟨ Subdivide the Bézier quadratic defined by a, b, c 411 ⟩ ≡
set_number_from_addition(ab, a, b); *number_half*(ab); *set_number_from_addition*(bc, b, c);
number_half(bc); *set_number_from_addition*(ac, ab, bc); *number_half*(ac);

This code is used in section 410.

412. The upper bound on a, b, and c:

#**define** *one_third_inf_t* ((**math_data** ∗) *mp*→*math*)→*one_third_inf_t*

⟨ Rescale if necessary to make sure a, b, and c are all less than `EL_GORDO` *div* 3 412 ⟩ ≡

```
while (number_greater(a, one_third_inf_t) ∨ number_greater(b, one_third_inf_t) ∨ number_greater(c,
        one_third_inf_t)) {
    number_halfp(a); number_half(b); number_halfp(c); number_halfp(x);
}
```

This code is used in section 410.

413. It is convenient to have a simpler interface to *arc_test* that requires no unnecessary arguments and ensures that each (dx, dy) pair has length less than *fraction_four*.

```
static void mp_do_arc_test(MP mp, mp_number *ret, mp_number dx0, mp_number
        dy0, mp_number dx1, mp_number dy1, mp_number dx2, mp_number dy2, mp_number
        a_goal)
{
    mp_number v0, v1, v2;    ▷ length of each (dx, dy) pair ◁
    mp_number v02;    ▷ twice the norm of the quadratic at t = 1/2 ◁
    new_number(v0); new_number(v1); new_number(v2); pyth_add(v0, dx0, dy0);
    pyth_add(v1, dx1, dy1); pyth_add(v2, dx2, dy2);
    if ((number_greaterequal(v0, fraction_four_t)) ∨ (number_greaterequal(v1,
            fraction_four_t)) ∨ (number_greaterequal(v2, fraction_four_t))) {
        mp→arith_error ← true;
        if (number_infinite(a_goal)) {
            set_number_to_inf(*ret);
        }
        else {
            set_number_to_unity(*ret); number_double(*ret); number_negate(*ret);
        }
    }
    else {
        mp_number arg1, arg2;
        new_number(v02); new_number(arg1); new_number(arg2);
        set_number_from_addition(arg1, dx0, dx2); number_half(arg1); number_add(arg1, dx1);
        set_number_from_addition(arg2, dy0, dy2); number_half(arg2); number_add(arg2, dy1);
        pyth_add(v02, arg1, arg2); free_number(arg1); free_number(arg2);
        mp_arc_test(mp, ret, dx0, dy0, dx1, dy1, dx2, dy2, v0, v02, v2, a_goal, arc_tol_k); free_number(v02);
    }
    free_number(v0); free_number(v1); free_number(v2);
}
```

414. Now it is easy to find the arc length of an entire path.

```
static void mp_get_arc_length(MP mp, mp_number *ret, mp_knot h)
{
  mp_knot p, q;   ▷ for traversing the path ◁
  mp_number a;   ▷ current arc length ◁
  mp_number a_tot;   ▷ total arc length ◁
  mp_number arg1, arg2, arg3, arg4, arg5, arg6;
  mp_number arcgoal;

  p ← h; new_number(a_tot); new_number(arg1); new_number(arg2); new_number(arg3);
  new_number(arg4); new_number(arg5); new_number(arg6); new_number(a); new_number(arcgoal);
  set_number_to_inf(arcgoal);
  while (mp_right_type(p) ≠ mp_endpoint) {
    q ← mp_next_knot(p); set_number_from_substraction(arg1, p→right_x, p→x_coord);
    set_number_from_substraction(arg2, p→right_y, p→y_coord);
    set_number_from_substraction(arg3, q→left_x, p→right_x);
    set_number_from_substraction(arg4, q→left_y, p→right_y);
    set_number_from_substraction(arg5, q→x_coord, q→left_x);
    set_number_from_substraction(arg6, q→y_coord, q→left_y);
    mp_do_arc_test(mp, &a, arg1, arg2, arg3, arg4, arg5, arg6, arcgoal); slow_add(a_tot, a, a_tot);
    if (q ≡ h) break;
    else p ← q;
  }
  free_number(arcgoal); free_number(a); free_number(arg1); free_number(arg2); free_number(arg3);
  free_number(arg4); free_number(arg5); free_number(arg6); check_arith( ); number_clone(*ret, a_tot);
  free_number(a_tot);
}
```

415. The inverse operation of finding the time on a path h when the arc length reaches some value *arc0* can also be accomplished via *do_arc_test*. Some care is required to handle very large times or negative times on cyclic paths. For non-cyclic paths, *arc0* values that are negative or too large cause *get_arc_time* to return 0 or the length of path h.

If *arc0* is greater than the arc length of a cyclic path h, the result is a time value greater than the length of the path. Since it could be much greater, we must be prepared to compute the arc length of path h and divide this into *arc0* to find how many multiples of the length of path h to add.

```
static void mp_get_arc_time(MP mp, mp_number *ret, mp_knot h, mp_number arc0_orig)
{
  mp_knot p, q;     ▷ for traversing the path ◁
  mp_number t_tot;     ▷ accumulator for the result ◁
  mp_number t;     ▷ the result of do_arc_test ◁
  mp_number arc, arc0;     ▷ portion of arc0 not used up so far ◁
  mp_number arg1, arg2, arg3, arg4, arg5, arg6;     ▷ do_arc_test arguments ◁
  if (number_negative(arc0_orig)) {
    ⟨Deal with a negative arc0_orig value and return 417⟩;
  }
  new_number(t_tot); new_number(arc0); number_clone(arc0, arc0_orig);
  if (number_infinite(arc0)) {
    number_add_scaled(arc0, −1);
  }
  new_number(arc); number_clone(arc, arc0); p ← h; new_number(arg1); new_number(arg2);
  new_number(arg3); new_number(arg4); new_number(arg5); new_number(arg6); new_number(t);
  while ((mp_right_type(p) ≠ mp_endpoint) ∧ number_positive(arc)) {
    q ← mp_next_knot(p); set_number_from_substraction(arg1, p→right_x, p→x_coord);
    set_number_from_substraction(arg2, p→right_y, p→y_coord);
    set_number_from_substraction(arg3, q→left_x, p→right_x);
    set_number_from_substraction(arg4, q→left_y, p→right_y);
    set_number_from_substraction(arg5, q→x_coord, q→left_x);
    set_number_from_substraction(arg6, q→y_coord, q→left_y);
    mp_do_arc_test(mp, &t, arg1, arg2, arg3, arg4, arg5, arg6, arc);
    ⟨Update arc and t_tot after do_arc_test has just returned t 416⟩;
    if (q ≡ h) ⟨Update t_tot and arc to avoid going around the cyclic path too many times but set
          arith_error ← true and goto done on overflow 418⟩
    p ← q;
  }
  check_arith(); number_clone(*ret, t_tot);
RETURN: free_number(t_tot); free_number(t); free_number(arc); free_number(arc0); free_number(arg1);
  free_number(arg2); free_number(arg3); free_number(arg4); free_number(arg5); free_number(arg6);
}
```

416. ⟨Update *arc* and *t_tot* after *do_arc_test* has just returned t 416⟩ ≡

```
if (number_negative(t)) {
  number_add(t_tot, t); number_add(t_tot, two_t); set_number_to_zero(arc);
}
else {
  number_add(t_tot, unity_t); number_substract(arc, t);
}
```

This code is used in section 415.

417. ⟨ Deal with a negative *arc0_orig* value and **return** 417 ⟩ ≡

```
{
  if (mp_left_type(h) ≡ mp_endpoint) {
    set_number_to_zero(*ret);
  }
  else {
    mp_number neg_arc0;
    p ← mp_htap_ypoc(mp, h); new_number(neg_arc0); number_clone(neg_arc0, arc0_orig);
    number_negate(neg_arc0); mp_get_arc_time(mp, ret, p, neg_arc0); number_negate(*ret);
    mp_toss_knot_list(mp, p); free_number(neg_arc0);
  }
  check_arith(); return;
}
```

This code is used in section 415.

418. ⟨ Update *t_tot* and *arc* to avoid going around the cyclic path too many times but set *arith_error* ← *true* and **goto** *done* on overflow 418 ⟩ ≡

```
if (number_positive(arc)) {
  mp_number n, n1, d1, v1;
  new_number(n); new_number(n1); new_number(d1); new_number(v1);
  set_number_from_substraction(d1, arc0, arc);    ▷ d1 ← arc0 − arc ◁
  if (number_greater(d1, arc)) {
    set_number_to_zero(n1);    ▷ n1 ← 0 ◁
  }
  else {
    set_number_from_div(n1, arc, d1);    ▷ n1 ← (arc/d1) ◁
    floor_scaled(n1);
  }
  number_clone(n, n1); set_number_from_mul(n1, n1, d1);    ▷ n1 ← (n1 ∗ d1) ◁
  number_substract(arc, n1);    ▷ arc ← arc − n1 ◁
  number_clone(d1, inf_t);    ▷ reuse d1 ◁
  number_clone(v1, n);    ▷ v1 ← n ◁
  set_number_from_int(v1, number_to_int(v1) + 1);    ▷ v1 ← n1 + 1 ◁
  set_number_from_div(d1, d1, v1);    ▷ d1 ← EL_GORDO/v1 ◁
  if (number_greater(t_tot, d1)) {
    mp→arith_error ← true; check_arith(); set_number_to_inf(*ret); free_number(n); free_number(n1);
    free_number(d1); free_number(v1); goto RETURN;
  }
  set_number_from_mul(t_tot, t_tot, v1); free_number(n); free_number(n1); free_number(d1);
  free_number(v1);
}
```

This code is used in section 415.

419. Data structures for pens. A Pen in METAPOST can be either elliptical or polygonal. Elliptical pens result in PostScript **stroke** commands, while anything drawn with a polygonal pen is converted into an area fill as described in the next part of this program. The mathematics behind this process is based on simple aspects of the theory of tracings developed by Leo Guibas, Lyle Ramshaw, and Jorge Stolfi ["A kinematic framework for computational geometry," Proc. IEEE Symp. Foundations of Computer Science **24** (1983), 100–111].

Polygonal pens are created from paths via METAPOST's **makepen** primitive. This path representation is almost sufficient for our purposes except that a pen path should always be a convex polygon with the vertices in counter-clockwise order. Since we will need to scan pen polygons both forward and backward, a pen should be represented as a doubly linked ring of knot nodes. There is room for the extra back pointer because we do not need the *mp_left_type* or *mp_right_type* fields. In fact, we don't need the *left_x*, *left_y*, *right_x*, or *right_y* fields either but we leave these alone so that certain procedures can operate on both pens and paths. In particular, pens can be copied using *copy_path* and recycled using *toss_knot_list*.

420. The *make_pen* procedure turns a path into a pen by initializing the *prev_knot* pointers and making sure the knots form a convex polygon. Thus each cubic in the given path becomes a straight line and the control points are ignored. If the path is not cyclic, the ends are connected by a straight line.

```
#define copy_pen(A) mp_make_pen(mp, mp_copy_path(mp, (A)), false)
  static mp_knot mp_make_pen(MP mp, mp_knot h, boolean need_hull)
  {
    mp_knot p, q;    ▷ two consecutive knots ◁
    q ← h;
    do {
      p ← q; q ← mp_next_knot(q); mp_prev_knot(q) ← p;
    } while (q ≠ h);
    if (need_hull) {
      h ← mp_convex_hull(mp, h); ⟨Make sure h isn't confused with an elliptical pen 422⟩;
    }
    return h;
  }
```

421. The only information required about an elliptical pen is the overall transformation that has been applied to the original **pencircle**. Since it suffices to keep track of how the three points $(0,0)$, $(1,0)$, and $(0,1)$ are transformed, an elliptical pen can be stored in a single knot node and transformed as if it were a path.

```
#define pen_is_elliptical(A) ((A) ≡ mp_next_knot((A)))
  static mp_knot mp_get_pen_circle(MP mp, mp_number diam)
  {
    mp_knot h;    ▷ the knot node to return ◁
    h ← mp_new_knot(mp); mp_next_knot(h) ← h; mp_prev_knot(h) ← h;
    mp_originator(h) ← mp_program_code; set_number_to_zero(h→x_coord);
    set_number_to_zero(h→y_coord); number_clone(h→left_x, diam); set_number_to_zero(h→left_y);
    set_number_to_zero(h→right_x); number_clone(h→right_y, diam); return h;
  }
```

422. If the polygon being returned by *make_pen* has only one vertex, it will be interpreted as an elliptical pen. This is no problem since a degenerate polygon can equally well be thought of as a degenerate ellipse. We need only initialize the *left_x*, *left_y*, *right_x*, and *right_y* fields.

⟨ Make sure h isn't confused with an elliptical pen 422 ⟩ ≡

```
if (pen_is_elliptical(h)) {
   number_clone(h→left_x, h→x_coord);  number_clone(h→left_y, h→y_coord);
   number_clone(h→right_x, h→x_coord);  number_clone(h→right_y, h→y_coord);
}
```

This code is used in section 420.

423. Printing a polygonal pen is very much like printing a path

⟨ Declarations 10 ⟩ +≡

```
static void mp_pr_pen(MP mp, mp_knot h);
```

424.

```
void mp_pr_pen(MP mp, mp_knot h)
{
   mp_knot p, q;     ▷ for list traversal ◁
   if (pen_is_elliptical(h)) ⟨ Print the elliptical pen h 426 ⟩
   else {
      p ← h;
      do {
         mp_print_two(mp, p→x_coord, p→y_coord);  mp_print_nl(mp, "␣..␣");
         ⟨ Advance p making sure the links are OK and return if there is a problem 425 ⟩;
      } while (p ≠ h);
      mp_print(mp, "cycle");
   }
}
```

425. ⟨ Advance p making sure the links are OK and **return** if there is a problem 425 ⟩ ≡

```
q ← mp_next_knot(p);
if ((q ≡ Λ) ∨ (mp_prev_knot(q) ≠ p)) {
   mp_print_nl(mp, "???");  return;     ▷ this won't happen ◁
}
p ← q
```

This code is used in section 424.

426. ⟨ Print the elliptical pen h 426 ⟩ ≡

```
{
   mp_number v1;
   new_number(v1);  mp_print(mp, "pencircle␣transformed␣(");  print_number(h→x_coord);
   mp_print_char(mp, xord(',');  print_number(h→y_coord);  mp_print_char(mp, xord(','));
   set_number_from_substraction(v1, h→left_x, h→x_coord);  print_number(v1);
   mp_print_char(mp, xord(','));  set_number_from_substraction(v1, h→right_x, h→x_coord);
   print_number(v1);  mp_print_char(mp, xord(','));
   set_number_from_substraction(v1, h→left_y, h→y_coord);  print_number(v1);
   mp_print_char(mp, xord(','));  set_number_from_substraction(v1, h→right_y, h→y_coord);
   print_number(v1);  mp_print_char(mp, xord(')'));  free_number(v1);
}
```

This code is used in section 424.

427. Here us another version of *pr_pen* that prints the pen as a diagnostic message.

⟨ Declarations 10 ⟩ +≡
static void *mp_print_pen*(**MP** *mp*, **mp_knot** *h*, **const char** ∗*s*, **boolean** *nuline*);

428. **void** *mp_print_pen*(**MP** *mp*, **mp_knot** *h*, **const char** ∗*s*, **boolean** *nuline*)

```
{
  mp_print_diagnostic(mp, "Pen", s, nuline); mp_print_ln(mp); mp_pr_pen(mp, h);
  mp_end_diagnostic(mp, true);
}
```

429. Making a polygonal pen into a path involves restoring the *mp_left_type* and *mp_right_type* fields and setting the control points so as to make a polygonal path.

```
static void mp_make_path(MP mp, mp_knot h)
{
  mp_knot p;   ▷ for traversing the knot list ◁
  quarterword k;   ▷ a loop counter ◁
  ⟨ Other local variables in make_path 433 ⟩;
  FUNCTION_TRACE1("make_path()\n");
  if (pen_is_elliptical(h)) {
    FUNCTION_TRACE1("make_path(elliptical)\n"); ⟨ Make the elliptical pen h into a path 431 ⟩;
  }
  else {
    p ← h;
    do {
      mp_left_type(p) ← mp_explicit; mp_right_type(p) ← mp_explicit;
      ⟨ Copy the coordinates of knot p into its control points 430 ⟩;
      p ← mp_next_knot(p);
    } while (p ≠ h);
  }
}
```

430. ⟨ Copy the coordinates of knot *p* into its control points 430 ⟩ ≡

```
number_clone(p→left_x, p→x_coord); number_clone(p→left_y, p→y_coord);
number_clone(p→right_x, p→x_coord); number_clone(p→right_y, p→y_coord)
```

This code is used in section 429.

431. We need an eight knot path to get a good approximation to an ellipse.

⟨ Make the elliptical pen h into a path 431 ⟩ ≡

```
{
  mp_number center_x, center_y;   ▷ translation parameters for an elliptical pen ◁
  mp_number width_x, width_y;   ▷ the effect of a unit change in x ◁
  mp_number height_x, height_y;   ▷ the effect of a unit change in y ◁
  mp_number dx, dy;   ▷ the vector from knot p to its right control point ◁
  new_number(center_x); new_number(center_y); new_number(width_x); new_number(width_y);
  new_number(height_x); new_number(height_y); new_number(dx); new_number(dy);
  ⟨ Extract the transformation parameters from the elliptical pen h 432 ⟩;
  p ← h;
  for (k ← 0; k ≤ 7; k++) {
    ⟨ Initialize p as the kth knot of a circle of unit diameter, transforming it appropriately 434 ⟩;
    if (k ≡ 7) mp_next_knot(p) ← h;
    else mp_next_knot(p) ← mp_new_knot(mp);
    p ← mp_next_knot(p);
  }
  free_number(dx); free_number(dy); free_number(center_x); free_number(center_y);
  free_number(width_x); free_number(width_y); free_number(height_x); free_number(height_y);
}
```

This code is used in section 429.

432. ⟨ Extract the transformation parameters from the elliptical pen h 432 ⟩ ≡

```
number_clone(center_x, h→x_coord); number_clone(center_y, h→y_coord);
set_number_from_substraction(width_x, h→left_x, center_x);
set_number_from_substraction(width_y, h→left_y, center_y);
set_number_from_substraction(height_x, h→right_x, center_x);
set_number_from_substraction(height_y, h→right_y, center_y);
```

This code is used in section 431.

433. ⟨ Other local variables in *make_path* 433 ⟩ ≡

```
integer kk;   ▷ k advanced 270° around the ring (cf. sin θ = cos(θ + 270)) ◁
```

This code is used in section 429.

434. The only tricky thing here are the tables *half_cos* and *d_cos* used to find the point $k/8$ of the way around the circle and the direction vector to use there.

⟨ Initialize p as the kth knot of a circle of unit diameter, transforming it appropriately 434 ⟩ ≡
kk ← $(k+6)$ % 8;
{
mp_number *r1*, *r2*;
new_fraction(*r1*); *new_fraction*(*r2*); *take_fraction*(*r1*, *mp→half_cos*[*k*], *width_x*);
take_fraction(*r2*, *mp→half_cos*[*kk*], *height_x*); *number_add*(*r1*, *r2*);
set_number_from_addition(*p→x_coord*, *center_x*, *r1*); *take_fraction*(*r1*, *mp→half_cos*[*k*], *width_y*);
take_fraction(*r2*, *mp→half_cos*[*kk*], *height_y*); *number_add*(*r1*, *r2*);
set_number_from_addition(*p→y_coord*, *center_y*, *r1*); *take_fraction*(*r1*, *mp→d_cos*[*kk*], *width_x*);
take_fraction(*r2*, *mp→d_cos*[*k*], *height_x*); *number_clone*(*dx*, *r1*); *number_negate*(*dx*);
number_add(*dx*, *r2*); *take_fraction*(*r1*, *mp→d_cos*[*kk*], *width_y*);
take_fraction(*r2*, *mp→d_cos*[*k*], *height_y*); *number_clone*(*dy*, *r1*); *number_negate*(*dy*);
number_add(*dy*, *r2*); *set_number_from_addition*(*p→right_x*, *p→x_coord*, *dx*);
set_number_from_addition(*p→right_y*, *p→y_coord*, *dy*);
set_number_from_substraction(*p→left_x*, *p→x_coord*, *dx*);
set_number_from_substraction(*p→left_y*, *p→y_coord*, *dy*); *free_number*(*r1*); *free_number*(*r2*);
}
mp_left_type(*p*) ← *mp_explicit*; *mp_right_type*(*p*) ← *mp_explicit*; *mp_originator*(*p*) ← *mp_program_code*

This code is used in section 431.

435. ⟨ Global variables 18 ⟩ +≡
mp_number *half_cos*[8]; ▷ $\frac{1}{2}\cos(45k)$ ◁
mp_number *d_cos*[8]; ▷ a magic constant times $\cos(45k)$ ◁

436. The magic constant for *d_cos* is the distance between $(\frac{1}{2}, 0)$ and $(\frac{1}{4}\sqrt{2}, \frac{1}{4}\sqrt{2})$ times the result of the *velocity* function for $\theta = \phi = 22.5°$. This comes out to be

$$d = \frac{\sqrt{2-\sqrt{2}}}{3 + 3\cos 22.5°} \approx 0.132608244919772.$$

⟨ Set initial values of key variables 42 ⟩ +≡
for (k ← 0; $k \le 7$; k++) {
new_fraction(*mp→half_cos*[*k*]); *new_fraction*(*mp→d_cos*[*k*]);
}
number_clone(*mp→half_cos*[0], *fraction_half_t*); *number_clone*(*mp→half_cos*[1], *twentysixbits_sqrt2_t*);
number_clone(*mp→half_cos*[2], *zero_t*); *number_clone*(*mp→d_cos*[0], *twentyeightbits_d_t*);
number_clone(*mp→d_cos*[1], *twentysevenbits_sqrt2_d_t*); *number_clone*(*mp→d_cos*[2], *zero_t*);
for (k ← 3; $k \le 4$; k++) {
number_clone(*mp→half_cos*[*k*], *mp→half_cos*[4 − *k*]); *number_negate*(*mp→half_cos*[*k*]);
number_clone(*mp→d_cos*[*k*], *mp→d_cos*[4 − *k*]); *number_negate*(*mp→d_cos*[*k*]);
}
for (k ← 5; $k \le 7$; k++) {
number_clone(*mp→half_cos*[*k*], *mp→half_cos*[8 − *k*]); *number_clone*(*mp→d_cos*[*k*], *mp→d_cos*[8 − *k*]);
}

437. ⟨ Dealloc variables 31 ⟩ +≡
for (k ← 0; $k \le 7$; k++) {
free_number(*mp→half_cos*[*k*]); *free_number*(*mp→d_cos*[*k*]);
}

438. The *convex_hull* function forces a pen polygon to be convex when it is returned by *make_pen* and after any subsequent transformation where rounding error might allow the convexity to be lost. The convex hull algorithm used here is described by F. P. Preparata and M. I. Shamos [*Computational Geometry*, Springer-Verlag, 1985].

⟨ Declarations 10 ⟩ +≡
  static mp_knot *mp_convex_hull*(**MP** *mp*, **mp_knot** *h*);

439. **mp_knot** *mp_convex_hull*(**MP** *mp*, **mp_knot** *h*)
  { ▷ Make a polygonal pen convex ◁
    mp_knot *l*, *r*; ▷ the leftmost and rightmost knots ◁
    mp_knot *p*, *q*; ▷ knots being scanned ◁
    mp_knot *s*; ▷ the starting point for an upcoming scan ◁
    mp_number *dx*, *dy*; ▷ a temporary pointer ◁
    mp_knot *ret*;
    new_number(*dx*); *new_number*(*dy*);
    if (*pen_is_elliptical*(*h*)) {
      ret ← *h*;
    }
    else {
      ⟨ Set *l* to the leftmost knot in polygon *h* 440 ⟩;
      ⟨ Set *r* to the rightmost knot in polygon *h* 441 ⟩;
      if ($l \neq r$) {
        s ← *mp_next_knot*(*r*);
        ⟨ Find any knots on the path from *l* to *r* above the *l*-*r* line and move them past *r* 442 ⟩;
        ⟨ Find any knots on the path from *s* to *l* below the *l*-*r* line and move them past *l* 445 ⟩;
        ⟨ Sort the path from *l* to *r* by increasing *x* 446 ⟩;
        ⟨ Sort the path from *r* to *l* by decreasing *x* 447 ⟩;
      }
      if ($l \neq$ *mp_next_knot*(*l*)) ⟨ Do a Gramm scan and remove vertices where there is no left turn 448 ⟩
      ret ← *l*;
    }
    free_number(*dx*); *free_number*(*dy*); **return** *ret*;
  }

440. All comparisons are done primarily on *x* and secondarily on *y*.

⟨ Set *l* to the leftmost knot in polygon *h* 440 ⟩ ≡
  l ← *h*; *p* ← *mp_next_knot*(*h*);
  while ($p \neq h$) {
    if (*number_lessequal*(*p*→*x_coord*, *l*→*x_coord*))
      if ((*number_less*(*p*→*x_coord*, *l*→*x_coord*)) ∨ (*number_less*(*p*→*y_coord*, *l*→*y_coord*))) *l* ← *p*;
    p ← *mp_next_knot*(*p*);
  }

This code is used in section 439.

441. ⟨ Set r to the rightmost knot in polygon h 441 ⟩ ≡

```
r ← h; p ← mp_next_knot(h);
while (p ≠ h) {
  if (number_greaterequal(p→x_coord, r→x_coord))
    if (number_greater(p→x_coord, r→x_coord) ∨ number_greater(p→y_coord, r→y_coord)) r ← p;
  p ← mp_next_knot(p);
}
```

This code is used in section 439.

442. ⟨ Find any knots on the path from l to r above the l-r line and move them past r 442 ⟩ ≡

```
{
  mp_number ab_vs_cd;
  mp_number arg1, arg2;
  new_number(arg1); new_number(arg2); new_number(ab_vs_cd);
  set_number_from_substraction(dx, r→x_coord, l→x_coord);
  set_number_from_substraction(dy, r→y_coord, l→y_coord); p ← mp_next_knot(l);
  while (p ≠ r) {
    q ← mp_next_knot(p); set_number_from_substraction(arg1, p→y_coord, l→y_coord);
    set_number_from_substraction(arg2, p→x_coord, l→x_coord); ab_vs_cd(ab_vs_cd, dx, arg1, dy, arg2);
    if (number_positive(ab_vs_cd)) mp_move_knot(mp, p, r);
    p ← q;
  }
  free_number(ab_vs_cd); free_number(arg1); free_number(arg2);
}
```

This code is used in section 439.

443. The *mp_move_knot* procedure removes p from a doubly linked list and inserts it after q.

⟨ Declarations 10 ⟩ +≡

```
static void mp_move_knot(MP mp, mp_knot p, mp_knot q);
```

444.

```
void mp_move_knot(MP mp, mp_knot p, mp_knot q)
{
  (void) mp; mp_next_knot(mp_prev_knot(p)) ← mp_next_knot(p);
  mp_prev_knot(mp_next_knot(p)) ← mp_prev_knot(p); mp_prev_knot(p) ← q;
  mp_next_knot(p) ← mp_next_knot(q); mp_next_knot(q) ← p; mp_prev_knot(mp_next_knot(p)) ← p;
}
```

445. ⟨ Find any knots on the path from s to l below the l-r line and move them past l 445 ⟩ ≡

```
{
  mp_number ab_vs_cd;
  mp_number arg1, arg2;
  new_number(ab_vs_cd); new_number(arg1); new_number(arg2); p ← s;
  while (p ≠ l) {
    q ← mp_next_knot(p); set_number_from_substraction(arg1, p→y_coord, l→y_coord);
    set_number_from_substraction(arg2, p→x_coord, l→x_coord); ab_vs_cd(ab_vs_cd, dx, arg1, dy, arg2);
    if (number_negative(ab_vs_cd)) mp_move_knot(mp, p, l);
    p ← q;
  }
  free_number(ab_vs_cd); free_number(arg1); free_number(arg2);
}
```

This code is used in section 439.

446. The list is likely to be in order already so we just do linear insertions. Secondary comparisons on y ensure that the sort is consistent with the choice of l and r.

⟨ Sort the path from l to r by increasing x 446 ⟩ ≡

```
p ← mp_next_knot(l);
while (p ≠ r) {
  q ← mp_prev_knot(p);
  while (number_greater(q→x_coord, p→x_coord)) q ← mp_prev_knot(q);
  while (number_equal(q→x_coord, p→x_coord)) {
    if (number_greater(q→y_coord, p→y_coord)) q ← mp_prev_knot(q);
    else break;
  }
  if (q ≡ mp_prev_knot(p)) {
    p ← mp_next_knot(p);
  }
  else {
    p ← mp_next_knot(p); mp_move_knot(mp, mp_prev_knot(p), q);
  }
}
```

This code is used in section 439.

447. ⟨ Sort the path from r to l by decreasing x 447 ⟩ ≡

```
p ← mp_next_knot(r);
while (p ≠ l) {
  q ← mp_prev_knot(p);
  while (number_less(q→x_coord, p→x_coord)) q ← mp_prev_knot(q);
  while (number_equal(q→x_coord, p→x_coord)) {
    if (number_less(q→y_coord, p→y_coord)) q ← mp_prev_knot(q);
    else break;
  }
  if (q ≡ mp_prev_knot(p)) {
    p ← mp_next_knot(p);
  }
  else {
    p ← mp_next_knot(p); mp_move_knot(mp, mp_prev_knot(p), q);
  }
}
```

This code is used in section 439.

448. The condition involving *ab_vs_cd* tests if there is not a left turn at knot q. There usually will be a left turn so we streamline the case where the *then* clause is not executed.

⟨ Do a Gramm scan and remove vertices where there is no left turn 448 ⟩ ≡

```
{
  mp_number ab_vs_cd;
  mp_number arg1, arg2;
  new_number(arg1); new_number(arg2); new_number(ab_vs_cd); p ← l; q ← mp_next_knot(l);
  while (1) {
    set_number_from_substraction(dx, q→x_coord, p→x_coord);
    set_number_from_substraction(dy, q→y_coord, p→y_coord); p ← q; q ← mp_next_knot(q);
    if (p ≡ l) break;
    if (p ≠ r) {
      set_number_from_substraction(arg1, q→y_coord, p→y_coord);
      set_number_from_substraction(arg2, q→x_coord, p→x_coord); ab_vs_cd(ab_vs_cd, dx, arg1, dy, arg2);
      if (number_nonpositive(ab_vs_cd)) ⟨ Remove knot p and back up p and q but don't go past l 449 ⟩
    }
  }
  free_number(ab_vs_cd); free_number(arg1); free_number(arg2);
}
```

This code is used in section 439.

449. ⟨ Remove knot p and back up p and q but don't go past l 449 ⟩ ≡

```
{
  s ← mp_prev_knot(p); mp_xfree(p); mp_next_knot(s) ← q; mp_prev_knot(q) ← s;
  if (s ≡ l) {
    p ← s;
  }
  else {
    p ← mp_prev_knot(s); q ← s;
  }
}
```

This code is used in section 448.

450. The *find_offset* procedure sets global variables (*cur_x*, *cur_y*) to the offset associated with the given direction (x, y). If two different offsets apply, it chooses one of them.

static void *mp_find_offset*(**MP** *mp*, **mp_number** *x_orig*, **mp_number** *y_orig*, **mp_knot** *h*)
{
  mp_knot *p*, *q*; ▷ consecutive knots ◁
  if (*pen_is_elliptical*(*h*)) {
    mp_fraction *xx*, *yy*; ▷ untransformed offset for an elliptical pen ◁
    mp_number *wx*, *wy*, *hx*, *hy*; ▷ the transformation matrix for an elliptical pen ◁
    mp_fraction *d*; ▷ a temporary register ◁
    new_fraction(*xx*); *new_fraction*(*yy*); *new_number*(*wx*); *new_number*(*wy*); *new_number*(*hx*);
    new_number(*hy*); *new_fraction*(*d*);
    ⟨Find the offset for (x, y) on the elliptical pen *h* 454⟩ *free_number*(*xx*); *free_number*(*yy*);
    free_number(*wx*); *free_number*(*wy*); *free_number*(*hx*); *free_number*(*hy*); *free_number*(*d*);
  }
  else {
    mp_number *ab_vs_cd*;
    mp_number *arg1*, *arg2*;
    new_number(*arg1*); *new_number*(*arg2*); *new_number*(*ab_vs_cd*); *q* ← *h*;
    do {
      p ← *q*; *q* ← *mp_next_knot*(*q*); *set_number_from_substraction*(*arg1*, *q*→*x_coord*, *p*→*x_coord*);
      set_number_from_substraction(*arg2*, *q*→*y_coord*, *p*→*y_coord*);
      ab_vs_cd(*ab_vs_cd*, *arg1*, *y_orig*, *arg2*, *x_orig*);
    } **while** (*number_negative*(*ab_vs_cd*));
    do {
      p ← *q*; *q* ← *mp_next_knot*(*q*); *set_number_from_substraction*(*arg1*, *q*→*x_coord*, *p*→*x_coord*);
      set_number_from_substraction(*arg2*, *q*→*y_coord*, *p*→*y_coord*);
      ab_vs_cd(*ab_vs_cd*, *arg1*, *y_orig*, *arg2*, *x_orig*);
    } **while** (*number_positive*(*ab_vs_cd*));
    number_clone(*mp*→*cur_x*, *p*→*x_coord*); *number_clone*(*mp*→*cur_y*, *p*→*y_coord*); *free_number*(*ab_vs_cd*);
    free_number(*arg1*); *free_number*(*arg2*);
  }
}

451. ⟨Global variables 18⟩ +≡
mp_number *cur_x*;
mp_number *cur_y*; ▷ all-purpose return value registers ◁

452. ⟨Initialize table entries 186⟩ +≡
new_number(*mp*→*cur_x*); *new_number*(*mp*→*cur_y*);

453. ⟨Dealloc variables 31⟩ +≡
free_number(*mp*→*cur_x*); *free_number*(*mp*→*cur_y*);

454. ⟨ Find the offset for (x, y) on the elliptical pen h 454 ⟩ ≡

```
if (number_zero(x_orig) ∧ number_zero(y_orig)) {
  number_clone(mp→cur_x, h→x_coord); number_clone(mp→cur_y, h→y_coord);
}
else {
  mp_number x, y, abs_x, abs_y;
  new_number(x); new_number(y); new_number(abs_x); new_number(abs_y); number_clone(x, x_orig);
  number_clone(y, y_orig); ⟨ Find the non-constant part of the transformation for h 455 ⟩;
  number_clone(abs_x, x); number_clone(abs_y, y); number_abs(abs_x); number_abs(abs_y);
  while (number_less(abs_x, fraction_half_t) ∧ number_less(abs_y, fraction_half_t)) {
    number_double(x); number_double(y); number_clone(abs_x, x); number_clone(abs_y, y);
    number_abs(abs_x); number_abs(abs_y);
  }
  ⟨ Make (xx, yy) the offset on the untransformed pencircle for the untransformed version of (x, y) 456 ⟩;
  {
    mp_number r1, r2;
    new_fraction(r1); new_fraction(r2); take_fraction(r1, xx, wx); take_fraction(r2, yy, hx);
    number_add(r1, r2); set_number_from_addition(mp→cur_x, h→x_coord, r1); take_fraction(r1, xx, wy);
    take_fraction(r2, yy, hy); number_add(r1, r2); set_number_from_addition(mp→cur_y, h→y_coord, r1);
    free_number(r1); free_number(r2);
  }
  free_number(abs_x); free_number(abs_y); free_number(x); free_number(y);
}
```

This code is used in section 450.

455. ⟨ Find the non-constant part of the transformation for h 455 ⟩ ≡

```
{
  set_number_from_substraction(wx, h→left_x, h→x_coord);
  set_number_from_substraction(wy, h→left_y, h→y_coord);
  set_number_from_substraction(hx, h→right_x, h→x_coord);
  set_number_from_substraction(hy, h→right_y, h→y_coord);
}
```

This code is used in section 454.

456. ⟨ Make (xx, yy) the offset on the untransformed **pencircle** for the untransformed version of (x, y) 456 ⟩ ≡

```
{
  mp_number r1, r2, arg1;
  new_number(arg1); new_fraction(r1); new_fraction(r2); take_fraction(r1, x, hy);
  number_clone(arg1, hx); number_negate(arg1); take_fraction(r2, y, arg1); number_add(r1, r2);
  number_negate(r1); number_clone(yy, r1); number_clone(arg1, wy); number_negate(arg1);
  take_fraction(r1, x, arg1); take_fraction(r2, y, wx); number_add(r1, r2); number_clone(xx, r1);
  free_number(arg1); free_number(r1); free_number(r2);
}
pyth_add(d, xx, yy);
if (number_positive(d)) {
  mp_number ret;
  new_fraction(ret); make_fraction(ret, xx, d); number_half(ret); number_clone(xx, ret);
  make_fraction(ret, yy, d); number_half(ret); number_clone(yy, ret); free_number(ret);
}
```

This code is used in section 454.

457. Finding the bounding box of a pen is easy except if the pen is elliptical. But we can handle that case by just calling *find_offset* twice. The answer is stored in the global variables *minx*, *maxx*, *miny*, and *maxy*.

```
static void mp_pen_bbox(MP mp, mp_knot h)
{
  mp_knot p;    ▷ for scanning the knot list ◁
  if (pen_is_elliptical(h)) ⟨Find the bounding box of an elliptical pen 458⟩
  else {
    number_clone(mp_minx, h→x_coord); number_clone(mp_maxx, mp_minx);
    number_clone(mp_miny, h→y_coord); number_clone(mp_maxy, mp_miny); p ← mp_next_knot(h);
    while (p ≠ h) {
      if (number_less(p→x_coord, mp_minx)) number_clone(mp_minx, p→x_coord);
      if (number_less(p→y_coord, mp_miny)) number_clone(mp_miny, p→y_coord);
      if (number_greater(p→x_coord, mp_maxx)) number_clone(mp_maxx, p→x_coord);
      if (number_greater(p→y_coord, mp_maxy)) number_clone(mp_maxy, p→y_coord);
      p ← mp_next_knot(p);
    }
  }
}
```

458. ⟨Find the bounding box of an elliptical pen 458⟩ ≡

```
{
  mp_number arg1, arg2;
  new_number(arg1); new_fraction(arg2); number_clone(arg2, fraction_one_t);
  mp_find_offset(mp, arg1, arg2, h); number_clone(mp_maxx, mp→cur_x);
  number_clone(mp_minx, h→x_coord); number_double(mp_minx);
  number_substract(mp_minx, mp→cur_x); number_negate(arg2); mp_find_offset(mp, arg2, arg1, h);
  number_clone(mp_maxy, mp→cur_y); number_clone(mp_miny, h→y_coord); number_double(mp_miny);
  number_substract(mp_miny, mp→cur_y); free_number(arg1); free_number(arg2);
}
```

This code is used in section 457.

459. Numerical values.

This first set goes into the header

⟨ MPlib internal header stuff 8 ⟩ +≡

#define mp_fraction mp_number
#define mp_angle mp_number
#define *new_number*(*A*) (((**math_data** ∗)(*mp*→*math*))→*allocate*)(*mp*, &(*A*), *mp_scaled_type*)
#define *new_fraction*(*A*) (((**math_data** ∗)(*mp*→*math*))→*allocate*)(*mp*, &(*A*), *mp_fraction_type*)
#define *new_angle*(*A*) (((**math_data** ∗)(*mp*→*math*))→*allocate*)(*mp*, &(*A*), *mp_angle_type*)
#define *free_number*(*A*) (((**math_data** ∗)(*mp*→*math*))→*free*)(*mp*, &(*A*))

460.

#define $set\_precision()$ $(((\mathbf{math\_data}\ *)(mp\to math))\to set\_precision)(mp)$
#define $free\_math()$ $(((\mathbf{math\_data}\ *)(mp\to math))\to free\_math)(mp)$
#define $scan\_numeric\_token(A)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to scan\_numeric)(mp, A)$
#define $scan\_fractional\_token(A)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to scan\_fractional)(mp, A)$
#define $set\_number\_from\_of\_the\_way(A, t, B, C)$
$(((\mathbf{math\_data}\ *)(mp\to math))\to from\_oftheway)(mp, \&(A), t, B, C)$
#define $set\_number\_from\_int(A, B)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to from\_int)(\&(A), B)$
#define $set\_number\_from\_scaled(A, B)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to from\_scaled)(\&(A), B)$
#define $set\_number\_from\_boolean(A, B)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to from\_boolean)(\&(A), B)$
#define $set\_number\_from\_double(A, B)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to from\_double)(\&(A), B)$
#define $set\_number\_from\_addition(A, B, C)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to from\_addition)(\&(A), B, C)$
#define $set\_number\_from\_substraction(A, B, C)$
$(((\mathbf{math\_data}\ *)(mp\to math))\to from\_substraction)(\&(A), B, C)$
#define $set\_number\_from\_div(A, B, C)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to from\_div)(\&(A), B, C)$
#define $set\_number\_from\_mul(A, B, C)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to from\_mul)(\&(A), B, C)$
#define $number\_int\_div(A, C)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to from\_int\_div)(\&(A), A, C)$
#define $set\_number\_from\_int\_mul(A, B, C)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to from\_int\_mul)(\&(A), B, C)$

#define $set\_number\_to\_unity(A)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to clone)(\&(A), unity\_t)$
#define $set\_number\_to\_zero(A)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to clone)(\&(A), zero\_t)$
#define $set\_number\_to\_inf(A)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to clone)(\&(A), inf\_t)$
#define $set\_number\_to\_neg\_inf(A)$
do {
$set\_number\_to\_inf(A)$; $number\_negate(A)$;
} **while** (0)

#define $init\_randoms(A)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to init\_randoms)(mp, A)$
#define $print\_number(A)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to print)(mp, A)$
#define $number\_tostring(A)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to tostring)(mp, A)$
#define $make\_scaled(R, A, B)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to make\_scaled)(mp, \&(R), A, B)$
#define $take\_scaled(R, A, B)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to take\_scaled)(mp, \&(R), A, B)$
#define $make\_fraction(R, A, B)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to make\_fraction)(mp, \&(R), A, B)$
#define $take\_fraction(R, A, B)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to take\_fraction)(mp, \&(R), A, B)$
#define $pyth\_add(R, A, B)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to pyth\_add)(mp, \&(R), A, B)$
#define $pyth\_sub(R, A, B)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to pyth\_sub)(mp, \&(R), A, B)$
#define $n\_arg(R, A, B)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to n\_arg)(mp, \&(R), A, B)$
#define $m\_log(R, A)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to m\_log)(mp, \&(R), A)$
#define $m\_exp(R, A)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to m\_exp)(mp, \&(R), A)$
#define $m\_unif\_rand(R, A)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to m\_unif\_rand)(mp, \&(R), A)$
#define $m\_norm\_rand(R)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to m\_norm\_rand)(mp, \&(R))$
#define $velocity(R, A, B, C, D, E)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to velocity)(mp, \&(R), A, B, C, D, E)$
#define $ab\_vs\_cd(R, A, B, C, D)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to ab\_vs\_cd)(mp, \&(R), A, B, C, D)$
#define $crossing\_point(R, A, B, C)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to crossing\_point)(mp, \&(R), A, B, C)$
#define $n\_sin\_cos(A, S, C)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to sin\_cos)(mp, A, \&(S), \&(C))$
#define $square\_rt(A, S)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to sqrt)(mp, \&(A), S)$
#define $slow\_add(R, A, B)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to slow\_add)(mp, \&(R), A, B)$
#define $round\_unscaled(A)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to round\_unscaled)(A)$
#define $floor\_scaled(A)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to floor\_scaled)(\&(A))$
#define $fraction\_to\_round\_scaled(A)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to fraction\_to\_round\_scaled)(\&(A))$
#define $number\_to\_int(A)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to to\_int)(A)$
#define $number\_to\_boolean(A)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to to\_boolean)(A)$
#define $number\_to\_scaled(A)$ $(((\mathbf{math\_data}\ *)(mp\to math))\to to\_scaled)(A)$

#**define** $number\_to\_double(A)$ $(((\mathbf{math\_data}\ *)(mp\rightarrow math))\rightarrow to\_double)(A)$
#**define** $number\_negate(A)$ $(((\mathbf{math\_data}\ *)(mp\rightarrow math))\rightarrow negate)(\&(A))$
#**define** $number\_add(A,B)$ $(((\mathbf{math\_data}\ *)(mp\rightarrow math))\rightarrow add)(\&(A),B)$
#**define** $number\_substract(A,B)$ $(((\mathbf{math\_data}\ *)(mp\rightarrow math))\rightarrow substract)(\&(A),B)$
#**define** $number\_half(A)$ $(((\mathbf{math\_data}\ *)(mp\rightarrow math))\rightarrow half)(\&(A))$
#**define** $number\_halfp(A)$ $(((\mathbf{math\_data}\ *)(mp\rightarrow math))\rightarrow halfp)(\&(A))$
#**define** $number\_double(A)$ $(((\mathbf{math\_data}\ *)(mp\rightarrow math))\rightarrow do\_double)(\&(A))$
#**define** $number\_add\_scaled(A,B)$ $(((\mathbf{math\_data}\ *)(mp\rightarrow math))\rightarrow add\_scaled)(\&(A),B)$
#**define** $number\_multiply\_int(A,B)$ $(((\mathbf{math\_data}\ *)(mp\rightarrow math))\rightarrow multiply\_int)(\&(A),B)$
#**define** $number\_divide\_int(A,B)$ $(((\mathbf{math\_data}\ *)(mp\rightarrow math))\rightarrow divide\_int)(\&(A),B)$
#**define** $number\_abs(A)$ $(((\mathbf{math\_data}\ *)(mp\rightarrow math))\rightarrow abs)(\&(A))$
#**define** $number\_modulo(A,B)$ $(((\mathbf{math\_data}\ *)(mp\rightarrow math))\rightarrow modulo)(\&(A),B)$
#**define** $number\_nonequalabs(A,B)$ $(((\mathbf{math\_data}\ *)(mp\rightarrow math))\rightarrow nonequalabs)(A,B)$
#**define** $number\_odd(A)$ $(((\mathbf{math\_data}\ *)(mp\rightarrow math))\rightarrow odd)(A)$
#**define** $number\_equal(A,B)$ $(((\mathbf{math\_data}\ *)(mp\rightarrow math))\rightarrow equal)(A,B)$
#**define** $number\_greater(A,B)$ $(((\mathbf{math\_data}\ *)(mp\rightarrow math))\rightarrow greater)(A,B)$
#**define** $number\_less(A,B)$ $(((\mathbf{math\_data}\ *)(mp\rightarrow math))\rightarrow less)(A,B)$
#**define** $number\_clone(A,B)$ $(((\mathbf{math\_data}\ *)(mp\rightarrow math))\rightarrow clone)(\&(A),B)$
#**define** $number\_swap(A,B)$ $(((\mathbf{math\_data}\ *)(mp\rightarrow math))\rightarrow swap)(\&(A),\&(B));$
#**define** $convert\_scaled\_to\_angle(A)$ $(((\mathbf{math\_data}\ *)(mp\rightarrow math))\rightarrow scaled\_to\_angle)(\&(A));$
#**define** $convert\_angle\_to\_scaled(A)$ $(((\mathbf{math\_data}\ *)(mp\rightarrow math))\rightarrow angle\_to\_scaled)(\&(A));$
#**define** $convert\_fraction\_to\_scaled(A)$ $(((\mathbf{math\_data}\ *)(mp\rightarrow math))\rightarrow fraction\_to\_scaled)(\&(A));$
#**define** $convert\_scaled\_to\_fraction(A)$ $(((\mathbf{math\_data}\ *)(mp\rightarrow math))\rightarrow scaled\_to\_fraction)(\&(A));$
#**define** $m\_get\_left\_endpoint(R,A)$ $(((\mathbf{math\_data}\ *)(mp\rightarrow math))\rightarrow m\_get\_left\_endpoint)(mp,\&(R),A)$
▷ math interval new primitives ◁
#**define** $m\_get\_right\_endpoint(R,A)$ $(((\mathbf{math\_data}\ *)(mp\rightarrow math))\rightarrow m\_get\_right\_endpoint)(mp,\&(R),A)$
▷ math interval new primitives ◁
#**define** $m\_interval\_set(R,A,B)$ $(((\mathbf{math\_data}\ *)(mp\rightarrow math))\rightarrow m\_interval\_set)(mp,\&(R),A,B)$
▷ math interval new primitives ◁

#**define** $number\_zero(A)$ $number\_equal(A,zero\_t)$
#**define** $number\_infinite(A)$ $number\_equal(A,inf\_t)$
#**define** $number\_unity(A)$ $number\_equal(A,unity\_t)$
#**define** $number\_negative(A)$ $number\_less(A,zero\_t)$
#**define** $number\_nonnegative(A)$ $(\neg number\_negative(A))$
#**define** $number\_positive(A)$ $number\_greater(A,zero\_t)$
#**define** $number\_nonpositive(A)$ $(\neg number\_positive(A))$
#**define** $number\_nonzero(A)$ $(\neg number\_zero(A))$
#**define** $number\_greaterequal(A,B)$ $(\neg number\_less(A,B))$
#**define** $number\_lessequal(A,B)$ $(\neg number\_greater(A,B))$

461. Edge structures. Now we come to METAPOST's internal scheme for representing pictures. The representation is very different from METAFONT's edge structures because METAPOST pictures contain PostScript graphics objects instead of pixel images. However, the basic idea is somewhat similar in that shapes are represented via their boundaries.

The main purpose of edge structures is to keep track of graphical objects until it is time to translate them into PostScript. Since METAPOST does not need to know anything about an edge structure other than how to translate it into PostScript and how to find its bounding box, edge structures can be just linked lists of graphical objects. METAPOST has no easy way to determine whether two such objects overlap, but it suffices to draw the first one first and let the second one overwrite it if necessary.

⟨ MPlib header stuff 205 ⟩ +≡
```
enum mp_graphical_object_code {
  ⟨ Graphical object codes 463 ⟩
  mp_final_graphic
};
```

462. Let's consider the types of graphical objects one at a time. First of all, a filled contour is represented by a eight-word node. The first word contains *type* and *link* fields, and the next six words contain a pointer to a cyclic path and the value to use for PostScript' **currentrgbcolor** parameter. If a pen is used for filling *pen_p*, *ljoin* and *miterlim* give the relevant information.

```
#define mp_path_p(A) (A)→path_p_   ▷ a pointer to the path that needs filling ◁
#define mp_pen_p(A) (A)→pen_p_   ▷ a pointer to the pen to fill or stroke with ◁
#define mp_color_model(A) ((mp_fill_node)(A))→color_model_   ▷ the color model ◁
#define cyan red
#define grey red
#define magenta green
#define yellow blue
#define mp_pre_script(A) ((mp_fill_node)(A))→pre_script_
#define mp_post_script(A) ((mp_fill_node)(A))→post_script_
```

⟨ MPlib internal header stuff 8 ⟩ +≡
```
typedef struct mp_fill_node_data {
  NODE_BODY;
  halfword color_model_;
  mp_number red;
  mp_number green;
  mp_number blue;
  mp_number black;
  mp_string pre_script_;
  mp_string post_script_;
  mp_knot path_p_;
  mp_knot pen_p_;
  unsigned char ljoin;
  mp_number miterlim;
} mp_fill_node_data;
typedef struct mp_fill_node_data *mp_fill_node;
```

463. ⟨ Graphical object codes 463 ⟩ ≡
```
mp_fill_code ← 1,
```
See also sections 467, 473, 477, and 1262.

This code is used in section 461.

464. Make a fill node for cyclic path p and color black.

```
#define fill_node_size  sizeof(struct mp_fill_node_data)
  static mp_node mp_new_fill_node(MP mp, mp_knot p)
  {
    mp_fill_node t ← malloc_node(fill_node_size);
    mp_type(t) ← mp_fill_node_type; mp_path_p(t) ← p; mp_pen_p(t) ← Λ;   ▷ Λ means don't use a pen ◁
    new_number(t→red); new_number(t→green); new_number(t→blue); new_number(t→black);
    new_number(t→miterlim); clear_color(t); mp_color_model(t) ← mp_uninitialized_model;
    mp_pre_script(t) ← Λ; mp_post_script(t) ← Λ;   ▷ Set the ljoin and miterlim fields in object t ◁
    if (number_greater(internal_value(mp_linejoin), unity_t)) t→ljoin ← 2;
    else if (number_positive(internal_value(mp_linejoin))) t→ljoin ← 1;
    else t→ljoin ← 0;
    if (number_less(internal_value(mp_miterlimit), unity_t)) {
      set_number_to_unity(t→miterlim);
    }
    else {
      number_clone(t→miterlim, internal_value(mp_miterlimit));
    }
    return (mp_node) t;
  }
```

465.
```
static void mp_free_fill_node(MP mp, mp_fill_node p)
  {
    mp_toss_knot_list(mp, mp_path_p(p));
    if (mp_pen_p(p) ≠ Λ) mp_toss_knot_list(mp, mp_pen_p(p));
    if (mp_pre_script(p) ≠ Λ) delete_str_ref(mp_pre_script(p));
    if (mp_post_script(p) ≠ Λ) delete_str_ref(mp_post_script(p));
    free_number(p→red); free_number(p→green); free_number(p→blue); free_number(p→black);
    free_number(p→miterlim); mp_free_node(mp, (mp_node) p, fill_node_size);
  }
```

466. A stroked path is represented by an eight-word node that is like a filled contour node except that it contains the current **linecap** value, a scale factor for the dash pattern, and a pointer that is non-NULL if the stroke is to be dashed. The purpose of the scale factor is to allow a picture to be transformed without touching the picture that *dash_p* points to.

#define *mp_dash_p*(*A*) ((*mp_stroked_node*)(*A*))→*dash_p_*
▷ a pointer to the edge structure that gives the dash pattern ◁

⟨ MPlib internal header stuff 8 ⟩ +≡

```
typedef struct mp_stroked_node_data {
  NODE_BODY;
  halfword color_model_;
  mp_number red;
  mp_number green;
  mp_number blue;
  mp_number black;
  mp_string pre_script_;
  mp_string post_script_;
  mp_knot path_p_;
  mp_knot pen_p_;
  unsigned char ljoin;
  mp_number miterlim;
  unsigned char lcap;
  mp_node dash_p_;
  mp_number dash_scale;
} mp_stroked_node_data;
typedef struct mp_stroked_node_data *mp_stroked_node;
```

467. ⟨ Graphical object codes 463 ⟩ +≡
mp_stroked_code ← 2,

468. Make a stroked node for path p with *mp_pen_p*(p) temporarily Λ.

```
#define stroked_node_size sizeof(struct mp_stroked_node_data)
  static mp_node mp_new_stroked_node(MP mp, mp_knot p)
  {
    mp_stroked_node t ← malloc_node(stroked_node_size);
    mp_type(t) ← mp_stroked_node_type; mp_path_p(t) ← p; mp_pen_p(t) ← Λ; mp_dash_p(t) ← Λ;
    new_number(t→dash_scale); set_number_to_unity(t→dash_scale); new_number(t→red);
    new_number(t→green); new_number(t→blue); new_number(t→black); new_number(t→miterlim);
    clear_color(t); mp_pre_script(t) ← Λ; mp_post_script(t) ← Λ;
      ▷ Set the ljoin and miterlim fields in object t ◁
    if (number_greater(internal_value(mp_linejoin), unity_t)) t→ljoin ← 2;
    else if (number_positive(internal_value(mp_linejoin))) t→ljoin ← 1;
    else t→ljoin ← 0;
    if (number_less(internal_value(mp_miterlimit), unity_t)) {
      set_number_to_unity(t→miterlim);
    }
    else {
      number_clone(t→miterlim, internal_value(mp_miterlimit));
    }
    if (number_greater(internal_value(mp_linecap), unity_t)) t→lcap ← 2;
    else if (number_positive(internal_value(mp_linecap))) t→lcap ← 1;
    else t→lcap ← 0;
    return (mp_node) t;
  }
```

469.

```
  static mp_edge_header_node mp_free_stroked_node(MP mp, mp_stroked_node p)
  {
    mp_edge_header_node e ← Λ;
    mp_toss_knot_list(mp, mp_path_p(p));
    if (mp_pen_p(p) ≠ Λ) mp_toss_knot_list(mp, mp_pen_p(p));
    if (mp_pre_script(p) ≠ Λ) delete_str_ref(mp_pre_script(p));
    if (mp_post_script(p) ≠ Λ) delete_str_ref(mp_post_script(p));
    e ← (mp_edge_header_node) mp_dash_p(p); free_number(p→dash_scale); free_number(p→red);
    free_number(p→green); free_number(p→blue); free_number(p→black); free_number(p→miterlim);
    mp_free_node(mp, (mp_node) p, stroked_node_size); return e;
  }
```

470. When a dashed line is computed in a transformed coordinate system, the dash lengths get scaled like the pen shape and we need to compensate for this. Since there is no unique scale factor for an arbitrary transformation, we use the square root of the determinant. The properties of the determinant make it easier to maintain the *dash_scale*. The computation is fairly straight-forward except for the initialization of the scale factor *s*. The factor of 64 is needed because *square_rt* scales its result by 2^8 while we need 2^{14} to counteract the effect of *take_fraction*.

```
void mp_sqrt_det(MP mp, mp_number *ret, mp_number a_orig, mp_number b_orig, mp_number
        c_orig, mp_number d_orig)
{
  mp_number a, b, c, d;
  mp_number maxabs;   ▷ max(a, b, c, d) ◁
  unsigned s;   ▷ amount by which the result of square_rt needs to be scaled ◁
  new_number(a); new_number(b); new_number(c); new_number(d); new_number(maxabs);
  number_clone(a, a_orig); number_clone(b, b_orig); number_clone(c, c_orig); number_clone(d, d_orig);
    ▷ Initialize maxabs ◁
  {
    mp_number tmp;
    new_number(tmp); number_clone(maxabs, a); number_abs(maxabs); number_clone(tmp, b);
    number_abs(tmp);
    if (number_greater(tmp, maxabs)) number_clone(maxabs, tmp);
    number_clone(tmp, c); number_abs(tmp);
    if (number_greater(tmp, maxabs)) number_clone(maxabs, tmp);
    number_clone(tmp, d); number_abs(tmp);
    if (number_greater(tmp, maxabs)) number_clone(maxabs, tmp);
    free_number(tmp);
  }
  s ← 64;
  while ((number_less(maxabs, fraction_one_t)) ∧ (s > 1)) {
    number_double(a); number_double(b); number_double(c); number_double(d);
    number_double(maxabs); s ← s/2;
  }
  {
    mp_number r1, r2;
    new_fraction(r1); new_fraction(r2); take_fraction(r1, a, d); take_fraction(r2, b, c);
    number_substract(r1, r2); number_abs(r1); square_rt(*ret, r1); number_multiply_int(*ret, s);
    free_number(r1); free_number(r2);
  }
  free_number(a); free_number(b); free_number(c); free_number(d); free_number(maxabs);
}
static void mp_get_pen_scale(MP mp, mp_number *ret, mp_knot p)
{
  if (p ≡ Λ) {
    set_number_to_zero(*ret);
  }
  else {
    mp_number a, b, c, d;
    new_number(a); new_number(b); new_number(c); new_number(d);
    set_number_from_substraction(a, p→left_x, p→x_coord);
    set_number_from_substraction(b, p→right_x, p→x_coord);
    set_number_from_substraction(c, p→left_y, p→y_coord);
```

```
    set_number_from_substraction(d, p→right_y, p→y_coord); mp_sqrt_det(mp, ret, a, b, c, d);
    free_number(a); free_number(b); free_number(c); free_number(d);
  }
}
```

471. ⟨ Declarations 10 ⟩ +≡

```
static void mp_sqrt_det(MP mp, mp_number *ret, mp_number a, mp_number b, mp_number
    c, mp_number d);
```

472. When a picture contains text, this is represented by a fourteen-word node where the color information and *type* and *link* fields are augmented by additional fields that describe the text and how it is transformed. The *path_p* and *mp_pen_p* pointers are replaced by a number that identifies the font and a string number that gives the text to be displayed. The *width*, *height*, and *depth* fields give the dimensions of the text at its design size, and the remaining six words give a transformation to be applied to the text. The *new_text_node* function initializes everything to default values so that the text comes out black with its reference point at the origin.

```
#define mp_text_p(A) ((mp_text_node)(A))→text_p_   ▷ a string pointer for the text to display ◁
#define mp_font_n(A) ((mp_text_node)(A))→font_n_   ▷ the font number ◁
```

⟨ MPlib internal header stuff 8 ⟩ +≡

```
typedef struct mp_text_node_data {
  NODE_BODY;
  halfword color_model_;
  mp_number red;
  mp_number green;
  mp_number blue;
  mp_number black;
  mp_string pre_script_;
  mp_string post_script_;
  mp_string text_p_;
  halfword font_n_;
  mp_number width;
  mp_number height;
  mp_number depth;
  mp_number tx;
  mp_number ty;
  mp_number txx;
  mp_number txy;
  mp_number tyx;
  mp_number tyy;
} mp_text_node_data;
typedef struct mp_text_node_data *mp_text_node;
```

473. ⟨ Graphical object codes 463 ⟩ +≡

```
mp_text_code ← 3,
```

474. Make a text node for font f and text string s.

#define *text_node_size* **sizeof**(**struct mp_text_node_data**)

static mp_node *mp_new_text_node*(**MP** *mp*, **char** $*f$, **mp_string** s)
{
  mp_text_node $t \leftarrow$ *malloc_node*(*text_node_size*);
  mp_type(t) $\leftarrow$ *mp_text_node_type*; *mp_text_p*(t) $\leftarrow s$; *add_str_ref*(s);
  mp_font_n(t) $\leftarrow$ (**halfword**) *mp_find_font*(*mp*, f); ▷ this identifies the font ◁
  new_number($t\to$*red*); *new_number*($t\to$*green*); *new_number*($t\to$*blue*); *new_number*($t\to$*black*);
  new_number($t\to$*width*); *new_number*($t\to$*height*); *new_number*($t\to$*depth*); *clear_color*(t);
  mp_pre_script(t) $\leftarrow \Lambda$; *mp_post_script*(t) $\leftarrow \Lambda$; *new_number*($t\to$*tx*); *new_number*($t\to$*ty*);
  new_number($t\to$*txx*); *new_number*($t\to$*txy*); *new_number*($t\to$*tyx*); *new_number*($t\to$*tyy*);
    ▷ *tx_val*(t) $\leftarrow 0$; *ty_val*(t) $\leftarrow 0$; ◁ ▷ *txy_val*(t) $\leftarrow 0$; *tyx_val*(t) $\leftarrow 0$; ◁
  set_number_to_unity($t\to$*txx*); *set_number_to_unity*($t\to$*tyy*); *mp_set_text_box*(*mp*, t);
    ▷ this finds the bounding box ◁
  return (**mp_node**) t;
}

475. **static void** *mp_free_text_node*(**MP** *mp*, **mp_text_node** p)
{ ▷ *delete_str_ref*(*mp_text_p*(p)); ◁ ▷ gives errors ◁
  if (*mp_pre_script*(p) $\neq \Lambda$) *delete_str_ref*(*mp_pre_script*(p));
  if (*mp_post_script*(p) $\neq \Lambda$) *delete_str_ref*(*mp_post_script*(p));
  free_number($p\to$*red*); *free_number*($p\to$*green*); *free_number*($p\to$*blue*); *free_number*($p\to$*black*);
  free_number($p\to$*width*); *free_number*($p\to$*height*); *free_number*($p\to$*depth*); *free_number*($p\to$*tx*);
  free_number($p\to$*ty*); *free_number*($p\to$*txx*); *free_number*($p\to$*txy*); *free_number*($p\to$*tyx*);
  free_number($p\to$*tyy*); *mp_free_node*(*mp*, (**mp_node**) p, *text_node_size*);
}

476. The last two types of graphical objects that can occur in an edge structure are clipping paths and **setbounds** paths. These are slightly more difficult to implement because we must keep track of exactly what is being clipped or bounded when pictures get merged together. For this reason, each clipping or **setbounds** operation is represented by a pair of nodes: first comes a node whose *path_p* gives the relevant path, then there is the list of objects to clip or bound followed by a closing node.

#define *has_color*(*A*) (*mp_type*((*A*)) < *mp_start_clip_node_type*)
▷ does a graphical object have color fields? ◁
#define *has_pen*(*A*) (*mp_type*((*A*)) < *mp_text_node_type*)
▷ does a graphical object have a *mp_pen_p* field? ◁
#define *is_start_or_stop*(*A*) (*mp_type*((*A*)) ≥ *mp_start_clip_node_type*)
#define *is_stop*(*A*) (*mp_type*((*A*)) ≥ *mp_stop_clip_node_type*)

⟨MPlib internal header stuff 8⟩ +≡

```
typedef struct mp_start_clip_node_data {
  NODE_BODY;
  mp_knot path_p_;
} mp_start_clip_node_data;
typedef struct mp_start_clip_node_data *mp_start_clip_node;
typedef struct mp_start_bounds_node_data {
  NODE_BODY;
  mp_knot path_p_;
} mp_start_bounds_node_data;
typedef struct mp_start_bounds_node_data *mp_start_bounds_node;
typedef struct mp_stop_clip_node_data {
  NODE_BODY;
} mp_stop_clip_node_data;
typedef struct mp_stop_clip_node_data *mp_stop_clip_node;
typedef struct mp_stop_bounds_node_data {
  NODE_BODY;
} mp_stop_bounds_node_data;
typedef struct mp_stop_bounds_node_data *mp_stop_bounds_node;
```

477. ⟨Graphical object codes 463⟩ +≡

mp_start_clip_code ← 4, ▷ *type* of a node that starts clipping ◁
mp_start_bounds_code ← 5, ▷ *type* of a node that gives a **setbounds** path ◁
mp_stop_clip_code ← 6, ▷ *type* of a node that stops clipping ◁
mp_stop_bounds_code ← 7, ▷ *type* of a node that stops **setbounds** ◁

478.

```
#define start_clip_size sizeof(struct mp_start_clip_node_data)
#define stop_clip_size sizeof(struct mp_stop_clip_node_data)
#define start_bounds_size sizeof(struct mp_start_bounds_node_data)
#define stop_bounds_size sizeof(struct mp_stop_bounds_node_data)
  static mp_node mp_new_bounds_node(MP mp, mp_knot p, quarterword c)
  {   ▷ make a node of type c where p is the clipping or setbounds path ◁
    if (c ≡ mp_start_clip_node_type) {
      mp_start_clip_node t;   ▷ the new node ◁
      t ← (mp_start_clip_node) malloc_node(start_clip_size); t→path_p_ ← p; mp_type(t) ← c;
      t→link ← Λ; return (mp_node) t;
    }
    else if (c ≡ mp_start_bounds_node_type) {
      mp_start_bounds_node t;   ▷ the new node ◁
      t ← (mp_start_bounds_node) malloc_node(start_bounds_size); t→path_p_ ← p; mp_type(t) ← c;
      t→link ← Λ; return (mp_node) t;
    }
    else if (c ≡ mp_stop_clip_node_type) {
      mp_stop_clip_node t;   ▷ the new node ◁
      t ← (mp_stop_clip_node) malloc_node(stop_clip_size); mp_type(t) ← c; t→link ← Λ;
      return (mp_node) t;
    }
    else if (c ≡ mp_stop_bounds_node_type) {
      mp_stop_bounds_node t;   ▷ the new node ◁
      t ← (mp_stop_bounds_node) malloc_node(stop_bounds_size); mp_type(t) ← c; t→link ← Λ;
      return (mp_node) t;
    }
    else {
      assert(0);
    }
    return Λ;
  }
```

479.

```
static void mp_free_start_clip_node(MP mp, mp_start_clip_node p)
  {
    mp_toss_knot_list(mp, mp_path_p(p)); mp_free_node(mp, (mp_node) p, start_clip_size);
  }
  static void mp_free_start_bounds_node(MP mp, mp_start_bounds_node p)
  {
    mp_toss_knot_list(mp, mp_path_p(p)); mp_free_node(mp, (mp_node) p, start_bounds_size);
  }
  static void mp_free_stop_clip_node(MP mp, mp_stop_clip_node p)
  {
    mp_free_node(mp, (mp_node) p, stop_clip_size);
  }
  static void mp_free_stop_bounds_node(MP mp, mp_stop_bounds_node p)
  {
    mp_free_node(mp, (mp_node) p, stop_bounds_size);
  }
```

480. All the essential information in an edge structure is encoded as a linked list of graphical objects as we have just seen, but it is helpful to add some redundant information. A single edge structure might be used as a dash pattern many times, and it would be nice to avoid scanning the same structure repeatedly. Thus, an edge structure known to be a suitable dash pattern has a header that gives a list of dashes in a sorted order designed for rapid translation into PostScript.

Each dash is represented by a three-word node containing the initial and final x coordinates as well as the usual *link* field. The *link* fields points to the dash node with the next higher x-coordinates and the final link points to a special location called *null_dash*. (There should be no overlap between dashes). Since the y coordinate of the dash pattern is needed to determine the period of repetition, this needs to be stored in the edge header along with a pointer to the list of dash nodes.

The *dash_info* is explained below.

```
#define dash_list(A) (mp_dash_node)(((mp_dash_node)(A))→link)
        ▷ in an edge header this points to the first dash node ◁
#define set_dash_list(A, B) ((mp_dash_node)(A))→link ← (mp_node)((B))
        ▷ in an edge header this points to the first dash node ◁
```

⟨ MPlib internal header stuff 8 ⟩ +≡

```
typedef struct mp_dash_node_data {
  NODE_BODY;
  mp_number start_x;   ▷ the starting x coordinate in a dash node ◁
  mp_number stop_x;   ▷ the ending x coordinate in a dash node ◁
  mp_number dash_y;   ▷ y value for the dash list in an edge header ◁
  mp_node dash_info_;
} mp_dash_node_data;
```

481. ⟨ Types in the outer block 37 ⟩ +≡

```
typedef struct mp_dash_node_data *mp_dash_node;
```

482. ⟨ Initialize table entries 186 ⟩ +≡

```
mp→null_dash ← mp_get_dash_node(mp);
```

483. ⟨ Free table entries 187 ⟩ +≡

```
mp_free_node(mp, (mp_node) mp→null_dash, dash_node_size);
```

484.

```
#define dash_node_size sizeof(struct mp_dash_node_data)

static mp_dash_node mp_get_dash_node(MP mp)
{
  mp_dash_node p ← (mp_dash_node) malloc_node(dash_node_size);
  p→has_number ← 0; new_number(p→start_x); new_number(p→stop_x); new_number(p→dash_y);
  mp_type(p) ← mp_dash_node_type; return p;
}
```

485. It is also convenient for an edge header to contain the bounding box information needed by the **llcorner** and **urcorner** operators so that this does not have to be recomputed unnecessarily. This is done by adding fields for the x and y extremes as well as a pointer that indicates how far the bounding box computation has gotten. Thus if the user asks for the bounding box and then adds some more text to the picture before asking for more bounding box information, the second computation need only look at the additional text.

When the bounding box has not been computed, the *bblast* pointer points to a dummy link at the head of the graphical object list while the *minx_val* and *miny_val* fields contain `EL_GORDO` and the *maxx_val* and *maxy_val* fields contain −`EL_GORDO`.

Since the bounding box of pictures containing objects of type **mp_start_bounds_node** depends on the value of **truecorners**, the bounding box data might not be valid for all values of this parameter. Hence, the *bbtype* field is needed to keep track of this.

```
#define bblast(A) ((mp_edge_header_node)(A))->bblast_
        ▷ last item considered in bounding box computation ◁
#define edge_list(A) ((mp_edge_header_node)(A))->list_
        ▷ where the object list begins in an edge header ◁
```

⟨ MPlib internal header stuff 8 ⟩ +≡

```
typedef struct mp_edge_header_node_data {
  NODE_BODY;
  mp_number start_x;
  mp_number stop_x;
  mp_number dash_y;
  mp_node dash_info_;
  mp_number minx;
  mp_number miny;
  mp_number maxx;
  mp_number maxy;
  mp_node bblast_;
  int bbtype;   ▷ tells how bounding box data depends on truecorners ◁
  mp_node list_;
  mp_node obj_tail_;   ▷ explained below ◁
  halfword ref_count_;   ▷ explained below ◁
} mp_edge_header_node_data;
typedef struct mp_edge_header_node_data *mp_edge_header_node;
```

486.

```
#define no_bounds 0   ▷ bbtype value when bounding box data is valid for all truecorners values ◁
#define bounds_set 1   ▷ bbtype value when bounding box data is for truecorners ≤ 0 ◁
#define bounds_unset 2   ▷ bbtype value when bounding box data is for truecorners > 0 ◁

static void mp_init_bbox(MP mp, mp_edge_header_node h)
{   ▷ Initialize the bounding box information in edge structure h ◁
  (void) mp; bblast(h) ← edge_list(h); h→bbtype ← no_bounds; set_number_to_inf(h→minx);
  set_number_to_inf(h→miny); set_number_to_neg_inf(h→maxx); set_number_to_neg_inf(h→maxy);
}
```

487. The only other entries in an edge header are a reference count in the first word and a pointer to the tail of the object list in the last word.

#define *obj_tail*(*A*) ((**mp_edge_header_node**)(*A*))→*obj_tail_*
▷ points to the last entry in the object list ◁
#define *edge_ref_count*(*A*) ((**mp_edge_header_node**)(*A*))→*ref_count_*
#define *edge_header_size* **sizeof**(**struct mp_edge_header_node_data**)

```
static mp_edge_header_node mp_get_edge_header_node(MP mp)
{
  mp_edge_header_node p ← (mp_edge_header_node) malloc_node(edge_header_size);
  mp_type(p) ← mp_edge_header_node_type; new_number(p→start_x); new_number(p→stop_x);
  new_number(p→dash_y); new_number(p→minx); new_number(p→miny); new_number(p→maxx);
  new_number(p→maxy); p→list_ ← mp_get_token_node(mp);   ▷ or whatever, just a need a link handle ◁
  return p;
}

static void mp_init_edges(MP mp, mp_edge_header_node h)
{   ▷ initialize an edge header to NULL values ◁
  set_dash_list(h, mp→null_dash); obj_tail(h) ← edge_list(h); mp_link(edge_list(h)) ← Λ;
  edge_ref_count(h) ← 0; mp_init_bbox(mp, h);
}
```

488. Here is how edge structures are deleted. The process can be recursive because of the need to dereference edge structures that are used as dash patterns.

#define *add_edge_ref*(*A*) *incr*(*edge_ref_count*((*A*)))
#define *delete_edge_ref*(*A*)

```
{
  if (edge_ref_count((A)) ≡ 0) mp_toss_edges(mp, (mp_edge_header_node)(A));
  else decr(edge_ref_count((A)));
}
```

⟨ Declarations 10 ⟩ +≡

```
static void mp_flush_dash_list(MP mp, mp_edge_header_node h);
static mp_edge_header_node mp_toss_gr_object(MP mp, mp_node p);
static void mp_toss_edges(MP mp, mp_edge_header_node h);
```

489.

```
void mp_toss_edges(MP mp, mp_edge_header_node h)
{
  mp_node p, q;    ▷ pointers that scan the list being recycled ◁
  mp_edge_header_node r;    ▷ an edge structure that object p refers to ◁
  mp_flush_dash_list(mp, h); q ← mp_link(edge_list(h));
  while ((q ≠ Λ)) {
    p ← q; q ← mp_link(q); r ← mp_toss_gr_object(mp, p);
    if (r ≠ Λ) delete_edge_ref(r);
  }
  free_number(h→start_x); free_number(h→stop_x); free_number(h→dash_y); free_number(h→minx);
  free_number(h→miny); free_number(h→maxx); free_number(h→maxy); mp_free_token_node(mp, h→list_);
  mp_free_node(mp, (mp_node) h, edge_header_size);
}
void mp_flush_dash_list(MP mp, mp_edge_header_node h)
{
  mp_dash_node p, q;    ▷ pointers that scan the list being recycled ◁
  q ← dash_list(h);
  while (q ≠ mp→null_dash) {    ▷ TODO: Λ check should not be needed ◁
    p ← q; q ← (mp_dash_node) mp_link(q); mp_free_node(mp, (mp_node) p, dash_node_size);
  }
  set_dash_list(h, mp→null_dash);
}
mp_edge_header_node mp_toss_gr_object(MP mp, mp_node p)
{    ▷ returns an edge structure that needs to be dereferenced ◁
  mp_edge_header_node e ← Λ;    ▷ the edge structure to return ◁
  switch (mp_type(p)) {
  case mp_fill_node_type: mp_free_fill_node(mp, (mp_fill_node) p); break;
  case mp_stroked_node_type: e ← mp_free_stroked_node(mp, (mp_stroked_node) p); break;
  case mp_text_node_type: mp_free_text_node(mp, (mp_text_node) p); break;
  case mp_start_clip_node_type: mp_free_start_clip_node(mp, (mp_start_clip_node) p); break;
  case mp_start_bounds_node_type: mp_free_start_bounds_node(mp, (mp_start_bounds_node) p);
    break;
  case mp_stop_clip_node_type: mp_free_stop_clip_node(mp, (mp_stop_clip_node) p); break;
  case mp_stop_bounds_node_type: mp_free_stop_bounds_node(mp, (mp_stop_bounds_node) p); break;
  default:    ▷ there are no other valid cases, but please the compiler ◁
    break;
  }
  return e;
}
```

490. If we use *add_edge_ref* to "copy" edge structures, the real copying needs to be done before making a significant change to an edge structure. Much of the work is done in a separate routine *copy_objects* that copies a list of graphical objects into a new edge header.

```
static mp_edge_header_node mp_private_edges(MP mp, mp_edge_header_node h)
{   ▷ make a private copy of the edge structure headed by h ◁
  mp_edge_header_node hh;   ▷ the edge header for the new copy ◁
  mp_dash_node p, pp;   ▷ pointers for copying the dash list ◁
  assert(mp_type(h) ≡ mp_edge_header_node_type);
  if (edge_ref_count(h) ≡ 0) {
    return h;
  }
  else {
    decr(edge_ref_count(h));
    hh ← (mp_edge_header_node) mp_copy_objects(mp, mp_link(edge_list(h)), Λ);
    ⟨Copy the dash list from h to hh 491⟩;
    ⟨Copy the bounding box information from h to hh and make bblast(hh) point into the new object
        list 493⟩;
    return hh;
  }
}
```

491. Here we use the fact that $dash\_list(hh) \leftarrow mp\_link(hh)$.

```
⟨Copy the dash list from h to hh 491⟩ ≡
  pp ← (mp_dash_node) hh; p ← dash_list(h);
  while ((p ≠ mp→null_dash)) {
    mp_link(pp) ← (mp_node) mp_get_dash_node(mp); pp ← (mp_dash_node) mp_link(pp);
    number_clone(pp→start_x, p→start_x); number_clone(pp→stop_x, p→stop_x);
    p ← (mp_dash_node) mp_link(p);
  }
  mp_link(pp) ← (mp_node) mp→null_dash; number_clone(hh→dash_y, h→dash_y)
```

This code is used in section 490.

492. *h* is an edge structure

```
static mp_dash_object *mp_export_dashes(MP mp, mp_stroked_node q, mp_number w)
{
  mp_dash_object *d;
  mp_dash_node p, h;
  mp_number scf;   /* scale factor */
  mp_number dashoff;
  double *dashes ← Λ;
  int num_dashes ← 1;

  h ← (mp_dash_node) mp_dash_p(q);
  if (h ≡ Λ ∨ dash_list(h) ≡ mp→null_dash) return Λ;
  new_number(scf); p ← dash_list(h); mp_get_pen_scale(mp, &scf, mp_pen_p(q));
  if (number_zero(scf)) {
    if (number_zero(w)) {
      number_clone(scf, q→dash_scale);
    }
    else {
      free_number(scf); return Λ;
    }
  }
  else {
    mp_number ret;

    new_number(ret); make_scaled(ret, w, scf); take_scaled(scf, ret, q→dash_scale); free_number(ret);
  }
  number_clone(w, scf); d ← xmalloc(1, sizeof(mp_dash_object));
  add_var_used(sizeof(mp_dash_object));
  set_number_from_addition(mp→null_dash→start_x, p→start_x, h→dash_y);
  {
    mp_number ret, arg1;

    new_number(ret); new_number(arg1); new_number(dashoff);
    while (p ≠ mp→null_dash) {
      dashes ← xrealloc(dashes, (num_dashes + 2), sizeof(double));
      set_number_from_substraction(arg1, p→stop_x, p→start_x); take_scaled(ret, arg1, scf);
      dashes[(num_dashes − 1)] ← number_to_double(ret);
      set_number_from_substraction(arg1, ((mp_dash_node) mp_link(p))→start_x, p→stop_x);
      take_scaled(ret, arg1, scf); dashes[(num_dashes)] ← number_to_double(ret);
      dashes[(num_dashes + 1)] ← −1.0;   /* terminus */
      num_dashes += 2; p ← (mp_dash_node) mp_link(p);
    }
    d→array ← dashes; mp_dash_offset(mp, &dashoff, h); take_scaled(ret, dashoff, scf);
    d→offset ← number_to_double(ret); free_number(ret); free_number(arg1);
  }
  free_number(dashoff); free_number(scf); return d;
}
```

493. ⟨ Copy the bounding box information from h to hh and make $bblast(hh)$ point into the new object list 493 ⟩ ≡

$number\_clone(hh\to minx, h\to minx)$; $number\_clone(hh\to miny, h\to miny)$; $number\_clone(hh\to maxx, h\to maxx)$; $number\_clone(hh\to maxy, h\to maxy)$; $hh\to bbtype \leftarrow h\to bbtype$; $p \leftarrow$ (**mp_dash_node**) $edge\_list(h)$;
$pp \leftarrow$ (**mp_dash_node**) $edge\_list(hh)$;
while $((p \neq$ (**mp_dash_node**) $bblast(h)))$ {
  if $(p \equiv \Lambda)$ $mp\_confusion(mp,$ `"bblast"`$)$;
  $p \leftarrow$ (**mp_dash_node**) $mp\_link(p)$; $pp \leftarrow$ (**mp_dash_node**) $mp\_link(pp)$;
}
$bblast(hh) \leftarrow$ (**mp_node**) pp

This code is used in section 490.

494. Here is the promised routine for copying graphical objects into a new edge structure. It starts copying at object p and stops just before object q. If q is NULL, it copies the entire sublist headed at p. The resulting edge structure requires further initialization by *init_bbox*.

⟨ Declarations 10 ⟩ +≡
  static mp_edge_header_node $mp\_copy\_objects$(**MP** mp, **mp_node** p, **mp_node** q);

495. **mp_edge_header_node** $mp\_copy\_objects$(**MP** mp, **mp_node** p, **mp_node** q)
{
  mp_edge_header_node hh; ▷ the new edge header ◁
  mp_node pp; ▷ the last newly copied object ◁
  quarterword $k \leftarrow 0$; ▷ temporary register ◁
  $hh \leftarrow mp\_get\_edge\_header\_node(mp)$; $set\_dash\_list(hh, mp\to null\_dash)$; $edge\_ref\_count(hh) \leftarrow 0$;
  $pp \leftarrow edge\_list(hh)$;
  while $(p \neq q)$ ⟨ Make $mp\_link(pp)$ point to a copy of object p, and update p and pp 496 ⟩
  $obj\_tail(hh) \leftarrow pp$; $mp\_link(pp) \leftarrow \Lambda$; **return** hh;
}

496. ⟨ Make $mp\_link(pp)$ point to a copy of object p, and update p and pp 496 ⟩ ≡
{
  switch $(mp\_type(p))$ {
  case $mp\_start\_clip\_node\_type$: $k \leftarrow start\_clip\_size$; **break**;
  case $mp\_start\_bounds\_node\_type$: $k \leftarrow start\_bounds\_size$; **break**;
  case $mp\_fill\_node\_type$: $k \leftarrow fill\_node\_size$; **break**;
  case $mp\_stroked\_node\_type$: $k \leftarrow stroked\_node\_size$; **break**;
  case $mp\_text\_node\_type$: $k \leftarrow text\_node\_size$; **break**;
  case $mp\_stop\_clip\_node\_type$: $k \leftarrow stop\_clip\_size$; **break**;
  case $mp\_stop\_bounds\_node\_type$: $k \leftarrow stop\_bounds\_size$; **break**;
  default: ▷ there are no other valid cases, but please the compiler ◁
    break;
  }
  $mp\_link(pp) \leftarrow malloc\_node(($**size_t**$)\,k)$; ▷ gr_object ◁
  $pp \leftarrow mp\_link(pp)$; $memcpy(pp, p, ($**size_t**$)\,k)$; $pp\to link \leftarrow \Lambda$;
  ⟨ Fix anything in graphical object pp that should differ from the corresponding field in p 497 ⟩;
  $p \leftarrow mp\_link(p)$;
}

This code is used in section 495.

497. ⟨ Fix anything in graphical object pp that should differ from the corresponding field in p 497 ⟩ ≡

switch ($mp\_type(p)$) {
case $mp\_start\_clip\_node\_type$:
{
mp_start_clip_node $tt \leftarrow$ (**mp_start_clip_node**) pp;
mp_start_clip_node $t \leftarrow$ (**mp_start_clip_node**) p;
$mp\_path\_p(tt) \leftarrow mp\_copy\_path(mp, mp\_path\_p(t))$;
}
break;
case $mp\_start\_bounds\_node\_type$:
{
mp_start_bounds_node $tt \leftarrow$ (**mp_start_bounds_node**) pp;
mp_start_bounds_node $t \leftarrow$ (**mp_start_bounds_node**) p;
$mp\_path\_p(tt) \leftarrow mp\_copy\_path(mp, mp\_path\_p(t))$;
}
break;
case $mp\_fill\_node\_type$:
{
mp_fill_node $tt \leftarrow$ (**mp_fill_node**) pp;
mp_fill_node $t \leftarrow$ (**mp_fill_node**) p;
$new\_number(tt\rightarrow red)$; $number\_clone(tt\rightarrow red, t\rightarrow red)$; $new\_number(tt\rightarrow green)$;
$number\_clone(tt\rightarrow green, t\rightarrow green)$; $new\_number(tt\rightarrow blue)$; $number\_clone(tt\rightarrow blue, t\rightarrow blue)$;
$new\_number(tt\rightarrow black)$; $number\_clone(tt\rightarrow black, t\rightarrow black)$; $new\_number(tt\rightarrow miterlim)$;
$number\_clone(tt\rightarrow miterlim, t\rightarrow miterlim)$; $mp\_path\_p(tt) \leftarrow mp\_copy\_path(mp, mp\_path\_p(t))$;
if ($mp\_pre\_script(p) \neq \Lambda$) $add\_str\_ref(mp\_pre\_script(p))$;
if ($mp\_post\_script(p) \neq \Lambda$) $add\_str\_ref(mp\_post\_script(p))$;
if ($mp\_pen\_p(t) \neq \Lambda$) $mp\_pen\_p(tt) \leftarrow copy\_pen(mp\_pen\_p(t))$;
}
break;
case $mp\_stroked\_node\_type$:
{
mp_stroked_node $tt \leftarrow$ (**mp_stroked_node**) pp;
mp_stroked_node $t \leftarrow$ (**mp_stroked_node**) p;
$new\_number(tt\rightarrow red)$; $number\_clone(tt\rightarrow red, t\rightarrow red)$; $new\_number(tt\rightarrow green)$;
$number\_clone(tt\rightarrow green, t\rightarrow green)$; $new\_number(tt\rightarrow blue)$; $number\_clone(tt\rightarrow blue, t\rightarrow blue)$;
$new\_number(tt\rightarrow black)$; $number\_clone(tt\rightarrow black, t\rightarrow black)$; $new\_number(tt\rightarrow miterlim)$;
$number\_clone(tt\rightarrow miterlim, t\rightarrow miterlim)$; $new\_number(tt\rightarrow dash\_scale)$;
$number\_clone(tt\rightarrow dash\_scale, t\rightarrow dash\_scale)$;
if ($mp\_pre\_script(p) \neq \Lambda$) $add\_str\_ref(mp\_pre\_script(p))$;
if ($mp\_post\_script(p) \neq \Lambda$) $add\_str\_ref(mp\_post\_script(p))$;
$mp\_path\_p(tt) \leftarrow mp\_copy\_path(mp, mp\_path\_p(t))$; $mp\_pen\_p(tt) \leftarrow copy\_pen(mp\_pen\_p(t))$;
if ($mp\_dash\_p(p) \neq \Lambda$) $add\_edge\_ref(mp\_dash\_p(pp))$;
}
break;
case $mp\_text\_node\_type$:
{
mp_text_node $tt \leftarrow$ (**mp_text_node**) pp;
mp_text_node $t \leftarrow$ (**mp_text_node**) p;
$new\_number(tt\rightarrow red)$; $number\_clone(tt\rightarrow red, t\rightarrow red)$; $new\_number(tt\rightarrow green)$;
$number\_clone(tt\rightarrow green, t\rightarrow green)$; $new\_number(tt\rightarrow blue)$; $number\_clone(tt\rightarrow blue, t\rightarrow blue)$;
$new\_number(tt\rightarrow black)$; $number\_clone(tt\rightarrow black, t\rightarrow black)$; $new\_number(tt\rightarrow width)$;

```
      number_clone(tt→width, t→width); new_number(tt→height); number_clone(tt→height, t→height);
      new_number(tt→depth); number_clone(tt→depth, t→depth); new_number(tt→tx);
      number_clone(tt→tx, t→tx); new_number(tt→ty); number_clone(tt→ty, t→ty); new_number(tt→txx);
      number_clone(tt→txx, t→txx); new_number(tt→tyx); number_clone(tt→tyx, t→tyx);
      new_number(tt→txy); number_clone(tt→txy, t→txy); new_number(tt→tyy);
      number_clone(tt→tyy, t→tyy);
      if (mp_pre_script(p) ≠ Λ) add_str_ref(mp_pre_script(p));
      if (mp_post_script(p) ≠ Λ) add_str_ref(mp_post_script(p));
      add_str_ref(mp_text_p(pp));
    }
    break;
  case mp_stop_clip_node_type: case mp_stop_bounds_node_type: break;
  default:    ▷ there are no other valid cases, but please the compiler ◁
    break;
  }
```

This code is used in section 496.

498. Here is one way to find an acceptable value for the second argument to *copy_objects*. Given a non-NULL graphical object list, *skip_1component* skips past one picture component, where a "picture component" is a single graphical object, or a start bounds or start clip object and everything up through the matching stop bounds or stop clip object.

```
  static mp_node mp_skip_1component(MP mp, mp_node p)
  {
    integer lev;    ▷ current nesting level ◁
    lev ← 0; (void) mp;
    do {
      if (is_start_or_stop(p)) {
        if (is_stop(p)) decr(lev);
        else incr(lev);
      }
      p ← mp_link(p);
    } while (lev ≠ 0);
    return p;
  }
```

499. Here is a diagnostic routine for printing an edge structure in symbolic form.

⟨ Declarations 10 ⟩ +≡

```
  static void mp_print_edges(MP mp, mp_node h, const char *s, boolean nuline);
```

500. **void** *mp_print_edges*(**MP** *mp*, **mp_node** *h*, **const char** ∗*s*, **boolean** *nuline*)
{
  mp_node *p*; ▷ a graphical object to be printed ◁
  mp_number *scf*; ▷ a scale factor for the dash pattern ◁
  boolean *ok_to_dash*; ▷ *false* for polygonal pen strokes ◁
  new_number(*scf*); *mp_print_diagnostic*(*mp*, "Edge␣structure", *s*, *nuline*); *p* ← *edge_list*(*h*);
  while (*mp_link*(*p*) ≠ Λ) {
    p ← *mp_link*(*p*); *mp_print_ln*(*mp*);
    switch (*mp_type*(*p*)) {
      ⟨ Cases for printing graphical object node *p* 501 ⟩;
    default: *mp_print*(*mp*, "[unknown␣object␣type!]"); **break**;
    }
  }
  mp_print_nl(*mp*, "End␣edges");
  if (*p* ≠ *obj_tail*(*h*)) *mp_print*(*mp*, "?");
  mp_end_diagnostic(*mp*, *true*); *free_number*(*scf*);
}

501. ⟨ Cases for printing graphical object node *p* 501 ⟩ ≡
case *mp_fill_node_type*: *mp_print*(*mp*, "Filled␣contour␣"); *mp_print_obj_color*(*mp*, *p*);
  mp_print_char(*mp*, *xord*(':')); *mp_print_ln*(*mp*); *mp_pr_path*(*mp*, *mp_path_p*((**mp_fill_node**) *p*));
  mp_print_ln(*mp*);
  if ((*mp_pen_p*((**mp_fill_node**) *p*) ≠ Λ)) {
    ⟨ Print join type for graphical object *p* 502 ⟩;
    mp_print(*mp*, "␣with␣pen"); *mp_print_ln*(*mp*); *mp_pr_pen*(*mp*, *mp_pen_p*((**mp_fill_node**) *p*));
  }
  break;

See also sections 506, 510, 511, and 512.

This code is used in section 500.

502. ⟨ Print join type for graphical object *p* 502 ⟩ ≡
  switch (((**mp_stroked_node**) *p*)→*ljoin*) {
  case 0: *mp_print*(*mp*, "mitered␣joins␣limited␣"); *print_number*(((**mp_stroked_node**) *p*)→*miterlim*);
    break;
  case 1: *mp_print*(*mp*, "round␣joins"); **break**;
  case 2: *mp_print*(*mp*, "beveled␣joins"); **break**;
  default: *mp_print*(*mp*, "??␣joins"); **break**;
  }

This code is used in sections 501 and 503.

503. For stroked nodes, we need to print *lcap_val*(*p*) as well.

⟨ Print join and cap types for stroked node *p* 503 ⟩ ≡
  switch (((**mp_stroked_node**) *p*)→*lcap*) {
  case 0: *mp_print*(*mp*, "butt"); **break**;
  case 1: *mp_print*(*mp*, "round"); **break**;
  case 2: *mp_print*(*mp*, "square"); **break**;
  default: *mp_print*(*mp*, "??"); **break**;
  }
  mp_print(*mp*, "␣ends,␣"); ⟨ Print join type for graphical object *p* 502 ⟩

This code is used in section 506.

504. Here is a routine that prints the color of a graphical object if it isn't black (the default color).

⟨ Declarations 10 ⟩ +≡
```
static void mp_print_obj_color(MP mp, mp_node p);
```

505.
```
void mp_print_obj_color(MP mp, mp_node p)
{
  mp_stroked_node p0 ← (mp_stroked_node) p;
  if (mp_color_model(p) ≡ mp_grey_model) {
    if (number_positive(p0→grey)) {
      mp_print(mp, "greyed␣"); mp_print_char(mp, xord('(')); print_number(p0→grey);
      mp_print_char(mp, xord(')'));
    }
  }
  else if (mp_color_model(p) ≡ mp_cmyk_model) {
    if (number_positive(p0→cyan) ∨ number_positive(p0→magenta) ∨ number_positive(p0→yellow) ∨
          number_positive(p0→black)) {
      mp_print(mp, "processcolored␣"); mp_print_char(mp, xord('(')); print_number(p0→cyan);
      mp_print_char(mp, xord(',')); print_number(p0→magenta); mp_print_char(mp, xord(','));
      print_number(p0→yellow); mp_print_char(mp, xord(',')); print_number(p0→black);
      mp_print_char(mp, xord(')'));
    }
  }
  else if (mp_color_model(p) ≡ mp_rgb_model) {
    if (number_positive(p0→red) ∨ number_positive(p0→green) ∨ number_positive(p0→blue)) {
      mp_print(mp, "colored␣"); mp_print_char(mp, xord('(')); print_number(p0→red);
      mp_print_char(mp, xord(',')); print_number(p0→green); mp_print_char(mp, xord(','));
      print_number(p0→blue); mp_print_char(mp, xord(')'));
    }
  }
}
```

506. ⟨ Cases for printing graphical object node p 501 ⟩ +≡
```
case mp_stroked_node_type: mp_print(mp, "Filled␣pen␣stroke␣"); mp_print_obj_color(mp, p);
  mp_print_char(mp, xord(':')); mp_print_ln(mp); mp_pr_path(mp, mp_path_p((mp_stroked_node) p));
  if (mp_dash_p(p) ≠ Λ) {
    mp_print_nl(mp, "dashed␣("); ⟨ Finish printing the dash pattern that p refers to 507 ⟩;
  }
  mp_print_ln(mp); ⟨ Print join and cap types for stroked node p 503 ⟩;
  mp_print(mp, "␣with␣pen"); mp_print_ln(mp);
  if (mp_pen_p((mp_stroked_node) p) ≡ Λ) {
    mp_print(mp, "???");   ▷ shouldn't happen ◁
  }
  else {
    mp_pr_pen(mp, mp_pen_p((mp_stroked_node) p));
  }
  break;
```

507. Normally, the *dash_list* field in an edge header is set to *null_dash* when it is not known to define a suitable dash pattern. This is disallowed here because the *mp_dash_p* field should never point to such an edge header. Note that memory is allocated for *start_x*(*null_dash*) and we are free to give it any convenient value.

⟨ Finish printing the dash pattern that *p* refers to 507 ⟩ ≡

```
{
  mp_dash_node ppd, hhd;
  ok_to_dash ← pen_is_elliptical(mp_pen_p((mp_stroked_node) p));
  if (¬ok_to_dash) set_number_to_unity(scf);
  else number_clone(scf, ((mp_stroked_node) p)→dash_scale);
  hhd ← (mp_dash_node) mp_dash_p(p); ppd ← dash_list(hhd);
  if ((ppd ≡ mp→null_dash) ∨ number_negative(hhd→dash_y)) {
    mp_print(mp, "␣??");
  }
  else {
    mp_number dashoff;
    mp_number ret, arg1;
    new_number(ret); new_number(arg1); new_number(dashoff);
    set_number_from_addition(mp→null_dash→start_x, ppd→start_x, hhd→dash_y);
    while (ppd ≠ mp→null_dash) {
      mp_print(mp, "on␣"); set_number_from_substraction(arg1, ppd→stop_x, ppd→start_x);
      take_scaled(ret, arg1, scf); print_number(ret); mp_print(mp, "␣off␣");
      set_number_from_substraction(arg1, ((mp_dash_node) mp_link(ppd))→start_x, ppd→stop_x);
      take_scaled(ret, arg1, scf); print_number(ret); ppd ← (mp_dash_node) mp_link(ppd);
      if (ppd ≠ mp→null_dash) mp_print_char(mp, xord('␣'));
    }
    mp_print(mp, ")␣shifted␣"); mp_dash_offset(mp, &dashoff, hhd); take_scaled(ret, dashoff, scf);
    number_negate(ret); print_number(ret); free_number(dashoff); free_number(ret); free_number(arg1);
    if (¬ok_to_dash ∨ number_zero(hhd→dash_y)) mp_print(mp, "␣(this␣will␣be␣ignored)");
  }
}
```

This code is used in section 506.

508. ⟨ Declarations 10 ⟩ +≡

```
static void mp_dash_offset(MP mp, mp_number *x, mp_dash_node h);
```

509.

```
void mp_dash_offset(MP mp, mp_number *x, mp_dash_node h)
{
  if (dash_list(h) ≡ mp→null_dash ∨ number_negative(h→dash_y)) mp_confusion(mp, "dash0");
  if (number_zero(h→dash_y)) {
    set_number_to_zero(*x);
  }
  else {
    number_clone(*x, (dash_list(h))→start_x); number_modulo(*x, h→dash_y); number_negate(*x);
    if (number_negative(*x)) number_add(*x, h→dash_y);
  }
}
```

510. ⟨ Cases for printing graphical object node *p* 501 ⟩ +≡

```
case mp_text_node_type:
  {
    mp_text_node p0 ← (mp_text_node) p;
    mp_print_char(mp, xord('"')); mp_print_str(mp, mp_text_p(p)); mp_print(mp, "\"␣infont␣\"");
    mp_print(mp, mp→font_name[mp_font_n(p)]); mp_print_char(mp, xord('"')); mp_print_ln(mp);
    mp_print_obj_color(mp, p); mp_print(mp, "transformed␣"); mp_print_char(mp, xord('('));
    print_number(p0→tx); mp_print_char(mp, xord(',')); print_number(p0→ty);
    mp_print_char(mp, xord(',')); print_number(p0→txx); mp_print_char(mp, xord(','));
    print_number(p0→txy); mp_print_char(mp, xord(',')); print_number(p0→tyx);
    mp_print_char(mp, xord(',')); print_number(p0→tyy); mp_print_char(mp, xord(')'));
  }
  break;
```

511. ⟨ Cases for printing graphical object node *p* 501 ⟩ +≡

```
case mp_start_clip_node_type: mp_print(mp, "clipping␣path:"); mp_print_ln(mp);
  mp_pr_path(mp, mp_path_p((mp_start_clip_node) p)); break;
case mp_stop_clip_node_type: mp_print(mp, "stop␣clipping"); break;
```

512. ⟨ Cases for printing graphical object node *p* 501 ⟩ +≡

```
case mp_start_bounds_node_type: mp_print(mp, "setbounds␣path:"); mp_print_ln(mp);
  mp_pr_path(mp, mp_path_p((mp_start_bounds_node) p)); break;
case mp_stop_bounds_node_type: mp_print(mp, "end␣of␣setbounds"); break;
```

513. To initialize the *dash_list* field in an edge header h, we need a subroutine that scans an edge structure and tries to interpret it as a dash pattern. This can only be done when there are no filled regions or clipping paths and all the pen strokes have the same color. The first step is to let y_0 be the initial y coordinate of the first pen stroke. Then we implicitly project all the pen stroke paths onto the line $y = y_0$ and require that there be no retracing. If the resulting paths cover a range of x coordinates of length Δx, we set *dash_y*(h) to the length of the dash pattern by finding the maximum of Δx and the absolute value of y_0.

```
static mp_edge_header_node mp_make_dashes(MP mp, mp_edge_header_node h)
{    ▷ returns h or Λ ◁
  mp_node p;    ▷ this scans the stroked nodes in the object list ◁
  mp_node p0;    ▷ if not Λ this points to the first stroked node ◁
  mp_knot pp, qq, rr;    ▷ pointers into mp_path_p(p) ◁
  mp_dash_node d, dd;    ▷ pointers used to create the dash list ◁
  mp_number y0;
  ⟨Other local variables in make_dashes 524⟩;
  if (dash_list(h) ≠ mp→null_dash) return h;
  new_number(y0);    ▷ the initial y coordinate ◁
  p0 ← Λ; p ← mp_link(edge_list(h));
  while (p ≠ Λ) {
    if (mp_type(p) ≠ mp_stroked_node_type) {
      ⟨Complain that the edge structure contains a node of the wrong type and goto not_found 514⟩;
    }
    pp ← mp_path_p((mp_stroked_node) p);
    if (p0 ≡ Λ) {
      p0 ← p; number_clone(y0, pp→y_coord);
    }
    ⟨Make d point to a new dash node created from stroke p and path pp or goto not_found if there is
        an error 517⟩;
    ⟨Insert d into the dash list and goto not_found if there is an error 520⟩;
    p ← mp_link(p);
  }
  if (dash_list(h) ≡ mp→null_dash) goto NOT_FOUND;    ▷ No error message ◁
  ⟨Scan dash_list(h) and deal with any dashes that are themselves dashed 523⟩;
  ⟨Set dash_y(h) and merge the first and last dashes if necessary 521⟩;
  free_number(y0); return h;
NOT_FOUND: free_number(y0); ⟨Flush the dash list, recycle h and return Λ 522⟩;
}
```

514. ⟨Complain that the edge structure contains a node of the wrong type and **goto** *not_found* 514⟩ ≡

```
{
  const char *hlp[] ← {"When␣you␣say␣‘dashed␣p’,␣picture␣p␣should␣not␣contain␣any",
      "text,␣filled␣regions,␣or␣clipping␣paths.␣␣This␣time␣it␣did",
      "so␣I’ll␣just␣make␣it␣a␣solid␣line␣instead.", Λ};
  mp_back_error(mp, "Picture␣is␣too␣complicated␣to␣use␣as␣a␣dash␣pattern", hlp, true);
  mp_get_x_next(mp); goto NOT_FOUND;
}
```

This code is used in section 513.

515. A similar error occurs when monotonicity fails.

⟨Declarations 10⟩ +≡

```
static void mp_x_retrace_error(MP mp);
```

516. **void** *mp_x_retrace_error*(**MP** *mp*)

```
{
  const char *hlp[] ← {"When␣you␣say␣‘dashed␣p’,␣every␣path␣in␣p␣should␣be␣monotone",
      "in␣x␣and␣there␣must␣be␣no␣overlapping.␣␣This␣failed",
      "so␣I’ll␣just␣make␣it␣a␣solid␣line␣instead.", Λ};
  mp_back_error(mp, "Picture␣is␣too␣complicated␣to␣use␣as␣a␣dash␣pattern", hlp, true);
  mp_get_x_next(mp);
}
```

517. We stash p in *dash_info*(d) if *mp_dash_p*(p) <> 0 so that subsequent processing can handle the case where the pen stroke p is itself dashed.

#**define** *dash_info*(*A*) ((**mp_dash_node**)(*A*))→*dash_info_*
▷ in an edge header this points to the first dash node ◁

⟨ Make d point to a new dash node created from stroke p and path *pp* or **goto** *not_found* if there is an error 517 ⟩ ≡

```
  ⟨ Make sure p and p0 are the same color and goto not_found if there is an error 519 ⟩;
  rr ← pp;
  if (mp_next_knot(pp) ≠ pp) {
    do {
      qq ← rr;  rr ← mp_next_knot(rr);
      ⟨ Check for retracing between knots qq and rr and goto not_found if there is a problem 518 ⟩;
    } while (mp_right_type(rr) ≠ mp_endpoint);
  }
  d ← (mp_dash_node) mp_get_dash_node(mp);
  if (mp_dash_p(p) ≡ Λ) dash_info(d) ← Λ;
  else dash_info(d) ← p;
  if (number_less(pp→x_coord, rr→x_coord)) {
    number_clone(d→start_x, pp→x_coord);  number_clone(d→stop_x, rr→x_coord);
  }
  else {
    number_clone(d→start_x, rr→x_coord);  number_clone(d→stop_x, pp→x_coord);
  }
```

This code is used in section 513.

518. We also need to check for the case where the segment from *qq* to *rr* is monotone in *x* but is reversed relative to the path from *pp* to *qq*.

⟨ Check for retracing between knots *qq* and *rr* and **goto** *not_found* if there is a problem 518 ⟩ ≡

```
{
  mp_number x0, x1, x2, x3;    ▷ x coordinates of the segment from qq to rr ◁
  new_number(x0); new_number(x1); new_number(x2); new_number(x3);
  number_clone(x0, qq→x_coord); number_clone(x1, qq→right_x); number_clone(x2, rr→left_x);
  number_clone(x3, rr→x_coord);
  if (number_greater(x0, x1) ∨ number_greater(x1, x2) ∨ number_greater(x2, x3)) {
    if (number_less(x0, x1) ∨ number_less(x1, x2) ∨ number_less(x2, x3)) {
      mp_number a1, a2, a3, a4;
      mp_number test;
      new_number(test); new_number(a1); new_number(a2); new_number(a3); new_number(a4);
      set_number_from_substraction(a1, x2, x1); set_number_from_substraction(a2, x2, x1);
      set_number_from_substraction(a3, x1, x0); set_number_from_substraction(a4, x3, x2);
      ab_vs_cd(test, a1, a2, a3, a4); free_number(a1); free_number(a2); free_number(a3);
      free_number(a4);
      if (number_positive(test)) {
        mp_x_retrace_error(mp); free_number(x0); free_number(x1); free_number(x2);
        free_number(x3); free_number(test); goto NOT_FOUND;
      }
      free_number(test);
    }
  }
  if (number_greater(pp→x_coord, x0) ∨ number_greater(x0, x3)) {
    if (number_less(pp→x_coord, x0) ∨ number_less(x0, x3)) {
      mp_x_retrace_error(mp); free_number(x0); free_number(x1); free_number(x2); free_number(x3);
      goto NOT_FOUND;
    }
  }
  free_number(x0); free_number(x1); free_number(x2); free_number(x3);
}
```

This code is used in section 517.

519. ⟨ Make sure *p* and *p0* are the same color and **goto** *not_found* if there is an error 519 ⟩ ≡

```
if (¬number_equal(((mp_stroked_node) p)→red,
      ((mp_stroked_node) p0)→red) ∨ ¬number_equal(((mp_stroked_node) p)→black,
      ((mp_stroked_node) p0)→black) ∨ ¬number_equal(((mp_stroked_node) p)→green,
      ((mp_stroked_node) p0)→green) ∨ ¬number_equal(((mp_stroked_node) p)→blue,
      ((mp_stroked_node) p0)→blue)) {
  const char *hlp[] ← {"When␣you␣say␣‘dashed␣p’,␣everything␣in␣picture␣p␣should",
      "be␣the␣same␣color.␣␣I␣can\’t␣handle␣your␣color␣changes",
      "so␣I’ll␣just␣make␣it␣a␣solid␣line␣instead.", Λ};
  mp_back_error(mp, "Picture␣is␣too␣complicated␣to␣use␣as␣a␣dash␣pattern", hlp, true);
  mp_get_x_next(mp); goto NOT_FOUND;
}
```

This code is used in section 517.

520. ⟨ Insert d into the dash list and **goto** *not_found* if there is an error 520 ⟩ ≡

$number\_clone(mp\rightarrow null\_dash\rightarrow start\_x, d\rightarrow stop\_x)$; $dd \leftarrow (\mathbf{mp\_dash\_node})\, h$;
  ▷ this makes $mp\_link(dd) \leftarrow dash\_list(h)$ ◁
while $(number\_less(((\mathbf{mp\_dash\_node})\, mp\_link(dd))\rightarrow start\_x, d\rightarrow stop\_x))$
  $dd \leftarrow (\mathbf{mp\_dash\_node})\, mp\_link(dd)$;
if $(dd \neq (\mathbf{mp\_dash\_node})\, h)$ {
  if $(number\_greater(dd\rightarrow stop\_x, d\rightarrow start\_x))$ {
    $mp\_x\_retrace\_error(mp)$; **goto** `NOT_FOUND`;
  }
}
$mp\_link(d) \leftarrow mp\_link(dd)$; $mp\_link(dd) \leftarrow (\mathbf{mp\_node})\, d$

This code is used in section 513.

521. ⟨ Set $dash\_y(h)$ and merge the first and last dashes if necessary 521 ⟩ ≡

$d \leftarrow dash\_list(h)$;
while $((mp\_link(d) \neq (\mathbf{mp\_node})\, mp\rightarrow null\_dash))$ $d \leftarrow (\mathbf{mp\_dash\_node})\, mp\_link(d)$;
$dd \leftarrow dash\_list(h)$; $set\_number\_from\_substraction(h\rightarrow dash\_y, d\rightarrow stop\_x, dd\rightarrow start\_x)$;
{
  mp_number *absval*;
  $new\_number(absval)$; $number\_clone(absval, y0)$; $number\_abs(absval)$;
  if $(number\_greater(absval, h\rightarrow dash\_y))$ {
    $number\_clone(h\rightarrow dash\_y, absval)$;
  }
  else if $(d \neq dd)$ {
    $set\_dash\_list(h, mp\_link(dd))$; $set\_number\_from\_addition(d\rightarrow stop\_x, dd\rightarrow stop\_x, h\rightarrow dash\_y)$;
    $mp\_free\_node(mp, (\mathbf{mp\_node})\, dd, dash\_node\_size)$;
  }
  $free\_number(absval)$;
}

This code is used in section 513.

522. We get here when the argument is a NULL picture or when there is an error. Recovering from an error involves making $dash\_list(h)$ empty to indicate that h is not known to be a valid dash pattern. We also dereference h since it is not being used for the return value.

⟨ Flush the dash list, recycle h and return Λ 522 ⟩ ≡
$mp\_flush\_dash\_list(mp, h)$; $delete\_edge\_ref(h)$; **return** Λ

This code is used in section 513.

523. Having carefully saved the dashed stroked nodes in the corresponding dash nodes, we must be prepared to break up these dashes into smaller dashes.

⟨ Scan *dash_list*(*h*) and deal with any dashes that are themselves dashed 523 ⟩ ≡

```
{
  mp_number hsf;    ▷ the dash pattern from hh gets scaled by this ◁
  new_number(hsf); d ← (mp_dash_node) h;    ▷ now mp_link(d) ← dash_list(h) ◁
  while (mp_link(d) ≠ (mp_node) mp→null_dash) {
    ds ← dash_info(mp_link(d));
    if (ds ≡ Λ) {
      d ← (mp_dash_node) mp_link(d);
    }
    else {
      hh ← (mp_edge_header_node) mp_dash_p(ds);
      number_clone(hsf, ((mp_stroked_node) ds)→dash_scale);
      if (hh ≡ Λ) mp_confusion(mp, "dash1");
      assert(hh);    ▷ clang: dereference null pointer 'hh' ◁
      if (number_zero(((mp_dash_node) hh)→dash_y)) {
        d ← (mp_dash_node) mp_link(d);
      }
      else {
        if (dash_list(hh) ≡ Λ) mp_confusion(mp, "dash1");
        ⟨ Replace mp_link(d) by a dashed version as determined by edge header hh and scale factor
            ds 525 ⟩;
      }
    }
  }
  free_number(hsf);
}
```

This code is used in section 513.

524. ⟨ Other local variables in *make_dashes* 524 ⟩ ≡

```
mp_dash_node dln;    ▷ mp_link(d) ◁
mp_edge_header_node hh;    ▷ an edge header that tells how to break up dln ◁
mp_node ds;    ▷ the stroked node from which hh and hsf are derived ◁
```

This code is used in section 513.

525. ⟨ Replace *mp_link*(d) by a dashed version as determined by edge header *hh* and scale factor *ds* 525 ⟩ ≡

```
{
  mp_number xoff;    ▷ added to x values in dash_list(hh) to match dln ◁
  mp_number dashoff;
  mp_number r1, r2;
  new_number(r1); new_number(r2); dln ← (mp_dash_node) mp_link(d); dd ← dash_list(hh);
    ▷ clang: dereference null pointer 'dd' ◁
  assert(dd); new_number(xoff); new_number(dashoff);
  mp_dash_offset(mp, &dashoff, (mp_dash_node) hh); take_scaled(r1, hsf, dd→start_x);
  take_scaled(r2, hsf, dashoff); number_add(r1, r2);
  set_number_from_substraction(xoff, dln→start_x, r1); free_number(dashoff);
  take_scaled(r1, hsf, dd→start_x); take_scaled(r2, hsf, hh→dash_y);
  set_number_from_addition(mp→null_dash→start_x, r1, r2);
  number_clone(mp→null_dash→stop_x, mp→null_dash→start_x);
  ⟨ Advance dd until finding the first dash that overlaps dln when offset by xoff 526 ⟩;
  while (number_lessequal(dln→start_x, dln→stop_x)) {
    ⟨ If dd has 'fallen off the end', back up to the beginning and fix xoff 527 ⟩;
    ⟨ Insert a dash between d and dln for the overlap with the offset version of dd 528 ⟩;
    dd ← (mp_dash_node) mp_link(dd); take_scaled(r1, hsf, dd→start_x);
    set_number_from_addition(dln→start_x, xoff, r1);
  }
  free_number(xoff); free_number(r1); free_number(r2); mp_link(d) ← mp_link(dln);
  mp_free_node(mp, (mp_node) dln, dash_node_size);
}
```

This code is used in section 523.

526. The name of this module is a bit of a lie because we just find the first *dd* where *take_scaled*(*hsf*, *stop_x*(*dd*)) is large enough to make an overlap possible. It could be that the unoffset version of dash *dln* falls in the gap between *dd* and its predecessor.

⟨ Advance *dd* until finding the first dash that overlaps *dln* when offset by *xoff* 526 ⟩ ≡

```
{
  mp_number r1;
  new_number(r1); take_scaled(r1, hsf, dd→stop_x); number_add(r1, xoff);
  while (number_less(r1, dln→start_x)) {
    dd ← (mp_dash_node) mp_link(dd); take_scaled(r1, hsf, dd→stop_x); number_add(r1, xoff);
  }
  free_number(r1);
}
```

This code is used in section 525.

527. ⟨ If *dd* has 'fallen off the end', back up to the beginning and fix *xoff* 527 ⟩ ≡

```
if (dd ≡ mp→null_dash) {
  mp_number ret;
  new_number(ret); dd ← dash_list(hh); take_scaled(ret, hsf, hh→dash_y); number_add(xoff, ret);
  free_number(ret);
}
```

This code is used in section 525.

528. At this point we already know that $start\_x(dln) \le xoff + take\_scaled(hsf, stop\_x(dd))$.

⟨ Insert a dash between d and dln for the overlap with the offset version of dd 528 ⟩ ≡

```
{
  mp_number r1;
  new_number(r1); take_scaled(r1, hsf, dd→start_x); number_add(r1, xoff);
  if (number_lessequal(r1, dln→stop_x)) {
    mp_link(d) ← (mp_node) mp_get_dash_node(mp); d ← (mp_dash_node) mp_link(d);
    mp_link(d) ← (mp_node) dln; take_scaled(r1, hsf, dd→start_x); number_add(r1, xoff);
    if (number_greater(dln→start_x, r1)) number_clone(d→start_x, dln→start_x);
    else number_clone(d→start_x, r1);
    take_scaled(r1, hsf, dd→stop_x); number_add(r1, xoff);
    if (number_less(dln→stop_x, r1)) number_clone(d→stop_x, dln→stop_x);
    else number_clone(d→stop_x, r1);
  }
  free_number(r1);
}
```

This code is used in section 525.

529. The next major task is to update the bounding box information in an edge header h. This is done via a procedure *adjust_bbox* that enlarges an edge header's bounding box to accommodate the box computed by *path_bbox* or *pen_bbox*. (This is stored in global variables *minx*, *miny*, *maxx*, and *maxy*.)

```
static void mp_adjust_bbox(MP mp, mp_edge_header_node h)
{
  if (number_less(mp_minx, h→minx)) number_clone(h→minx, mp_minx);
  if (number_less(mp_miny, h→miny)) number_clone(h→miny, mp_miny);
  if (number_greater(mp_maxx, h→maxx)) number_clone(h→maxx, mp_maxx);
  if (number_greater(mp_maxy, h→maxy)) number_clone(h→maxy, mp_maxy);
}
```

530. Here is a special routine for updating the bounding box information in edge header h to account for the squared-off ends of a non-cyclic path p that is to be stroked with the pen pp.

static void *mp_box_ends*(**MP** *mp*, **mp_knot** *p*, **mp_knot** *pp*, **mp_edge_header_node** *h*)
{
  mp_knot *q*; ▷ a knot node adjacent to knot p ◁
  mp_fraction *dx*, *dy*; ▷ a unit vector in the direction out of the path at p ◁
  mp_number *d*; ▷ a factor for adjusting the length of (dx, dy) ◁
  mp_number *z*; ▷ a coordinate being tested against the bounding box ◁
  mp_number *xx*, *yy*; ▷ the extreme pen vertex in the (dx, dy) direction ◁
  integer *i*; ▷ a loop counter ◁
  new_fraction(*dx*); *new_fraction*(*dy*); *new_number*(*xx*); *new_number*(*yy*); *new_number*(*z*);
  new_number(*d*);
  if (*mp_right_type*(*p*) ≠ *mp_endpoint*) {
    $q \leftarrow$ *mp_next_knot*(*p*);
    while (1) {
      ⟨Make (dx, dy) the final direction for the path segment from q to p; set d 531⟩;
      pyth_add(*d*, *dx*, *dy*);
      if (*number_positive*(*d*)) {
        ⟨Normalize the direction (dx, dy) and find the pen offset (xx, yy) 532⟩;
        for ($i \leftarrow 1$; $i \le 2$; i++) {
          ⟨Use (dx, dy) to generate a vertex of the square end cap and update the bounding box to accommodate it 533⟩;
          number_negate(*dx*); *number_negate*(*dy*);
        }
      }
      if (*mp_right_type*(*p*) ≡ *mp_endpoint*) {
        goto `DONE`;
      }
      else ⟨Advance p to the end of the path and make q the previous knot 534⟩
    }
  }
`DONE`: *free_number*(*dx*); *free_number*(*dy*); *free_number*(*xx*); *free_number*(*yy*); *free_number*(*z*);
  free_number(*d*);
}

531. ⟨ Make (dx, dy) the final direction for the path segment from q to p; set d 531 ⟩ ≡

```
if (q ≡ mp_next_knot(p)) {
   set_number_from_substraction(dx, p→x_coord, p→right_x);
   set_number_from_substraction(dy, p→y_coord, p→right_y);
   if (number_zero(dx) ∧ number_zero(dy)) {
      set_number_from_substraction(dx, p→x_coord, q→left_x);
      set_number_from_substraction(dy, p→y_coord, q→left_y);
   }
}
else {
   set_number_from_substraction(dx, p→x_coord, p→left_x);
   set_number_from_substraction(dy, p→y_coord, p→left_y);
   if (number_zero(dx) ∧ number_zero(dy)) {
      set_number_from_substraction(dx, p→x_coord, q→right_x);
      set_number_from_substraction(dy, p→y_coord, q→right_y);
   }
}
set_number_from_substraction(dx, p→x_coord, q→x_coord);
set_number_from_substraction(dy, p→y_coord, q→y_coord);
```

This code is used in section 530.

532. ⟨ Normalize the direction (dx, dy) and find the pen offset (xx, yy) 532 ⟩ ≡

```
{
   mp_number arg1, r;
   new_fraction(r); new_number(arg1); make_fraction(r, dx, d); number_clone(dx, r);
   make_fraction(r, dy, d); number_clone(dy, r); free_number(r); number_clone(arg1, dy);
   number_negate(arg1); mp_find_offset(mp, arg1, dx, pp); free_number(arg1);
   number_clone(xx, mp→cur_x); number_clone(yy, mp→cur_y);
}
```

This code is used in section 530.

533. ⟨ Use (dx, dy) to generate a vertex of the square end cap and update the bounding box to accommodate it 533 ⟩ ≡

```
{
   mp_number r1, r2, arg1;
   new_number(arg1); new_fraction(r1); new_fraction(r2); mp_find_offset(mp, dx, dy, pp);
   set_number_from_substraction(arg1, xx, mp→cur_x); take_fraction(r1, arg1, dx);
   set_number_from_substraction(arg1, yy, mp→cur_y); take_fraction(r2, arg1, dy);
   set_number_from_addition(d, r1, r2);
   if ((number_negative(d) ∧ (i ≡ 1)) ∨ (number_positive(d) ∧ (i ≡ 2))) mp_confusion(mp, "box_ends");
   take_fraction(r1, d, dx); set_number_from_addition(z, p→x_coord, mp→cur_x); number_add(z, r1);
   if (number_less(z, h→minx)) number_clone(h→minx, z);
   if (number_greater(z, h→maxx)) number_clone(h→maxx, z);
   take_fraction(r1, d, dy); set_number_from_addition(z, p→y_coord, mp→cur_y); number_add(z, r1);
   if (number_less(z, h→miny)) number_clone(h→miny, z);
   if (number_greater(z, h→maxy)) number_clone(h→maxy, z);
   free_number(r1); free_number(r2); free_number(arg1);
}
```

This code is used in section 530.

534. ⟨ Advance p to the end of the path and make q the previous knot 534 ⟩ ≡

```
do {
  q ← p; p ← mp_next_knot(p);
} while (mp_right_type(p) ≠ mp_endpoint);
```

This code is used in section 530.

535. The major difficulty in finding the bounding box of an edge structure is the effect of clipping paths. We treat them conservatively by only clipping to the clipping path's bounding box, but this still requires recursive calls to *set_bbox* in order to find the bounding box of the objects to be clipped. Such calls are distinguished by the fact that the boolean parameter *top_level* is false.

```
void mp_set_bbox(MP mp, mp_edge_header_node h, boolean top_level)
{
  mp_node p;   ▷ a graphical object being considered ◁
  integer lev;   ▷ nesting level for mp_start_bounds_node nodes ◁   ▷ Wipe out any existing
      bounding box information if bbtype(h) is incompatible with internal[mp_true_corners] ◁
  switch (h→bbtype) {
  case no_bounds: break;
  case bounds_set:
    if (number_positive(internal_value(mp_true_corners))) mp_init_bbox(mp, h);
    break;
  case bounds_unset:
    if (number_nonpositive(internal_value(mp_true_corners))) mp_init_bbox(mp, h);
    break;
  }   ▷ there are no other cases ◁
  while (mp_link(bblast(h)) ≠ Λ) {
    p ← mp_link(bblast(h)); bblast(h) ← p;
    switch (mp_type(p)) {
    case mp_stop_clip_node_type:
      if (top_level) mp_confusion(mp, "bbox");
      else return;
      break;
    ⟨ Other cases for updating the bounding box based on the type of object p 537 ⟩
    default:   ▷ there are no other valid cases, but please the compiler ◁
      break;
    }
  }
  if (¬top_level) mp_confusion(mp, "bbox");
}
```

536. ⟨ Declarations 10 ⟩ +≡

```
static void mp_set_bbox(MP mp, mp_edge_header_node h, boolean top_level);
```

537. ⟨ Other cases for updating the bounding box based on the type of object p 537 ⟩ ≡
case *mp_fill_node_type*: *mp_path_bbox*(*mp*, *mp_path_p*((**mp_fill_node**) *p*));
  if (*mp_pen_p*((**mp_fill_node**) *p*) $\neq \Lambda$) {
    mp_number *x0a*, *y0a*, *x1a*, *y1a*;
    new_number(*x0a*); *new_number*(*y0a*); *new_number*(*x1a*); *new_number*(*y1a*);
    number_clone(*x0a*, *mp_minx*); *number_clone*(*y0a*, *mp_miny*); *number_clone*(*x1a*, *mp_maxx*);
    number_clone(*y1a*, *mp_maxy*); *mp_pen_bbox*(*mp*, *mp_pen_p*((**mp_fill_node**) *p*));
    number_add(*mp_minx*, *x0a*); *number_add*(*mp_miny*, *y0a*); *number_add*(*mp_maxx*, *x1a*);
    number_add(*mp_maxy*, *y1a*); *free_number*(*x0a*); *free_number*(*y0a*); *free_number*(*x1a*);
    free_number(*y1a*);
  }
  mp_adjust_bbox(*mp*, *h*); **break**;

See also sections 538, 540, 541, and 542.

This code is used in section 535.

538. ⟨ Other cases for updating the bounding box based on the type of object p 537 ⟩ +≡
case *mp_start_bounds_node_type*:
  if (*number_positive*(*internal_value*(*mp_true_corners*))) {
    h→*bbtype* ← *bounds_unset*;
  }
  else {
    h→*bbtype* ← *bounds_set*; *mp_path_bbox*(*mp*, *mp_path_p*((**mp_start_bounds_node**) *p*));
    mp_adjust_bbox(*mp*, *h*);
    ⟨ Scan to the matching **mp_stop_bounds_node** node and update *p* and *bblast*(*h*) 539 ⟩;
  }
  break;
case *mp_stop_bounds_node_type*:
  if (*number_nonpositive*(*internal_value*(*mp_true_corners*))) *mp_confusion*(*mp*, "bbox2");
  break;

539. ⟨ Scan to the matching **mp_stop_bounds_node** node and update *p* and *bblast*(*h*) 539 ⟩ ≡
  lev ← 1;
  while (*lev* $\neq$ 0) {
    if (*mp_link*(*p*) ≡ Λ) *mp_confusion*(*mp*, "bbox2");   ▷ clang: dereference null pointer ◁
    assert(*mp_link*(*p*)); *p* ← *mp_link*(*p*);
    if (*mp_type*(*p*) ≡ *mp_start_bounds_node_type*) *incr*(*lev*);
    else if (*mp_type*(*p*) ≡ *mp_stop_bounds_node_type*) *decr*(*lev*);
  }
  bblast(*h*) ← *p*

This code is used in section 538.

540. It saves a lot of grief here to be slightly conservative and not account for omitted parts of dashed lines. We also don't worry about the material omitted when using butt end caps. The basic computation is for round end caps and *box_ends* augments it for square end caps.

⟨ Other cases for updating the bounding box based on the type of object *p* 537 ⟩ +≡
case *mp_stroked_node_type*: *mp_path_bbox*(*mp*, *mp_path_p*((**mp_stroked_node**) *p*));
{
mp_number *x0a*, *y0a*, *x1a*, *y1a*;
new_number(*x0a*); *new_number*(*y0a*); *new_number*(*x1a*); *new_number*(*y1a*);
number_clone(*x0a*, *mp_minx*); *number_clone*(*y0a*, *mp_miny*); *number_clone*(*x1a*, *mp_maxx*);
number_clone(*y1a*, *mp_maxy*); *mp_pen_bbox*(*mp*, *mp_pen_p*((**mp_stroked_node**) *p*));
number_add(*mp_minx*, *x0a*); *number_add*(*mp_miny*, *y0a*); *number_add*(*mp_maxx*, *x1a*);
number_add(*mp_maxy*, *y1a*); *free_number*(*x0a*); *free_number*(*y0a*); *free_number*(*x1a*);
free_number(*y1a*);
}
mp_adjust_bbox(*mp*, *h*);
if ((*mp_left_type*(*mp_path_p*((**mp_stroked_node**) *p*)) ≡ *mp_endpoint*)
∧ (((**mp_stroked_node**) *p*)→*lcap* ≡ 2))
mp_box_ends(*mp*, *mp_path_p*((**mp_stroked_node**) *p*), *mp_pen_p*((**mp_stroked_node**) *p*), *h*);
break;

541. The height width and depth information stored in a text node determines a rectangle that needs to be transformed according to the transformation parameters stored in the text node.

⟨ Other cases for updating the bounding box based on the type of object p 537 ⟩ +≡

```
case mp_text_node_type:
  {
    mp_number x0a, y0a, x1a, y1a, arg1;
    mp_text_node p0 ← (mp_text_node) p;
    new_number(x0a); new_number(x1a); new_number(y0a); new_number(y1a); new_number(arg1);
    number_clone(arg1, p0→depth); number_negate(arg1); take_scaled(x1a, p0→txx, p0→width);
    take_scaled(y0a, p0→txy, arg1); take_scaled(y1a, p0→txy, p0→height); number_clone(mp_minx, p0→tx);
    number_clone(mp_maxx, mp_minx);
    if (number_less(y0a, y1a)) {
      number_add(mp_minx, y0a); number_add(mp_maxx, y1a);
    }
    else {
      number_add(mp_minx, y1a); number_add(mp_maxx, y0a);
    }
    if (number_negative(x1a)) number_add(mp_minx, x1a);
    else number_add(mp_maxx, x1a);
    take_scaled(x1a, p0→tyx, p0→width); number_clone(arg1, p0→depth); number_negate(arg1);
    take_scaled(y0a, p0→tyy, arg1); take_scaled(y1a, p0→tyy, p0→height); number_clone(mp_miny, p0→ty);
    number_clone(mp_maxy, mp_miny);
    if (number_less(y0a, y1a)) {
      number_add(mp_miny, y0a); number_add(mp_maxy, y1a);
    }
    else {
      number_add(mp_miny, y1a); number_add(mp_maxy, y0a);
    }
    if (number_negative(x1a)) number_add(mp_miny, x1a);
    else number_add(mp_maxy, x1a);
    mp_adjust_bbox(mp, h); free_number(x0a); free_number(y0a); free_number(x1a); free_number(y1a);
    free_number(arg1);
  }
  break;
```

542. This case involves a recursive call that advances *bblast*(h) to the node of type **mp_stop_clip_node** that matches p.

⟨ Other cases for updating the bounding box based on the type of object p 537 ⟩ +≡
case *mp_start_clip_node_type*:
  {
    mp_number *sminx*, *sminy*, *smaxx*, *smaxy*; ▷ for saving the bounding box during recursive calls ◁
    mp_number *x0a*, *y0a*, *x1a*, *y1a*;
    new_number(*x0a*); *new_number*(*y0a*); *new_number*(*x1a*); *new_number*(*y1a*); *new_number*(*sminx*); *new_number*(*sminy*); *new_number*(*smaxx*); *new_number*(*smaxy*);
    mp_path_bbox(*mp*, *mp_path_p*((**mp_start_clip_node**) *p*)); *number_clone*(*x0a*, *mp_minx*); *number_clone*(*y0a*, *mp_miny*); *number_clone*(*x1a*, *mp_maxx*); *number_clone*(*y1a*, *mp_maxy*); *number_clone*(*sminx*, *h*→*minx*); *number_clone*(*sminy*, *h*→*miny*); *number_clone*(*smaxx*, *h*→*maxx*); *number_clone*(*smaxy*, *h*→*maxy*);
    ⟨ Reinitialize the bounding box in header h and call *set_bbox* recursively starting at *mp_link*(p) 543 ⟩;
    ⟨ Clip the bounding box in h to the rectangle given by *x0a*, *x1a*, *y0a*, *y1a* 544 ⟩;
    number_clone(*mp_minx*, *sminx*); *number_clone*(*mp_miny*, *sminy*); *number_clone*(*mp_maxx*, *smaxx*); *number_clone*(*mp_maxy*, *smaxy*); *mp_adjust_bbox*(*mp*, *h*); *free_number*(*sminx*); *free_number*(*sminy*); *free_number*(*smaxx*); *free_number*(*smaxy*); *free_number*(*x0a*); *free_number*(*y0a*); *free_number*(*x1a*); *free_number*(*y1a*);
  }
  break;

543. ⟨ Reinitialize the bounding box in header h and call *set_bbox* recursively starting at *mp_link*(p) 543 ⟩ ≡
  set_number_to_inf(*h*→*minx*); *set_number_to_inf*(*h*→*miny*); *set_number_to_neg_inf*(*h*→*maxx*); *set_number_to_neg_inf*(*h*→*maxy*); *mp_set_bbox*(*mp*, *h*, *false*)

This code is used in section 542.

544. ⟨ Clip the bounding box in h to the rectangle given by *x0a*, *x1a*, *y0a*, *y1a* 544 ⟩ ≡
  if (*number_less*(*h*→*minx*, *x0a*)) *number_clone*(*h*→*minx*, *x0a*);
  if (*number_less*(*h*→*miny*, *y0a*)) *number_clone*(*h*→*miny*, *y0a*);
  if (*number_greater*(*h*→*maxx*, *x1a*)) *number_clone*(*h*→*maxx*, *x1a*);
  if (*number_greater*(*h*→*maxy*, *y1a*)) *number_clone*(*h*→*maxy*, *y1a*);

This code is used in section 542.

545. Finding an envelope. When METAPOST has a path and a polygonal pen, it needs to express the desired shape in terms of things PostScript can understand. The present task is to compute a new path that describes the region to be filled. It is convenient to define this as a two step process where the first step is determining what offset to use for each segment of the path.

546. Given a pointer c to a cyclic path, and a pointer h to the first knot of a pen polygon, the *offset_prep* routine changes the path into cubics that are associated with particular pen offsets. Thus if the cubic between p and q is associated with the kth offset and the cubic between q and r has offset l then $mp\_info(q) \leftarrow zero\_off + l - k$. (The constant *zero_off* is added to because $l - k$ could be negative.)

After overwriting the type information with offset differences, we no longer have a true path so we refer to the knot list returned by *offset_prep* as an "envelope spec." Since an envelope spec only determines relative changes in pen offsets, *offset_prep* sets a global variable *spec_offset* to the relative change from h to the first offset.

#**define** *zero_off* 16384 ▷ added to offset changes to make them positive ◁

⟨ Global variables 18 ⟩ +≡
  integer *spec_offset*; ▷ number of pen edges between h and the initial offset ◁

547. The next function calculates $1/3B'(t) = (-p+(3c_1+(-3c_2+q)))*t^2+(2p+(-4c_1+2*c_2))t+(-p+c_1)$, for cubic curve $B(t)$ given by $p,c1,c2,q$ and it's used for t near 0 and t near 1. We use double mode, otherwise we have to take care of overflow.

static mp_knot *mp_offset_prep*(**MP** *mp*, **mp_knot** *c*, **mp_knot** *h*)
{
  int *n*; ▷ the number of vertices in the pen polygon ◁
  mp_knot *c0*, *p*, *q*, *q0*, *r*, *w*, *ww*; ▷ for list manipulation ◁
  int *k_needed*; ▷ amount to be added to *mp_info*(*p*) when it is computed ◁
  mp_knot *w0*; ▷ a pointer to pen offset to use just before *p* ◁
  mp_number *dxin*, *dyin*; ▷ the direction into knot *p* ◁
  int *turn_amt*; ▷ change in pen offsets for the current cubic ◁
  mp_number *max_coef*; ▷ used while scaling ◁
  mp_number *ss*;
  ⟨Other local variables for *offset_prep* 561⟩;
  new_number(*max_coef*); *new_number*(*dxin*); *new_number*(*dyin*); *new_number*(*dx0*);
  new_number(*dy0*); *new_number*(*x0*); *new_number*(*y0*); *new_number*(*x1*); *new_number*(*y1*);
  new_number(*x2*); *new_number*(*y2*); *new_number*(*du*); *new_number*(*dv*); *new_number*(*dx*);
  new_number(*dy*); *new_number*(*x0a*); *new_number*(*y0a*); *new_number*(*x1a*); *new_number*(*y1a*);
  new_number(*x2a*); *new_number*(*y2a*); *new_number*(*t0*); *new_number*(*t1*); *new_number*(*t2*);
  new_number(*u0*); *new_number*(*u1*); *new_number*(*v0*); *new_number*(*v1*); *new_number*(*dx_m*);
  new_number(*dy_m*); *new_number*(*dxin_m*); *new_number*(*dx_ap*); *new_number*(*dy_ap*);
  new_number(*dxin_ap*); *new_number*(*dyin_ap*); *new_number*(*ueps_ap*); *new_fraction*(*ss*);
  new_fraction(*s*); *new_fraction*(*t*); ⟨Initialize the pen size *n* 550⟩
  ⟨Initialize the incoming direction and pen offset at *c* 551⟩*p* ← *c*; *c0* ← *c*; *k_needed* ← 0;
#ifdef `DEBUGENVELOPE`
  dbg_nl; *dbg_str*(|–[==[BEGIN]==]); *dbg_nl*; *dbg_str*(|return); *dbg_nl*; *dbg_n*(*w0*→*x_coord*);
  dbg_n(*w0*→*y_coord*);
#endif
  do {
    q ← *mp_next_knot*(*p*);
#ifdef `DEBUGENVELOPE`
    dbg_nl; *dbg_open_t*; *dbg_str*(|–[==[begin loop]==]); *dbg_nl*; *dbg_n*(*p*→*x_coord*); *dbg_n*(*p*→*y_coord*);
    dbg_n(*p*→*right_x*); *dbg_n*(*p*→*right_y*); *dbg_n*(*q*→*left_x*); *dbg_n*(*q*→*left_y*); *dbg_n*(*q*→*x_coord*);
    dbg_n(*q*→*y_coord*); *dbg_n*(*w0*→*x_coord*); *dbg_n*(*w0*→*y_coord*);
#endif
    ⟨Split the cubic between *p* and *q*, if necessary, into cubics associated with single offsets, after which *q* should point to the end of the final such cubic 558⟩;
#ifdef `DEBUGENVELOPE`
    dbg_key(|end Split the cubic between p and q); *dbg_open_t*; *dbg_nl*; *dbg_n*(*w*→*x_coord*);
    dbg_n(*w*→*y_coord*); *dbg_n*(*w0*→*x_coord*); *dbg_n*(*w0*→*y_coord*); *dbg_close_t*; *dbg_comma*; *dbg_nl*;
#endif
  `NOT_FOUND`: ⟨Advance *p* to node *q*, removing any "dead" cubics that might have been introduced by the splitting process 552⟩;
#ifdef `DEBUGENVELOPE`
    dbg_n(*w0*→*x_coord*); *dbg_n*(*w0*→*y_coord*); *dbg_str*(|–[==[end loop]==]); *dbg_nl*; *dbg_close_t*;
    dbg_comma; *dbg_nl*;
#endif
  } **while** ($q \neq c$);
#ifdef `DEBUGENVELOPE`
  dbg_key(|Fix the offset change); *dbg_open_t*; *dbg_nl*; *dbg_n*(*p*→*x_coord*); *dbg_n*(*p*→*y_coord*);
  dbg_key_ival(*info pre*, *mp_knot_info*(*p*)); *dbg_comma*; *dbg_nl*; *dbg_n*(*c*→*x_coord*); *dbg_n*(*c*→*y_coord*);
  dbg_key_ival(*info pre*, *mp_knot_info*(*c*)); *dbg_close_t*; *dbg_comma*; *dbg_nl*;

#endif
⟨ Fix the offset change in *mp_knot_info*(*c*) and set *c* to the return value of *offset_prep* 572 ⟩;
#ifdef DEBUGENVELOPE
dbg_n(*p*→*x_coord*); *dbg_n*(*p*→*y_coord*); *dbg_key_ival*(*info post*, *mp_knot_info*(*p*)); *dbg_comma*; *dbg_nl*;
dbg_n(*c*→*x_coord*); *dbg_n*(*c*→*y_coord*); *dbg_key_ival*(*info post*, *mp_knot_info*(*c*)); *dbg_close_t*; *dbg_nl*;
dbg_str(|–[==[END]==]); *dbg_nl*;
#endif
free_number(*ss*); *free_number*(*s*); *free_number*(*dxin*); *free_number*(*dyin*); *free_number*(*dx0*);
free_number(*dy0*); *free_number*(*x0*); *free_number*(*y0*); *free_number*(*x1*); *free_number*(*y1*);
free_number(*x2*); *free_number*(*y2*); *free_number*(*max_coef*); *free_number*(*du*); *free_number*(*dv*);
free_number(*dx*); *free_number*(*dy*); *free_number*(*x0a*); *free_number*(*y0a*); *free_number*(*x1a*);
free_number(*y1a*); *free_number*(*x2a*); *free_number*(*y2a*); *free_number*(*t0*); *free_number*(*t1*);
free_number(*t2*); *free_number*(*u0*); *free_number*(*u1*); *free_number*(*v0*); *free_number*(*v1*);
free_number(*dx_m*); *free_number*(*dy_m*); *free_number*(*dxin_m*); *free_number*(*dx_ap*);
free_number(*dy_ap*); *free_number*(*dxin_ap*); *free_number*(*dyin_ap*); *free_number*(*ueps_ap*);
free_number(*t*); **return** *c*;
}

548. We shall want to keep track of where certain knots on the cyclic path wind up in the envelope spec. It doesn't suffice just to keep pointers to knot nodes because some nodes are deleted while removing dead cubics. Thus *offset_prep* updates the following pointers

⟨ Global variables 18 ⟩ +≡
mp_knot *spec_p1*;
mp_knot *spec_p2*; ▷ pointers to distinguished knots ◁

549. ⟨ Set initial values of key variables 42 ⟩ +≡
mp→*spec_p1* ← Λ; *mp*→*spec_p2* ← Λ;

550. ⟨ Initialize the pen size *n* 550 ⟩ ≡
n ← 0; *p* ← *h*;
do {
incr(*n*); *p* ← *mp_next_knot*(*p*);
} **while** (*p* ≠ *h*);

This code is used in section 547.

551. Since the true incoming direction isn't known yet, we just pick a direction consistent with the pen offset *h*. If this is wrong, it can be corrected later.

⟨ Initialize the incoming direction and pen offset at *c* 551 ⟩ ≡
{
mp_knot *hn* ← *mp_next_knot*(*h*);
mp_knot *hp* ← *mp_prev_knot*(*h*);
set_number_from_substraction(*dxin*, *hn*→*x_coord*, *hp*→*x_coord*);
set_number_from_substraction(*dyin*, *hn*→*y_coord*, *hp*→*y_coord*);
if (*number_zero*(*dxin*) ∧ *number_zero*(*dyin*)) {
set_number_from_substraction(*dxin*, *hp*→*y_coord*, *h*→*y_coord*);
set_number_from_substraction(*dyin*, *h*→*x_coord*, *hp*→*x_coord*);
}
}
w0 ← *h*;

This code is used in section 547.

552. We must be careful not to remove the only cubic in a cycle.

But we must also be careful for another reason. If the user-supplied path starts with a set of degenerate cubics, the target node q can be collapsed to the initial node p which might be the same as the initial node c of the curve. This would cause the *offset_prep* routine to bail out too early, causing distress later on. (See for example the testcase reported by Bogusław Jackowski in tracker id 267, case 52c on Sarovar.)

⟨ Advance p to node q, removing any "dead" cubics that might have been introduced by the splitting process 552 ⟩ ≡

```
#ifdef DEBUGENVELOPE
  dbg_comment(|Advance p to node q); dbg_nl;
#endif
  q0 ← q;
  do {
    r ← mp_next_knot(p);
    if (number_equal(p→x_coord, p→right_x) ∧ number_equal(p→y_coord, p→right_y) ∧
          number_equal(p→x_coord, r→left_x) ∧ number_equal(p→y_coord, r→left_y) ∧
          number_equal(p→x_coord, r→x_coord) ∧ number_equal(p→y_coord, r→y_coord) ∧ r ≠ p ∧ r ≠ q)
      ⟨ Remove the cubic following p and update the data structures to merge r into p 553 ⟩
    p ← r;
  } while (p ≠ q);    ▷ Check if we removed too much ◁
  if ((q ≠ q0) ∧ (q ≠ c ∨ c ≡ c0)) q ← mp_next_knot(q)
```

This code is used in section 547.

553. ⟨ Remove the cubic following p and update the data structures to merge r into p 553 ⟩ ≡

```
  {
#ifdef DEBUGENVELOPE
    dbg_key(|Remove the cubic following p); dbg_open_t; dbg_nl; dbg_n(p→x_coord); dbg_n(p→y_coord);
    dbg_key_ival(pre info(p), mp_knot_info(p)); dbg_close_t; dbg_comma; dbg_nl;
#endif
    k_needed ← mp_knot_info(p) − zero_off;
    if (r ≡ q) {
      q ← p;
    }
    else {
      mp_knot_info(p) ← k_needed + mp_knot_info(r); k_needed ← 0;
    }
    if (r ≡ c) {
      mp_knot_info(p) ← mp_knot_info(c); c ← p;
    }
    if (r ≡ mp→spec_p1) mp→spec_p1 ← p;
    if (r ≡ mp→spec_p2) mp→spec_p2 ← p;
    r ← p; mp_remove_cubic(mp, p);
#ifdef DEBUGENVELOPE
    dbg_key(|Remove the cubic following p); dbg_open_t; dbg_nl; dbg_n(p→x_coord); dbg_n(p→y_coord);
    dbg_key_ival(post info(p), mp_knot_info(p)); dbg_close_t; dbg_comma; dbg_nl;
#endif
  }
```

This code is used in section 552.

554. Not setting the *info* field of the newly created knot allows the splitting routine to work for paths.

⟨ Declarations 10 ⟩ +≡

```
  static void mp_split_cubic(MP mp, mp_knot p, mp_number t);
```

555. **void** mp_split_cubic(**MP** mp, **mp_knot** p, **mp_number** t)
{ ▷ splits the cubic after p ◁
mp_number v; ▷ an intermediate value ◁
mp_knot q, r; ▷ for list manipulation ◁
$q \leftarrow mp\_next\_knot(p)$; $r \leftarrow mp\_new\_knot(mp)$; $mp\_next\_knot(p) \leftarrow r$; $mp\_next\_knot(r) \leftarrow q$;
$mp\_originator(r) \leftarrow mp\_program\_code$; $mp\_left\_type(r) \leftarrow mp\_explicit$;
$mp\_right\_type(r) \leftarrow mp\_explicit$; $new\_number(v)$; $set\_number\_from\_of\_the\_way(v, t, p\rightarrow right\_x, q\rightarrow left\_x)$;
$set\_number\_from\_of\_the\_way(p\rightarrow right\_x, t, p\rightarrow x\_coord, p\rightarrow right\_x)$;
$set\_number\_from\_of\_the\_way(q\rightarrow left\_x, t, q\rightarrow left\_x, q\rightarrow x\_coord)$;
$set\_number\_from\_of\_the\_way(r\rightarrow left\_x, t, p\rightarrow right\_x, v)$;
$set\_number\_from\_of\_the\_way(r\rightarrow right\_x, t, v, q\rightarrow left\_x)$;
$set\_number\_from\_of\_the\_way(r\rightarrow x\_coord, t, r\rightarrow left\_x, r\rightarrow right\_x)$;
$set\_number\_from\_of\_the\_way(v, t, p\rightarrow right\_y, q\rightarrow left\_y)$;
$set\_number\_from\_of\_the\_way(p\rightarrow right\_y, t, p\rightarrow y\_coord, p\rightarrow right\_y)$;
$set\_number\_from\_of\_the\_way(q\rightarrow left\_y, t, q\rightarrow left\_y, q\rightarrow y\_coord)$;
$set\_number\_from\_of\_the\_way(r\rightarrow left\_y, t, p\rightarrow right\_y, v)$;
$set\_number\_from\_of\_the\_way(r\rightarrow right\_y, t, v, q\rightarrow left\_y)$;
$set\_number\_from\_of\_the\_way(r\rightarrow y\_coord, t, r\rightarrow left\_y, r\rightarrow right\_y)$; $free\_number(v)$;
}

556. This does not set $mp\_knot\_info(p)$ or $mp\_right\_type(p)$.

⟨ Declarations 10 ⟩ +≡
static void mp_remove_cubic(**MP** mp, **mp_knot** p);

557. **void** mp_remove_cubic(**MP** mp, **mp_knot** p)
{ ▷ removes the dead cubic following p ◁
mp_knot q; ▷ the node that disappears ◁
(**void**) mp; $q \leftarrow mp\_next\_knot(p)$; $mp\_next\_knot(p) \leftarrow mp\_next\_knot(q)$;
$number\_clone(p\rightarrow right\_x, q\rightarrow right\_x)$; $number\_clone(p\rightarrow right\_y, q\rightarrow right\_y)$; $mp\_xfree(q)$;
}

558. Let $d \prec d'$ mean that the counter-clockwise angle from d to d' is strictly between zero and 180°. Then we can define $d \preceq d'$ to mean that the angle could be zero or 180°. If $w_k = (u_k, v_k)$ is the kth pen offset, the kth pen edge direction is defined by the formula

$$d_k = (u_{k+1} - u_k,\, v_{k+1} - v_k).$$

When listed by increasing k, these directions occur in counter-clockwise order so that $d_k \preceq d_{k+1}$ for all k. The goal of *offset_prep* is to find an offset index k to associate with each cubic, such that the direction $d(t)$ of the cubic satisfies

$$d_{k-1} \preceq d(t) \preceq d_k \qquad \text{for } 0 \le t \le 1. \tag{$*$}$$

We may have to split a cubic into many pieces before each piece corresponds to a unique offset.

⟨ Split the cubic between p and q, if necessary, into cubics associated with single offsets, after which q should point to the end of the final such cubic 558 ⟩ ≡

#ifdef `DEBUGENVELOPE`
dbg_comment(|Split the cubic between p and q); *dbg_nl*; *dbg_key*(|Split the cubic); *dbg_open_t*; *dbg_nl*;
dbg_key_ival(*pre info*(*p*), *mp_knot_info*(*p*)); *dbg_comma*; *dbg_n*(*w0*→*x_coord*); *dbg_n*(*w0*→*y_coord*);
#endif
mp_knot_info(*p*) ← *zero_off* + *k_needed*;
#ifdef `DEBUGENVELOPE`
dbg_key_ival(*post info*(*p*), *mp_knot_info*(*p*)); *dbg_close_t*; *dbg_comma*; *dbg_nl*;
#endif
k_needed ← 0; ⟨ Prepare for derivative computations; **goto** *not_found* if the current cubic is dead 562 ⟩;
⟨ Find the initial direction (*dx*, *dy*) 567 ⟩;
⟨ Update *mp_knot_info*(*p*) and find the offset w_k such that $d_{k-1} \preceq (dx, dy) \prec d_k$; also advance *w0* for the direction change at p 569 ⟩;
⟨ Find the final direction (*dxin*, *dyin*) 568 ⟩;
⟨ Decide on the net change in pen offsets and set *turn_amt* 577 ⟩;
⟨ Complete the offset splitting process 573 ⟩;
w0 ← *mp_pen_walk*(*mp*, *w0*, *turn_amt*)

This code is used in section 547.

559. ⟨ Declarations 10 ⟩ +≡
static mp_knot *mp_pen_walk*(**MP** *mp*, **mp_knot** *w*, **integer** *k*);

560. **mp_knot** *mp_pen_walk*(**MP** *mp*, **mp_knot** *w*, **integer** *k*)

```
{   ▷ walk k steps around a pen from w ◁
  (void) mp;
  while (k > 0) {
    w ← mp_next_knot(w); decr(k);
  }
  while (k < 0) {
    w ← mp_prev_knot(w); incr(k);
  }
  return w;
}
```

561. The direction of a cubic $B(z_0, z_1, z_2, z_3; t) = \bigl(x(t), y(t)\bigr)$ can be calculated from the quadratic polynomials $\frac{1}{3}x'(t) = B(x_1 - x_0, x_2 - x_1, x_3 - x_2; t)$ and $\frac{1}{3}y'(t) = B(y_1 - y_0, y_2 - y_1, y_3 - y_2; t)$. Since we may be calculating directions from several cubics split from the current one, it is desirable to do these calculations without losing too much precision. "Scaled up" values of the derivatives, which will be less tainted by accumulated errors than derivatives found from the cubics themselves, are maintained in local variables *x0*, *x1*, and *x2*, representing $X_0 = 2^l(x_1 - x_0)$, $X_1 = 2^l(x_2 - x_1)$, and $X_2 = 2^l(x_3 - x_2)$; similarly *y0*, *y1*, and *y2* represent $Y_0 = 2^l(y_1 - y_0)$, $Y_1 = 2^l(y_2 - y_1)$, and $Y_2 = 2^l(y_3 - y_2)$.

⟨ Other local variables for *offset_prep* 561 ⟩ ≡
mp_number *x0*, *x1*, *x2*, *y0*, *y1*, *y2*; ▷ representatives of derivatives ◁
mp_number *t0*, *t1*, *t2*; ▷ coefficients of polynomial for slope testing ◁
mp_number *du*, *dv*, *dx*, *dy*; ▷ for directions of the pen and the curve ◁
mp_number *dx0*, *dy0*; ▷ initial direction for the first cubic in the curve ◁
mp_number *x0a*, *x1a*, *x2a*, *y0a*, *y1a*, *y2a*; ▷ intermediate values ◁
mp_number *t*; ▷ where the derivative passes through zero ◁
mp_number *s*; ▷ a temporary value ◁
mp_number *dx_m*; ▷ signal a pertubation of dx ◁
mp_number *dy_m*; ▷ signal a pertubation of dx ◁
mp_number *dxin_m*; ▷ signal a pertubation of dxin ◁

See also section 576.

This code is used in section 547.

562. ⟨ Prepare for derivative computations; **goto** *not_found* if the current cubic is dead 562 ⟩ ≡

```
set_number_from_substraction(x0, p→right_x, p→x_coord);
set_number_from_substraction(x2, q→x_coord, q→left_x);
set_number_from_substraction(x1, q→left_x, p→right_x);
set_number_from_substraction(y0, p→right_y, p→y_coord);
set_number_from_substraction(y2, q→y_coord, q→left_y);
set_number_from_substraction(y1, q→left_y, p→right_y);
#ifdef DEBUGENVELOPE
  dbg_key(|Prepare for derivative computations); dbg_open_t; dbg_nl; dbg_n(x0); dbg_n(y0); dbg_n(x1);
  dbg_n(y1); dbg_n(x2); dbg_n(y2); dbg_close_t; dbg_comma; dbg_nl;
#endif
  {
    mp_number absval;

    new_number(absval); number_clone(absval, x1); number_abs(absval); number_clone(max_coef, x0);
    number_abs(max_coef);
    if (number_greater(absval, max_coef)) {
      number_clone(max_coef, absval);
    }
    number_clone(absval, x2); number_abs(absval);
    if (number_greater(absval, max_coef)) {
      number_clone(max_coef, absval);
    }
    number_clone(absval, y0); number_abs(absval);
    if (number_greater(absval, max_coef)) {
      number_clone(max_coef, absval);
    }
    number_clone(absval, y1); number_abs(absval);
    if (number_greater(absval, max_coef)) {
      number_clone(max_coef, absval);
    }
    number_clone(absval, y2); number_abs(absval);
    if (number_greater(absval, max_coef)) {
      number_clone(max_coef, absval);
    }
    if (number_zero(max_coef)) {
      goto NOT_FOUND;
    }
    free_number(absval);
  }
  while (number_less(max_coef, fraction_half_t)) {
    number_double(max_coef); number_double(x0); number_double(x1); number_double(x2);
    number_double(y0); number_double(y1); number_double(y2);
  }
```

This code is used in section 558.

563. Let us first solve a special case of the problem: Suppose we know an index k such that either (i) $d(t) \succeq d_{k-1}$ for all t and $d(0) \prec d_k$, or (ii) $d(t) \preceq d_k$ for all t and $d(0) \succ d_{k-1}$. Then, in a sense, we're halfway done, since one of the two relations in ($*$) is satisfied, and the other couldn't be satisfied for any other value of k.

Actually, the conditions can be relaxed somewhat since a relation such as $d(t) \succeq d_{k-1}$ restricts $d(t)$ to a half plane when all that really matters is whether $d(t)$ crosses the ray in the d_{k-1} direction from the origin. The condition for case (i) becomes $d_{k-1} \preceq d(0) \prec d_k$ and $d(t)$ never crosses the d_{k-1} ray in the clockwise direction. Case (ii) is similar except $d(t)$ cannot cross the d_k ray in the counterclockwise direction.

The *fin_offset_prep* subroutine solves the stated subproblem. It has a parameter called *rise* that is 1 in case (i), −1 in case (ii). Parameters *x0* through *y2* represent the derivative of the cubic following p. The w parameter should point to offset w_k and *mp_info*(p) should already be set properly. The *turn_amt* parameter gives the absolute value of the overall net change in pen offsets.

⟨ Declarations 10 ⟩ +≡

static void *mp_fin_offset_prep*(**MP** *mp*, **mp_knot** *p*, **mp_knot** *w*,
  mp_number *x0*, **mp_number** *x1*, **mp_number** *x2*,
  mp_number *y0*, **mp_number** *y1*, **mp_number** *y2*, **integer** *rise*, **integer** *turn_amt*);

564. **void** *mp_fin_offset_prep*(**MP** *mp*, **mp_knot** *p*, **mp_knot** *w*, **mp_number** *x0*, **mp_number** *x1*, **mp_number** *x2*, **mp_number** *y0*, **mp_number** *y1*, **mp_number** *y2*, **integer** *rise*, **integer** *turn_amt*)

```
{
  mp_knot ww;    ▷ for list manipulation ◁
  mp_number du, dv;    ▷ for slope calculation ◁
  mp_number t0, t1, t2;    ▷ test coefficients ◁
  mp_number t;    ▷ place where the derivative passes a critical slope ◁
  mp_number s;    ▷ slope or reciprocal slope ◁
  mp_number v;    ▷ intermediate value for updating x0 .. y2 ◁
  mp_knot q;    ▷ original mp_next_knot(p) ◁

  q ← mp_next_knot(p); new_number(du); new_number(dv); new_number(v); new_number(t0);
  new_number(t1); new_number(t2); new_fraction(s); new_fraction(t);
#ifdef DEBUGENVELOPE
  dbg_key(mp_fin_offset_prep); dbg_open_t; dbg_nl;
#endif
  while (1) {
    if (rise > 0) ww ← mp_next_knot(w);    ▷ a pointer to w_{k+1} ◁
    else ww ← mp_prev_knot(w);    ▷ a pointer to w_{k-1} ◁
#ifdef DEBUGENVELOPE
    dbg_comment(|begin iteration); dbg_open_t; dbg_nl; dbg_n(w→x_coord); dbg_n(w→y_coord);
    dbg_n(ww→x_coord); dbg_n(ww→y_coord); dbg_n(x0); dbg_n(x1); dbg_n(x2); dbg_n(y0); dbg_n(y1);
    dbg_n(y2); dbg_in(rise);
#endif
    ⟨Compute test coefficients (t0, t1, t2) for d(t) versus d_k or d_{k-1} 565⟩;
#ifdef DEBUGENVELOPE
    dbg_comment(|crossing_point);
#endif
    crossing_point(t, t0, t1, t2);
#ifdef DEBUGENVELOPE
    dbg_n(t); dbg_n(t0); dbg_n(t1); dbg_n(t2); dbg_in(number_greaterequal(t, fraction_one_t));
    dbg_in(turn_amt); dbg_close_t; dbg_comma; dbg_nl;
#endif
    if (number_greaterequal(t, fraction_one_t)) {
      if (turn_amt > 0) number_clone(t, fraction_one_t);
      else goto RETURN;
    }
#ifdef DEBUGENVELOPE
    dbg_comment(|Split the cubic at t, and split off another cubic if the derivative crosses back);
#endif
    ⟨Split the cubic at t, and split off another cubic if the derivative crosses back 566⟩;
    w ← ww;
#ifdef DEBUGENVELOPE
    dbg_comment(|end iteration);
#endif
  }
RETURN:
#ifdef DEBUGENVELOPE
  dbg_comment(|RETURN); dbg_n(t);
#endif
  free_number(s); free_number(t); free_number(du); free_number(dv); free_number(v); free_number(t0);
  free_number(t1); free_number(t2);
```

```
#ifdef DEBUGENVELOPE
    dbg_close_t; dbg_comma; dbg_nl;
#endif
  }
```

565. We want $B(t0, t1, t2; t)$ to be the dot product of $d(t)$ with a $-90°$ rotation of the vector from w to ww. This makes the resulting function cross from positive to negative when $d_{k-1} \preceq d(t) \preceq d_k$ begins to fail.

⟨ Compute test coefficients $(t0, t1, t2)$ for $d(t)$ versus d_k or d_{k-1} 565 ⟩ ≡

```
  {
    mp_number abs_du, abs_dv;
    new_number(abs_du); new_number(abs_dv);
#ifdef DEBUGENVELOPE
    dbg_key(|Compute test coefficients (t0,t1,t2) for d(t) versus...); dbg_open_t; dbg_nl;
#endif
    set_number_from_substraction(du, ww→x_coord, w→x_coord);
    set_number_from_substraction(dv, ww→y_coord, w→y_coord); number_clone(abs_du, du);
    number_abs(abs_du); number_clone(abs_dv, dv); number_abs(abs_dv);
#ifdef DEBUGENVELOPE
    dbg_CUBIC; dbg_n(w→x_coord); dbg_n(w→y_coord); dbg_n(ww→x_coord); dbg_n(ww→y_coord);
    dbg_n(x0); dbg_n(x1); dbg_n(x2); dbg_n(y0); dbg_n(y1); dbg_n(y2); dbg_n(abs_du); dbg_n(abs_dv);
    dbg_n(du); dbg_n(dv); dbg_in(number_greaterequal(abs_du, abs_dv));
#endif
    if (number_greaterequal(abs_du, abs_dv)) {
      mp_number r1;
      new_fraction(r1); make_fraction(s, dv, du); take_fraction(r1, x0, s);
      set_number_from_substraction(t0, r1, y0); take_fraction(r1, x1, s);
      set_number_from_substraction(t1, r1, y1); take_fraction(r1, x2, s);
      set_number_from_substraction(t2, r1, y2);
      if (number_negative(du)) {
        number_negate(t0); number_negate(t1); number_negate(t2);
      }
      free_number(r1);
    }
    else {
      mp_number r1;
      new_fraction(r1); make_fraction(s, du, dv); take_fraction(r1, y0, s);
      set_number_from_substraction(t0, x0, r1); take_fraction(r1, y1, s);
      set_number_from_substraction(t1, x1, r1); take_fraction(r1, y2, s);
      set_number_from_substraction(t2, x2, r1);
      if (number_negative(dv)) {
        number_negate(t0); number_negate(t1); number_negate(t2);
      }
      free_number(r1);
    }
    free_number(abs_du); free_number(abs_dv);
    if (number_negative(t0)) set_number_to_zero(t0);    ▷ should be positive without rounding error ◁
#ifdef DEBUGENVELOPE
    dbg_n(t0); dbg_n(t1); dbg_n(t2); dbg_close_t; dbg_comma; dbg_nl;
#endif
  }
```

This code is used in sections 564 and 573.

566. The curve has crossed d_k or d_{k-1}; its initial segment satisfies $(*)$, and it might cross again and return towards s_{k-1} or s_k, respectively, yielding another solution of $(*)$.

⟨ Split the cubic at t, and split off another cubic if the derivative crosses back 566 ⟩ ≡

```
{
  mp_split_cubic(mp, p, t); p ← mp_next_knot(p); mp_knot_info(p) ← zero_off + rise; decr(turn_amt);
  set_number_from_of_the_way(v, t, x0, x1); set_number_from_of_the_way(x1, t, x1, x2);
  set_number_from_of_the_way(x0, t, v, x1); set_number_from_of_the_way(v, t, y0, y1);
  set_number_from_of_the_way(y1, t, y1, y2); set_number_from_of_the_way(y0, t, v, y1);
  if (turn_amt < 0) {
    mp_number arg1, arg2, arg3;
    new_number(arg1); new_number(arg2); new_number(arg3);
    set_number_from_of_the_way(t1, t, t1, t2);
    if (number_positive(t1)) set_number_to_zero(t1);    ▷ without rounding error, t1 would be ≤ 0 ◁
    number_clone(arg2, t1); number_negate(arg2); number_clone(arg3, t2); number_negate(arg3);
    crossing_point(t, arg1, arg2, arg3);    ▷ arg1 is zero ◁
    free_number(arg1); free_number(arg2); free_number(arg3);
    if (number_greater(t, fraction_one_t)) number_clone(t, fraction_one_t);
    incr(turn_amt);
    if (number_equal(t, fraction_one_t) ∧ (mp_next_knot(p) ≠ q)) {
      mp_knot_info(mp_next_knot(p)) ← mp_knot_info(mp_next_knot(p)) − rise;
    }
    else {
      mp_split_cubic(mp, p, t); mp_knot_info(mp_next_knot(p)) ← zero_off − rise;
      set_number_from_of_the_way(v, t, x1, x2); set_number_from_of_the_way(x1, t, x0, x1);
      set_number_from_of_the_way(x2, t, x1, v); set_number_from_of_the_way(v, t, y1, y2);
      set_number_from_of_the_way(y1, t, y0, y1); set_number_from_of_the_way(y2, t, y1, v);
    }
  }
}
```

This code is used in section 564.

567. Now we must consider the general problem of *offset_prep*, when nothing is known about a given cubic. We start by finding its direction in the vicinity of $t \leftarrow 0$.

If $z'(t) = 0$, the given cubic is numerically unstable but *offset_prep* has not yet introduced any more numerical errors. Thus we can compute the true initial direction for the given cubic, even if it is almost degenerate.

⟨ Find the initial direction (*dx*, *dy*) 567 ⟩ ≡

```
#ifdef DEBUGENVELOPE
  dbg_nl; dbg_comment(|Find the initial direction (dx,dy)); dbg_nl; dbg_n(w0→x_coord); dbg_n(w0→y_coord);
#endif
  number_clone(dx_m, zero_t); number_clone(dy_m, zero_t); number_clone(dx, x0); number_clone(dy, y0);
  if (number_zero(dx) ∧ number_zero(dy)) {
    number_clone(dx, x1); number_clone(dy, y1);
    if (number_zero(dx) ∧ number_zero(dy)) {
      number_clone(dx, x2); number_clone(dy, y2);
    }
  }
  if (p ≡ c) {
    number_clone(dx0, dx); number_clone(dy0, dy);
  }    ▷ BEGIN PATCH ◁
#ifdef DEBUGENVELOPE
  dbg_nl; dbg_key(mp_dx_dy_approx_t_1); dbg_open_t; dbg_nl; dbg_n(ueps_ap); dbg_n(p→x_coord);
  dbg_n(p→y_coord); dbg_n(p→right_x); dbg_n(p→right_y); dbg_n(q→left_x); dbg_n(q→left_y);
  dbg_n(q→x_coord); dbg_n(q→y_coord);
#endif
#ifdef DEBUGENVELOPE
  dbg_n(dxin_ap); dbg_n(dyin_ap); dbg_close_t; dbg_comma; dbg_nl;
#endif
#ifdef DEBUGENVELOPE
  dbg_nl; dbg_key(mp_dx_dy_approx_t_0); dbg_open_t; dbg_nl; dbg_n(ueps_ap); dbg_n(p→x_coord);
  dbg_n(p→y_coord); dbg_n(p→right_x); dbg_n(p→right_y); dbg_n(q→left_x); dbg_n(q→left_y);
  dbg_n(q→x_coord); dbg_n(q→y_coord);
#endif
#ifdef DEBUGENVELOPE
  dbg_close_t; dbg_comma; dbg_nl; dbg_key(|derivatives); dbg_open_t; dbg_nl; dbg_n(dx_m); dbg_n(dy_m);
  dbg_n(dx); dbg_n(dy); dbg_n(dx_ap); dbg_n(dy_ap); dbg_close_t; dbg_comma; dbg_nl;
#endif
#ifdef DEBUGENVELOPE
  dbg_key(|derivatives after first patch); dbg_open_t; dbg_nl; dbg_n(dx_m); dbg_n(dy_m); dbg_n(dx);
  dbg_n(dy); dbg_n(dx_ap); dbg_n(dy_ap); dbg_close_t; dbg_comma; dbg_nl;
#endif
#ifdef DEBUGENVELOPE
  dbg_key(|derivatives patched); dbg_open_t; dbg_nl; dbg_n(dx_m); dbg_n(dy_m); dbg_n(dx); dbg_n(dy);
  dbg_n(dx_ap); dbg_n(dy_ap); dbg_close_t; dbg_comma; dbg_nl;
#endif    ▷ END PATCH ◁
```

This code is used in section 558.

568. ⟨Find the final direction $(dxin, dyin)$ 568⟩ ≡

```
number_clone(dxin, x2); number_clone(dyin, y2);
if (number_zero(dxin) ∧ number_zero(dyin)) {
  number_clone(dxin, x1); number_clone(dyin, y1);
  if (number_zero(dxin) ∧ number_zero(dyin)) {
    number_clone(dxin, x0); number_clone(dyin, y0);
  }
}
#ifdef DEBUGENVELOPE
  dbg_key(|dxin dyin before); dbg_open_t; dbg_nl; dbg_n(dxin); dbg_n(dyin); dbg_close_t; dbg_comma;
#endif
#ifdef DEBUGENVELOPE
  dbg_key(|dxin dyin after); dbg_open_t; dbg_nl; dbg_n(dxin); dbg_n(dyin); dbg_close_t; dbg_comma;
#endif    ▷ BEGIN PATCH ◁
#ifdef DEBUGENVELOPE
  dbg_key(|dx dy dxin dyin after patch); dbg_open_t; dbg_nl; dbg_n(dx); dbg_n(dy); dbg_n(dx_ap);
  dbg_n(dy_ap); dbg_n(dxin); dbg_n(dyin); dbg_n(dxin_ap); dbg_n(dyin_ap); dbg_close_t; dbg_comma;
#endif    ▷ END PATCH ◁
```

This code is used in section 558.

569. The next step is to bracket the initial direction between consecutive edges of the pen polygon. We must be careful to turn clockwise only if this makes the turn less than 180°. (A 180° turn must be counterclockwise in order to make **doublepath** envelopes come out right.) This code depends on *w0* being the offset for (*dxin*, *dyin*).

⟨ Update *mp_knot_info*(*p*) and find the offset w_k such that $d_{k-1} \preceq (dx, dy) \prec d_k$; also advance *w0* for the direction change at *p* 569 ⟩ ≡

```
{
  mp_number ab_vs_cd;
  new_number(ab_vs_cd); ab_vs_cd(ab_vs_cd, dy, dxin, dx, dyin);
#ifdef DEBUGENVELOPE
  dbg_nl; dbg_comment(|Update mp_knot_info(p)); dbg_nl; dbg_key(mp_get_turn_amt_dx_dy); dbg_open_t;
  dbg_str(|--[==[call mp_get_turn_amt]==]); dbg_nl; dbg_n(w0→x_coord); dbg_n(w0→y_coord); dbg_n(dx);
  dbg_n(dy); dbg_in(number_nonnegative(ab_vs_cd)); dbg_n(ab_vs_cd);
#endif
  is_dxdy ← true; turn_amt ← mp_get_turn_amt(mp, w0, dx, dy, number_nonnegative(ab_vs_cd));
  is_dxdy ← false;
#ifdef DEBUGENVELOPE
  dbg_dn(turn_amt); dbg_close_t; dbg_comma; dbg_nl;
#endif
  free_number(ab_vs_cd);
#ifdef DEBUGENVELOPE
  dbg_key(|w0 before walk); dbg_open_t; dbg_nl; dbg_n(w0→x_coord); dbg_n(w0→y_coord);
  dbg_dn(turn_amt); dbg_close_t; dbg_comma;
#endif
  w ← mp_pen_walk(mp, w0, turn_amt); w0 ← w;
#ifdef DEBUGENVELOPE
  dbg_key(|w0 after walk); dbg_open_t; dbg_nl; dbg_n(w0→x_coord); dbg_n(w0→y_coord); dbg_close_t;
  dbg_comma; dbg_open_t; dbg_in(mp_knot_info(p));
#endif
  mp_knot_info(p) ← mp_knot_info(p) + turn_amt;
#ifdef DEBUGENVELOPE
  dbg_in(mp_knot_info(p)); dbg_close_t; dbg_comma;
#endif
}
```

This code is used in section 558.

570. Decide how many pen offsets to go away from *w* in order to find the offset for (*dx*, *dy*), going counterclockwise if *ccw* is *true*. This assumes that *w* is the offset for some direction (x', y') from which the angle to (*dx*, *dy*) in the sense determined by *ccw* is less than or equal to 180°.

If the pen polygon has only two edges, they could both be parallel to (*dx*, *dy*). In this case, we must be careful to stop after crossing the first such edge in order to avoid an infinite loop.

⟨ Declarations 10 ⟩ +≡

```
static integer mp_get_turn_amt(MP mp, mp_knot w, mp_number dx, mp_number dy, boolean ccw);
```

```
571. integer mp_get_turn_amt(MP mp, mp_knot w, mp_number dx, mp_number dy, boolean ccw)
  {
    mp_knot ww;      ▷ a neighbor of knot w ◁
    integer s;      ▷ turn amount so far ◁
    mp_number t;      ▷ ab_vs_cd result ◁
    mp_number t_ap;      ▷ ab_vs_cd approx. result ◁
    mp_number arg1, arg2;
    s ← 0; new_number(arg1); new_number(arg2); new_number(t); new_number(t_ap);
    if (ccw) {
      ww ← mp_next_knot(w);
      do {
        set_number_from_substraction(arg1, ww→x_coord, w→x_coord);
        set_number_from_substraction(arg2, ww→y_coord, w→y_coord); ab_vs_cd(t, dy, arg1, dx, arg2);
#ifdef DEBUGENVELOPE
        dbg_sp; dbg_open_t; dbg_str(|–[==[inside mp_get_turn_amt do loop]==]); dbg_nl;
        dbg_n(w→x_coord); dbg_n(w→y_coord); dbg_n(ww→x_coord); dbg_n(ww→y_coord); dbg_n(t);
        dbg_n(dy); dbg_n(arg1); dbg_n(dx); dbg_n(arg2); dbg_n(t_ap); dbg_n(dy_ap); dbg_n(dx_ap);
        dbg_n(dyin_ap); dbg_n(dxin_ap); dbg_close_t; dbg_comma;
        dbg_in(number_zero(dx) ∧ number_zero(arg1) ∧ number_positive(dy) ∧ number_positive(arg2) ∧
            is_dxdy); dbg_in(is_dxdy ∧ number_zero(dx) ∧ number_zero(arg1) ∧ number_negative(dy) ∧
            number_negative(arg2) ∧ number_positive(dyin_ap));
        dbg_in(is_dxindyin ∧ number_zero(dx) ∧ number_zero(arg1) ∧ number_positive(dy) ∧
            number_positive(arg2) ∧ number_negative(dyin_ap));
        dbg_in(number_zero(dy) ∧ number_zero(arg2) ∧ number_negative(dx) ∧ number_negative(arg1));
        dbg_in(number_zero(dx) ∧ number_zero(arg1) ∧ number_negative(dy) ∧ number_positive(arg2));
        dbg_in(number_zero(dy) ∧ number_zero(arg2) ∧ number_positive(dx) ∧ number_negative(arg1));
        dbg_nl;
#endif
        if (number_negative(t)) break;
        incr(s); w ← ww; ww ← mp_next_knot(ww);
      } while (number_positive(t));
    }
    else {
      ww ← mp_prev_knot(w); set_number_from_substraction(arg1, w→x_coord, ww→x_coord);
      set_number_from_substraction(arg2, w→y_coord, ww→y_coord); ab_vs_cd(t, dy, arg1, dx, arg2);
#ifdef DEBUGENVELOPE
      dbg_sp; dbg_open_t; dbg_str(|–[==[outside mp_get_turn_amt do loop]==]); dbg_nl; dbg_n(w→x_coord);
      dbg_n(w→y_coord); dbg_n(ww→x_coord); dbg_n(ww→y_coord); dbg_n(t); dbg_n(dy); dbg_n(arg1);
      dbg_n(dx); dbg_n(arg2); dbg_n(t_ap); dbg_n(dy_ap); dbg_n(dx_ap); dbg_n(dyin_ap); dbg_n(dxin_ap);
      dbg_close_t; dbg_comma; dbg_nl;
#endif
      while (number_negative(t)) {
        decr(s); w ← ww; ww ← mp_prev_knot(ww);
        set_number_from_substraction(arg1, w→x_coord, ww→x_coord);
        set_number_from_substraction(arg2, w→y_coord, ww→y_coord); ab_vs_cd(t, dy, arg1, dx, arg2);
#ifdef DEBUGENVELOPE
        dbg_sp; dbg_open_t; dbg_str(|–[==[inside mp_get_turn_amt do loop for t¡0]==]); dbg_nl;
        dbg_n(w→x_coord); dbg_n(w→y_coord); dbg_n(ww→x_coord); dbg_n(ww→y_coord); dbg_n(t);
        dbg_n(dy); dbg_n(arg1); dbg_n(dx); dbg_n(arg2); dbg_n(t_ap); dbg_n(dy_ap); dbg_n(dx_ap);
        dbg_close_t; dbg_comma; dbg_nl;
#endif
      }
```

```
    }
    free_number(t); free_number(t_ap); free_number(arg1); free_number(arg2); return s;
  }
```

572. When we're all done, the final offset is *w0* and the final curve direction is (*dxin*, *dyin*). With this knowledge of the incoming direction at *c*, we can correct *mp_info*(*c*) which was erroneously based on an incoming offset of *h*.

#define *fix_by*(*A*) *mp_knot_info*(*c*) ← *mp_knot_info*(*c*) + (*A*)

⟨ Fix the offset change in *mp_knot_info*(*c*) and set *c* to the return value of *offset_prep* 572 ⟩ ≡

```
  mp→spec_offset ← mp_knot_info(c) − zero_off;
  if (mp_next_knot(c) ≡ c) {
    mp_knot_info(c) ← zero_off + n;
  }
  else {
    mp_number ab_vs_cd;

    new_number(ab_vs_cd); fix_by(k_needed);
    while (w0 ≠ h) {
      fix_by(1); w0 ← mp_next_knot(w0);
    }
    while (mp_knot_info(c) ≤ zero_off − n) fix_by(n);
    while (mp_knot_info(c) > zero_off) fix_by(−n);
    ab_vs_cd(ab_vs_cd, dy0, dxin, dx0, dyin);
    if ((mp_knot_info(c) ≠ zero_off) ∧ number_nonnegative(ab_vs_cd)) fix_by(n);
    free_number(ab_vs_cd);
  }
```

This code is used in section 547.

573. Finally we want to reduce the general problem to situations that *fin_offset_prep* can handle. We split the cubic into at most three parts with respect to d_{k-1}, and apply *fin_offset_prep* to each part.

⟨ Complete the offset splitting process 573 ⟩ ≡
  ww ← *mp_prev_knot*(*w*);
#ifdef DEBUGENVELOPE
  dbg_key(|Complete the offset splitting process); *dbg_open_t*; *dbg_nl*; *dbg_n*(*w*→*x_coord*); *dbg_n*(*w*→*y_coord*);
  dbg_n(*ww*→*x_coord*); *dbg_n*(*ww*→*y_coord*); *dbg_close_t*; *dbg_comma*; *dbg_nl*;
#endif
  ⟨ Compute test coefficients (*t0*, *t1*, *t2*) for $d(t)$ versus d_k or d_{k-1} 565 ⟩;
#ifdef DEBUGENVELOPE
  dbg_key(|after Compute test coeff); *dbg_open_t*; *dbg_nl*; *dbg_n*(*w*→*x_coord*); *dbg_n*(*w*→*y_coord*);
  dbg_n(*ww*→*x_coord*); *dbg_n*(*ww*→*y_coord*); *dbg_close_t*; *dbg_comma*; *dbg_nl*;
#endif
  ⟨ Find the first t where $d(t)$ crosses d_{k-1} or set t: ← *fraction_one* + 1 575 ⟩;
  if (*number_greater*(*t*, *fraction_one_t*)) {
#ifdef DEBUGENVELOPE
    dbg_key(|t ¿ fraction_one_t); *dbg_open_t*; *dbg_nl*; *dbg_n*(*p*→*x_coord*); *dbg_n*(*p*→*y_coord*);
    dbg_n(*w*→*x_coord*); *dbg_n*(*w*→*y_coord*); *dbg_n*(*x0*); *dbg_n*(*x1*); *dbg_n*(*x2*); *dbg_n*(*y0*); *dbg_n*(*y1*);
    dbg_n(*y2*); *dbg_close_t*; *dbg_comma*; *dbg_nl*;
#endif
    mp_fin_offset_prep(*mp*, *p*, *w*, *x0*, *x1*, *x2*, *y0*, *y1*, *y2*, 1, *turn_amt*);
  }
  else {
    mp_split_cubic(*mp*, *p*, *t*); *r* ← *mp_next_knot*(*p*); *set_number_from_of_the_way*(*x1a*, *t*, *x0*, *x1*);
    set_number_from_of_the_way(*x1*, *t*, *x1*, *x2*); *set_number_from_of_the_way*(*x2a*, *t*, *x1a*, *x1*);
    set_number_from_of_the_way(*y1a*, *t*, *y0*, *y1*); *set_number_from_of_the_way*(*y1*, *t*, *y1*, *y2*);
    set_number_from_of_the_way(*y2a*, *t*, *y1a*, *y1*);
#ifdef DEBUGENVELOPE
    dbg_key(|t ¡= fraction_one_t); *dbg_open_t*; *dbg_nl*; *dbg_n*(*p*→*x_coord*); *dbg_n*(*p*→*y_coord*); *dbg_n*(*t*);
    dbg_n(*r*→*x_coord*); *dbg_n*(*r*→*y_coord*); *dbg_n*(*w*→*x_coord*); *dbg_n*(*w*→*y_coord*); *dbg_n*(*x0*); *dbg_n*(*x1a*);
    dbg_n(*x2a*); *dbg_n*(*y0*); *dbg_n*(*y1a*); *dbg_n*(*y2a*); *dbg_close_t*; *dbg_comma*; *dbg_nl*;
#endif
    mp_fin_offset_prep(*mp*, *p*, *w*, *x0*, *x1a*, *x2a*, *y0*, *y1a*, *y2a*, 1, 0); *number_clone*(*x0*, *x2a*);
    number_clone(*y0*, *y2a*); *mp_knot_info*(*r*) ← *zero_off* − 1;
    if (*turn_amt* ≥ 0) {
      mp_number *arg1*, *arg2*, *arg3*;

      new_number(*arg1*); *new_number*(*arg2*); *new_number*(*arg3*);
      set_number_from_of_the_way(*t1*, *t*, *t1*, *t2*);
      if (*number_positive*(*t1*)) *set_number_to_zero*(*t1*);
      number_clone(*arg2*, *t1*); *number_negate*(*arg2*); *number_clone*(*arg3*, *t2*); *number_negate*(*arg3*);
      crossing_point(*t*, *arg1*, *arg2*, *arg3*); *free_number*(*arg1*); *free_number*(*arg2*); *free_number*(*arg3*);
      if (*number_greater*(*t*, *fraction_one_t*)) *number_clone*(*t*, *fraction_one_t*);
      ⟨ Split off another rising cubic for *fin_offset_prep* 574 ⟩;
      mp_fin_offset_prep(*mp*, *r*, *ww*, *x0*, *x1*, *x2*, *y0*, *y1*, *y2*, −1, 0);
    }
    else {
      mp_fin_offset_prep(*mp*, *r*, *ww*, *x0*, *x1*, *x2*, *y0*, *y1*, *y2*, −1, (−1 − *turn_amt*));
    }
  }
#ifdef DEBUGENVELOPE

dbg_key(|end Complete the offset splitting process); *dbg_open_t*; *dbg_nl*; *dbg_n*(*w*→*x_coord*);
dbg_n(*w*→*y_coord*); *dbg_n*(*w0*→*x_coord*); *dbg_n*(*w0*→*y_coord*); *dbg_in*(*turn_amt*); *dbg_close_t*; *dbg_comma*;
dbg_nl;

#endif

This code is used in section 558.

574. ⟨ Split off another rising cubic for *fin_offset_prep* 574 ⟩ ≡
mp_split_cubic(*mp*, *r*, *t*); *mp_knot_info*(*mp_next_knot*(*r*)) ← *zero_off* + 1;
set_number_from_of_the_way(*x1a*, *t*, *x1*, *x2*); *set_number_from_of_the_way*(*x1*, *t*, *x0*, *x1*);
set_number_from_of_the_way(*x0a*, *t*, *x1*, *x1a*); *set_number_from_of_the_way*(*y1a*, *t*, *y1*, *y2*);
set_number_from_of_the_way(*y1*, *t*, *y0*, *y1*); *set_number_from_of_the_way*(*y0a*, *t*, *y1*, *y1a*);
mp_fin_offset_prep(*mp*, *mp_next_knot*(*r*), *w*, *x0a*, *x1a*, *x2*, *y0a*, *y1a*, *y2*, 1, *turn_amt*);
number_clone(*x2*, *x0a*); *number_clone*(*y2*, *y0a*)

This code is used in section 573.

575. At this point, the direction of the incoming pen edge is $(-du, -dv)$. When the component of $d(t)$ perpendicular to $(-du, -dv)$ crosses zero, we need to decide whether the directions are parallel or antiparallel. We can test this by finding the dot product of $d(t)$ and $(-du, -dv)$, but this should be avoided when the value of *turn_amt* already determines the answer. If $t2 < 0$, there is one crossing and it is antiparallel only if $turn\_amt \geq 0$. If $turn\_amt < 0$, there should always be at least one crossing and the first crossing cannot be antiparallel.

⟨Find the first t where $d(t)$ crosses d_{k-1} or set t: ← *fraction_one* + 1 575⟩ ≡

```
#ifdef DEBUGENVELOPE
  dbg_key(|Find the first t where); dbg_open_t; dbg_nl;
#endif
  crossing_point(t, t0, t1, t2);
  if (turn_amt ≥ 0) {
    if (number_negative(t2)) {
      number_clone(t, fraction_one_t); number_add_scaled(t, 1);
    }
    else {
      mp_number tmp, arg1, r1;
      new_fraction(r1); new_number(tmp); new_number(arg1);
      set_number_from_of_the_way(u0, t, x0, x1); set_number_from_of_the_way(u1, t, x1, x2);
      set_number_from_of_the_way(tmp, t, u0, u1); number_clone(arg1, du); number_negate(arg1);
      take_fraction(ss, arg1, tmp); set_number_from_of_the_way(v0, t, y0, y1);
      set_number_from_of_the_way(v1, t, y1, y2); set_number_from_of_the_way(tmp, t, v0, v1);
      number_clone(arg1, dv); number_negate(arg1); take_fraction(r1, arg1, tmp); number_add(ss, r1);
      free_number(tmp);
      if (number_negative(ss)) {
        number_clone(t, fraction_one_t); number_add_scaled(t, 1);
      }
      free_number(arg1); free_number(r1);
    }
  }
  else if (number_greater(t, fraction_one_t)) {
    number_clone(t, fraction_one_t);
  }
#ifdef DEBUGENVELOPE
  dbg_n(t); dbg_close_t; dbg_comma; dbg_nl;
#endif
```

This code is used in section 573.

576. ⟨Other local variables for *offset_prep* 561⟩ +≡

```
  mp_number u0, u1, v0, v1;    ▷ intermediate values for d(t) calculation ◁
  int d_sign;    ▷ sign of overall change in direction for this cubic ◁
```

577. If the cubic almost has a cusp, it is a numerically ill-conditioned problem to decide which way it loops around but that's OK as long we're consistent. To make **doublepath** envelopes work properly, reversing the path should always change the sign of *turn_amt*.

⟨ Decide on the net change in pen offsets and set *turn_amt* 577 ⟩ ≡

```
{
  mp_number ab_vs_cd;
  mp_number t_ap;
  new_number(t_ap); new_number(ab_vs_cd);
#ifdef DEBUGENVELOPE
  dbg_sp; dbg_key(|Decide on the net change in pen offsets and set turn_amt); dbg_open_t; dbg_nl;
#endif
  ab_vs_cd(ab_vs_cd, dx, dyin, dxin, dy);
#ifdef DEBUGENVELOPE
  dbg_n(ab_vs_cd); dbg_n(dx); dbg_n(dyin); dbg_n(dxin); dbg_n(dy);
#endif  ▷ BEGIN PATCH ◁
#ifdef DEBUGENVELOPE
  dbg_key_nval(ab_vs_cd patched, ab_vs_cd); dbg_close_t; dbg_comma; dbg_nl;
#endif  ▷ END PATCH ◁
  if (number_negative(ab_vs_cd)) d_sign ← −1;
  else if (number_zero(ab_vs_cd)) d_sign ← 0;
  else d_sign ← 1;
  free_number(ab_vs_cd); free_number(t_ap);
}
if (d_sign ≡ 0) ⟨ Check rotation direction based on node position 578 ⟩
if (d_sign ≡ 0) {
  if (number_zero(dx)) {
    if (number_positive(dy)) d_sign ← 1;
    else d_sign ← −1;
  }
  else {
    if (number_positive(dx)) d_sign ← 1;
    else d_sign ← −1;
  }
}
⟨ Make ss negative if and only if the total change in direction is more than 180° 579 ⟩;
#ifdef DEBUGENVELOPE
dbg_nl; dbg_key(|Make ss negative if and only if); dbg_open_t; dbg_nl;
dbg_key(mp_get_turn_amt_dxin_dyin); dbg_open_t; dbg_str(|–[==[call mp_get_turn_amt]==]); dbg_nl;
dbg_n(w→x_coord); dbg_n(w→y_coord); dbg_n(dxin); dbg_n(dyin); dbg_in((d_sign > 0));
#endif
is_dxindyin ← true; turn_amt ← mp_get_turn_amt(mp, w, dxin, dyin, (d_sign > 0)); is_dxindyin ← false;
#ifdef DEBUGENVELOPE
dbg_key_dval(turn_amt1, turn_amt); dbg_comma; dbg_nl; dbg_key_nval(ss, ss); dbg_comma; dbg_nl;
dbg_key_ival(d_sign, d_sign); dbg_comma; dbg_nl; dbg_key_ival(n, n); dbg_comma; dbg_nl;
#endif
if (number_negative(ss)) turn_amt ← turn_amt − d_sign ∗ n;
#ifdef DEBUGENVELOPE
dbg_key_dval(turn_amt2, turn_amt); dbg_comma; dbg_nl; dbg_close_t; dbg_comma; dbg_nl; dbg_close_t;
dbg_comma; dbg_nl;
#endif
```

This code is used in section 558.

578. We check rotation direction by looking at the vector connecting the current node with the next. If its angle with incoming and outgoing tangents has the same sign, we pick this as *d_sign*, since it means we have a flex, not a cusp. Otherwise we proceed to the cusp code.

⟨ Check rotation direction based on node position 578 ⟩ ≡
{
mp_number *ab_vs_cd1*, *ab_vs_cd2*, *t*;
new_number(*ab_vs_cd1*); *new_number*(*ab_vs_cd2*); *new_number*(*t*);
set_number_from_substraction(*u0*, *q*→*x_coord*, *p*→*x_coord*);
set_number_from_substraction(*u1*, *q*→*y_coord*, *p*→*y_coord*); *ab_vs_cd*(*ab_vs_cd1*, *dx*, *u1*, *u0*, *dy*);
ab_vs_cd(*ab_vs_cd2*, *u0*, *dyin*, *dxin*, *u1*); *set_number_from_addition*(*t*, *ab_vs_cd1*, *ab_vs_cd2*);
number_half(*t*);
if (*number_negative*(*t*)) *d_sign* ← −1;
else if (*number_zero*(*t*)) *d_sign* ← 0;
else *d_sign* ← 1;
free_number(*t*); *free_number*(*ab_vs_cd1*); *free_number*(*ab_vs_cd2*);
}

This code is used in section 577.

579. In order to be invariant under path reversal, the result of this computation should not change when $x0$, $y0$, ... are all negated and $(x0, y0)$ is then swapped with $(x2, y2)$. We make use of the identities $take\_fraction(-a, -b) \leftarrow take\_fraction(a, b)$ and $t\_of\_the\_way(-a, -b) \leftarrow -(t\_of\_the\_way(a, b))$.

⟨ Make *ss* negative if and only if the total change in direction is more than 180° 579 ⟩ ≡

```
  {
    mp_number r1, r2, arg1;
    new_number(arg1); new_fraction(r1); new_fraction(r2); take_fraction(r1, x0, y2);
    take_fraction(r2, x2, y0);
#ifdef DEBUGENVELOPE
    dbg_sp; dbg_open_t; dbg_dn(d_sign); dbg_close_t; dbg_comma; dbg_nl;
#endif
    number_half(r1); number_half(r2); set_number_from_substraction(t0, r1, r2);
    set_number_from_addition(arg1, y0, y2); take_fraction(r1, x1, arg1);
    set_number_from_addition(arg1, x0, x2);    ▷ take_fraction(r1, y1, arg1); ◁
      ▷ The old one, is it correct ? ◁
    take_fraction(r2, y1, arg1); number_half(r1); number_half(r2);
    set_number_from_substraction(t1, r1, r2); free_number(arg1); free_number(r1); free_number(r2);
  }
  if (number_zero(t0)) set_number_from_scaled(t0, d_sign);    ▷ path reversal always negates d_sign ◁
  if (number_positive(t0)) {
    mp_number arg3;
    new_number(arg3); number_clone(arg3, t0); number_negate(arg3); crossing_point(t, t0, t1, arg3);
    free_number(arg3); set_number_from_of_the_way(u0, t, x0, x1);
    set_number_from_of_the_way(u1, t, x1, x2); set_number_from_of_the_way(v0, t, y0, y1);
    set_number_from_of_the_way(v1, t, y1, y2);
  }
  else {
    mp_number arg1;
    new_number(arg1); number_clone(arg1, t0); number_negate(arg1); crossing_point(t, arg1, t1, t0);
    free_number(arg1); set_number_from_of_the_way(u0, t, x2, x1);
    set_number_from_of_the_way(u1, t, x1, x0); set_number_from_of_the_way(v0, t, y2, y1);
    set_number_from_of_the_way(v1, t, y1, y0);
  }
  {
    mp_number tmp1, tmp2, r1, r2, arg1;
    mp_number abs_ss, eps_ss;
    new_fraction(r1); new_fraction(r2); new_number(arg1); new_number(tmp1); new_number(tmp2);
    set_number_from_of_the_way(tmp1, t, u0, u1); set_number_from_of_the_way(tmp2, t, v0, v1);
    set_number_from_addition(arg1, x0, x2); take_fraction(r1, arg1, tmp1);
    set_number_from_addition(arg1, y0, y2); take_fraction(r2, arg1, tmp2);
    set_number_from_addition(ss, r1, r2);    ▷ BEGIN PATCH ◁
#ifdef DEBUGENVELOPE
    dbg_key(|patch ss before); dbg_open_t; dbg_n(ss); dbg_close_t; dbg_comma;
#endif
#ifdef DEBUGENVELOPE
    dbg_key(|patch ss after); dbg_open_t; dbg_n(ss); dbg_close_t; dbg_comma;
#endif
    free_number(abs_ss); free_number(eps_ss);    ▷ END PATCH ◁
    free_number(arg1); free_number(r1); free_number(r2); free_number(tmp1); free_number(tmp2);
  }
```

This code is used in section 577.

580. Here's a routine that prints an envelope spec in symbolic form. It assumes that the *cur_pen* has not been walked around to the first offset.

```
static void mp_print_spec(MP mp, mp_knot cur_spec, mp_knot cur_pen, const char *s)
{
  mp_knot p, q;    ▷ list traversal ◁
  mp_knot w;    ▷ the current pen offset ◁
  mp_print_diagnostic(mp, "Envelope␣spec", s, true);  p ← cur_spec;
  w ← mp_pen_walk(mp, cur_pen, mp→spec_offset);  mp_print_ln(mp);
  mp_print_two(mp, cur_spec→x_coord, cur_spec→y_coord);
  mp_print(mp, "␣%␣beginning␣with␣offset␣");  mp_print_two(mp, w→x_coord, w→y_coord);
  do {
    while (1) {
      q ← mp_next_knot(p);  ⟨Print the cubic between p and q 582⟩;
      p ← q;
      if ((p ≡ cur_spec) ∨ (mp_knot_info(p) ≠ zero_off)) break;
    }
    if (mp_knot_info(p) ≠ zero_off)
      ⟨Update w as indicated by mp_knot_info(p) and print an explanation 581⟩
  } while (p ≠ cur_spec);
  mp_print_nl(mp, "␣&␣cycle");  mp_end_diagnostic(mp, true);
}
```

581. ⟨Update *w* as indicated by *mp_knot_info*(*p*) and print an explanation 581⟩ ≡

```
{
  w ← mp_pen_walk(mp, w, (mp_knot_info(p) − zero_off));  mp_print(mp, "␣%␣");
#ifdef DEBUGENVELOPE
  dbg_nl; dbg_open_t; dbg_str(|−[==[START]==]); dbg_nl; dbg_key(|Printing mp_knot_info (p));
  dbg_open_t; dbg_nl; dbg_n(p→x_coord); dbg_n(p→y_coord); dbg_in(mp_knot_info(p)); dbg_close_t;
  dbg_close_t; dbg_comma; dbg_nl; dbg_nl; dbg_str(|−[==[STOP]==]); dbg_nl;
#endif
  if (mp_knot_info(p) > zero_off) mp_print(mp, "counter");
  mp_print(mp, "clockwise␣to␣offset␣");  mp_print_two(mp, w→x_coord, w→y_coord);
}
```

This code is used in section 580.

582. ⟨Print the cubic between *p* and *q* 582⟩ ≡

```
{
  mp_print_nl(mp, "␣␣␣..controls␣");  mp_print_two(mp, p→right_x, p→right_y);
  mp_print(mp, "␣and␣");  mp_print_two(mp, q→left_x, q→left_y);  mp_print_nl(mp, "␣..");
  mp_print_two(mp, q→x_coord, q→y_coord);
}
```

This code is used in section 580.

583. Once we have an envelope spec, the remaining task to construct the actual envelope by offsetting each cubic as determined by the *info* fields in the knots. First we use *offset_prep* to convert the c into an envelope spec. Then we add the offsets so that c becomes a cyclic path that represents the envelope.

The *ljoin* and *miterlim* parameters control the treatment of points where the pen offset changes, and *lcap* controls the endpoints of a **doublepath**. The endpoints are easily located because c is given in undoubled form and then doubled in this procedure. We use *spec_p1* and *spec_p2* to keep track of the endpoints and treat them like very sharp corners. Butt end caps are treated like beveled joins; round end caps are treated like round joins; and square end caps are achieved by setting *join_type*: ← 3.

None of these parameters apply to inside joins where the convolution tracing has retrograde lines. In such cases we use a simple connect-the-endpoints approach that is achieved by setting *join_type*: ← 2.

```
static mp_knot mp_make_envelope(MP mp, mp_knot c, mp_knot h, quarterword
        ljoin, quarterword lcap, mp_number miterlim)
{
  mp_knot p, q, r, q0;   ▷ for manipulating the path ◁
  mp_knot w, w0;   ▷ the pen knot for the current offset ◁
  halfword k, k0;   ▷ controls pen edge insertion ◁
  mp_number qx, qy;   ▷ unshifted coordinates of q ◁
  mp_fraction dxin, dyin, dxout, dyout;   ▷ directions at q when square or mitered ◁
  int join_type ← 0;   ▷ codes 0..3 for mitered, round, beveled, or square ◁
  ⟨Other local variables for make_envelope 587⟩;
  new_number(max_ht); new_number(tmp); new_fraction(dxin); new_fraction(dyin);
  new_fraction(dxout); new_fraction(dyout); mp→spec_p1 ← Λ; mp→spec_p2 ← Λ; new_number(qx);
  new_number(qy); ⟨If endpoint, double the path c, and set spec_p1 and spec_p2 598⟩;
  ⟨Use offset_prep to compute the envelope spec then walk h around to the initial offset 584⟩;
  w ← h; p ← c;
  do {
    q ← mp_next_knot(p); q0 ← q; number_clone(qx, q→x_coord); number_clone(qy, q→y_coord);
    k ← mp_knot_info(q); k0 ← k; w0 ← w;
    if (k ≠ zero_off) ⟨Set join_type to indicate how to handle offset changes at q 585⟩
    ⟨Add offset w to the cubic from p to q 588⟩;
    while (k ≠ zero_off) {
      ⟨Step w and move k one step closer to zero_off 589⟩;
      if ((join_type ≡ 1) ∨ (k ≡ zero_off)) {
        mp_number xtot, ytot;
        new_number(xtot); new_number(ytot); set_number_from_addition(xtot, qx, w→x_coord);
        set_number_from_addition(ytot, qy, w→y_coord); q ← mp_insert_knot(mp, q, xtot, ytot);
        free_number(xtot); free_number(ytot);
      }
    }
    if (q ≠ mp_next_knot(p))
      ⟨Set p ← mp_link(p) and add knots between p and q as required by join_type 592⟩
    p ← q;
  } while (q0 ≠ c);
  free_number(max_ht); free_number(tmp); free_number(qx); free_number(qy); free_number(dxin);
  free_number(dyin); free_number(dxout); free_number(dyout); return c;
}
```

584. ⟨ Use *offset_prep* to compute the envelope spec then walk h around to the initial offset 584 ⟩ ≡

$c \leftarrow mp\_offset\_prep(mp, c, h)$;
if $(number\_positive(internal\_value(mp\_tracing\_specs)))$ $mp\_print\_spec(mp, c, h, "")$;
$h \leftarrow mp\_pen\_walk(mp, h, mp\rightarrow spec\_offset)$

This code is used in section 583.

585. Mitered and squared-off joins depend on path directions that are difficult to compute for degenerate cubics. The envelope spec computed by *offset_prep* can have degenerate cubics only if the entire cycle collapses to a single degenerate cubic. Setting *join_type*: ← 2 in this case makes the computed envelope degenerate as well.

⟨ Set *join_type* to indicate how to handle offset changes at q 585 ⟩ ≡

```
{
  if (k < zero_off) {
    join_type ← 2;
  }
  else {
    if ((q ≠ mp→spec_p1) ∧ (q ≠ mp→spec_p2)) join_type ← ljoin;
    else if (lcap ≡ 2) join_type ← 3;
    else join_type ← 2 − lcap;
    if ((join_type ≡ 0) ∨ (join_type ≡ 3)) {
      ⟨ Set the incoming and outgoing directions at q; in case of degeneracy set join_type: ← 2 600 ⟩;
      if (join_type ≡ 0)
        ⟨ If miterlim is less than the secant of half the angle at q then set join_type: ← 2 586 ⟩
    }
  }
}
```

This code is used in section 583.

586. ⟨ If *miterlim* is less than the secant of half the angle at q then set *join_type*: ← 2 586 ⟩ ≡

```
{
  mp_number r1, r2;
  new_fraction(r1); new_fraction(r2); take_fraction(r1, dxin, dxout); take_fraction(r2, dyin, dyout);
  number_add(r1, r2); number_half(r1); number_add(r1, fraction_half_t);
  take_fraction(tmp, miterlim, r1);
  if (number_less(tmp, unity_t)) {
    mp_number ret;
    new_number(ret); take_scaled(ret, miterlim, tmp);
    if (number_less(ret, unity_t)) join_type ← 2;
    free_number(ret);
  }
  free_number(r1); free_number(r2);
}
```

This code is used in section 585.

587. ⟨ Other local variables for *make_envelope* 587 ⟩ ≡

mp_number *tmp*; ▷ a temporary value ◁

See also section 595.

This code is used in section 583.

588. The coordinates of p have already been shifted unless p is the first knot in which case they get shifted at the very end.

⟨ Add offset w to the cubic from p to q 588 ⟩ ≡
number_add(p→*right_x*, w→*x_coord*); *number_add*(p→*right_y*, w→*y_coord*); *number_add*(q→*left_x*, w→*x_coord*);
number_add(q→*left_y*, w→*y_coord*); *number_add*(q→*x_coord*, w→*x_coord*);
number_add(q→*y_coord*, w→*y_coord*); *mp_left_type*(q) ← *mp_explicit*; *mp_right_type*(q) ← *mp_explicit*

This code is used in section 583.

589. ⟨ Step w and move k one step closer to *zero_off* 589 ⟩ ≡
if (k > *zero_off*) {
  w ← *mp_next_knot*(w); *decr*(k);
}
else {
  w ← *mp_prev_knot*(w); *incr*(k);
}

This code is used in section 583.

590. The cubic from q to the new knot at (x, y) becomes a line segment and the *mp_right_x* and *mp_right_y* fields of r are set from q. This is done in case the cubic containing these control points is "yet to be examined."

⟨ Declarations 10 ⟩ +≡
static mp_knot *mp_insert_knot*(**MP** *mp*, **mp_knot** q, **mp_number** x, **mp_number** y);

591. **mp_knot** *mp_insert_knot*(**MP** *mp*, **mp_knot** q, **mp_number** x, **mp_number** y)
{ ▷ returns the inserted knot ◁
  mp_knot r; ▷ the new knot ◁
  r ← *mp_new_knot*(*mp*); *mp_next_knot*(r) ← *mp_next_knot*(q); *mp_next_knot*(q) ← r;
  number_clone(r→*right_x*, q→*right_x*); *number_clone*(r→*right_y*, q→*right_y*); *number_clone*(r→*x_coord*, x);
  number_clone(r→*y_coord*, y); *number_clone*(q→*right_x*, q→*x_coord*); *number_clone*(q→*right_y*, q→*y_coord*);
  number_clone(r→*left_x*, r→*x_coord*); *number_clone*(r→*left_y*, r→*y_coord*); *mp_left_type*(r) ← *mp_explicit*;
  mp_right_type(r) ← *mp_explicit*; *mp_originator*(r) ← *mp_program_code*; **return** r;
}

592. After setting p: ← *mp_link*(p), either *join_type* ← 1 or q ← *mp_link*(p).

⟨ Set p ← *mp_link*(p) and add knots between p and q as required by *join_type* 592 ⟩ ≡
{
  p ← *mp_next_knot*(p);
  if ((*join_type* ≡ 0) ∨ (*join_type* ≡ 3)) {
    if (*join_type* ≡ 0) ⟨ Insert a new knot r between p and q as required for a mitered join 593 ⟩
    else ⟨ Make r the last of two knots inserted between p and q to form a squared join 594 ⟩
    if (r ≠ Λ) {
      number_clone(r→*right_x*, r→*x_coord*); *number_clone*(r→*right_y*, r→*y_coord*);
    }
  }
}

This code is used in section 583.

593. For very small angles, adding a knot is unnecessary and would cause numerical problems, so we just set r: ← Λ in that case.

#**define** *near_zero_angle_k* ((**math_data** ∗) *mp→math*)→*near_zero_angle_t*

⟨ Insert a new knot r between p and q as required for a mitered join 593 ⟩ ≡

```
{
  mp_number det;    ▷ a determinant used for mitered join calculations ◁
  mp_number absdet;
  mp_number r1, r2;
  new_fraction(r1); new_fraction(r2); new_fraction(det); new_fraction(absdet);
  take_fraction(r1, dyout, dxin); take_fraction(r2, dxout, dyin);
  set_number_from_substraction(det, r1, r2); number_clone(absdet, det); number_abs(absdet);
  if (number_less(absdet, near_zero_angle_k)) {
    r ← Λ;    ▷ sine < 10^-4 ◁
  }
  else {
    mp_number xtot, ytot, xsub, ysub;
    new_fraction(xsub); new_fraction(ysub); new_number(xtot); new_number(ytot);
    set_number_from_substraction(tmp, q→x_coord, p→x_coord); take_fraction(r1, tmp, dyout);
    set_number_from_substraction(tmp, q→y_coord, p→y_coord); take_fraction(r2, tmp, dxout);
    set_number_from_substraction(tmp, r1, r2); make_fraction(r1, tmp, det); number_clone(tmp, r1);
    take_fraction(xsub, tmp, dxin); take_fraction(ysub, tmp, dyin);
    set_number_from_addition(xtot, p→x_coord, xsub); set_number_from_addition(ytot, p→y_coord, ysub);
    r ← mp_insert_knot(mp, p, xtot, ytot); free_number(xtot); free_number(ytot); free_number(xsub);
    free_number(ysub);
  }
  free_number(r1); free_number(r2); free_number(det); free_number(absdet);
}
```

This code is used in section 592.

594. ⟨ Make r the last of two knots inserted between p and q to form a squared join 594 ⟩ ≡

```
{
  mp_number ht_x, ht_y;    ▷ perpendicular to the segment from p to q ◁
  mp_number ht_x_abs, ht_y_abs;    ▷ absolutes ◁
  mp_number xtot, ytot, xsub, ysub;

  new_fraction(xsub); new_fraction(ysub); new_number(xtot); new_number(ytot); new_fraction(ht_x);
  new_fraction(ht_y); new_fraction(ht_x_abs); new_fraction(ht_y_abs);
  set_number_from_substraction(ht_x, w→y_coord, w0→y_coord);
  set_number_from_substraction(ht_y, w0→x_coord, w→x_coord); number_clone(ht_x_abs, ht_x);
  number_clone(ht_y_abs, ht_y); number_abs(ht_x_abs); number_abs(ht_y_abs);
  while (number_less(ht_x_abs, fraction_half_t) ∧ number_less(ht_y_abs, fraction_half_t)) {
    number_double(ht_x); number_double(ht_y); number_clone(ht_x_abs, ht_x);
    number_clone(ht_y_abs, ht_y); number_abs(ht_x_abs); number_abs(ht_y_abs);
  }
  ⟨ Scan the pen polygon between w0 and w and make max_ht the range dot product with
      (ht_x, ht_y) 596 ⟩;
  {
    mp_number r1, r2;

    new_fraction(r1); new_fraction(r2); take_fraction(r1, dxin, ht_x); take_fraction(r2, dyin, ht_y);
    number_add(r1, r2); make_fraction(tmp, max_ht, r1); free_number(r1); free_number(r2);
  }
  take_fraction(xsub, tmp, dxin); take_fraction(ysub, tmp, dyin);
  set_number_from_addition(xtot, p→x_coord, xsub); set_number_from_addition(ytot, p→y_coord, ysub);
  r ← mp_insert_knot(mp, p, xtot, ytot);    ▷ clang: value never read ◁
  assert(r);
  {
    mp_number r1, r2;

    new_fraction(r1); new_fraction(r2); take_fraction(r1, dxout, ht_x); take_fraction(r2, dyout, ht_y);
    number_add(r1, r2); make_fraction(tmp, max_ht, r1); free_number(r1); free_number(r2);
  }
  take_fraction(xsub, tmp, dxout); take_fraction(ysub, tmp, dyout);
  set_number_from_addition(xtot, q→x_coord, xsub); set_number_from_addition(ytot, q→y_coord, ysub);
  r ← mp_insert_knot(mp, r, xtot, ytot); free_number(xsub); free_number(ysub); free_number(xtot);
  free_number(ytot); free_number(ht_x); free_number(ht_y); free_number(ht_x_abs);
  free_number(ht_y_abs);
}
```

This code is used in section 592.

595. ⟨ Other local variables for *make_envelope* 587 ⟩ +≡

```
mp_number max_ht;    ▷ maximum height of the pen polygon above the w0-w line ◁
halfword kk;    ▷ keeps track of the pen vertices being scanned ◁
mp_knot ww;    ▷ the pen vertex being tested ◁
```

596. The dot product of the vector from $w0$ to ww with (ht_x, ht_y) ranges from zero to max_ht.

⟨ Scan the pen polygon between $w0$ and w and make max_ht the range dot product with (ht_x, ht_y) 596 ⟩ ≡
  set_number_to_zero(*max_ht*); *kk* ← *zero_off*; *ww* ← *w*;
  while (1) {
    ⟨ Step *ww* and move *kk* one step closer to *k0* 597 ⟩;
    if (*kk* ≡ *k0*) **break**;
    {
      mp_number *r1*, *r2*;
      new_fraction(*r1*); *new_fraction*(*r2*); *set_number_from_substraction*(*tmp*, *ww*→*x_coord*, *w0*→*x_coord*);
      take_fraction(*r1*, *tmp*, *ht_x*); *set_number_from_substraction*(*tmp*, *ww*→*y_coord*, *w0*→*y_coord*);
      take_fraction(*r2*, *tmp*, *ht_y*); *set_number_from_addition*(*tmp*, *r1*, *r2*); *free_number*(*r1*);
      free_number(*r2*);
    }
    if (*number_greater*(*tmp*, *max_ht*)) *number_clone*(*max_ht*, *tmp*);
  }

This code is used in section 594.

597. ⟨ Step *ww* and move *kk* one step closer to *k0* 597 ⟩ ≡
  if (*kk* > *k0*) {
    ww ← *mp_next_knot*(*ww*); *decr*(*kk*);
  }
  else {
    ww ← *mp_prev_knot*(*ww*); *incr*(*kk*);
  }

This code is used in section 596.

598. ⟨ If endpoint, double the path *c*, and set *spec_p1* and *spec_p2* 598 ⟩ ≡
  if (*mp_left_type*(*c*) ≡ *mp_endpoint*) {
    mp→*spec_p1* ← *mp_htap_ypoc*(*mp*, *c*); *mp*→*spec_p2* ← *mp*→*path_tail*;
    mp_originator(*mp*→*spec_p1*) ← *mp_program_code*;
    mp_next_knot(*mp*→*spec_p2*) ← *mp_next_knot*(*mp*→*spec_p1*); *mp_next_knot*(*mp*→*spec_p1*) ← *c*;
    mp_remove_cubic(*mp*, *mp*→*spec_p1*); *c* ← *mp*→*spec_p1*;
    if (*c* ≠ *mp_next_knot*(*c*)) {
      mp_originator(*mp*→*spec_p2*) ← *mp_program_code*; *mp_remove_cubic*(*mp*, *mp*→*spec_p2*);
    }
    else ⟨ Make *c* look like a cycle of length one 599 ⟩
  }

This code is used in section 583.

599. ⟨ Make *c* look like a cycle of length one 599 ⟩ ≡
  {
    mp_left_type(*c*) ← *mp_explicit*; *mp_right_type*(*c*) ← *mp_explicit*; *number_clone*(*c*→*left_x*, *c*→*x_coord*);
    number_clone(*c*→*left_y*, *c*→*y_coord*); *number_clone*(*c*→*right_x*, *c*→*x_coord*);
    number_clone(*c*→*right_y*, *c*→*y_coord*);
  }

This code is used in section 598.

600. In degenerate situations we might have to look at the knot preceding q. That knot is p but if $p <> c$, its coordinates have already been offset by w.

⟨ Set the incoming and outgoing directions at q; in case of degeneracy set *join_type*: ← 2 600 ⟩ ≡

```
{
  set_number_from_substraction(dxin, q→x_coord, q→left_x);
  set_number_from_substraction(dyin, q→y_coord, q→left_y);
  if (number_zero(dxin) ∧ number_zero(dyin)) {
    set_number_from_substraction(dxin, q→x_coord, p→right_x);
    set_number_from_substraction(dyin, q→y_coord, p→right_y);
    if (number_zero(dxin) ∧ number_zero(dyin)) {
      set_number_from_substraction(dxin, q→x_coord, p→x_coord);
      set_number_from_substraction(dyin, q→y_coord, p→y_coord);
      if (p ≠ c) {     ▷ the coordinates of p have been offset by w ◁
        number_add(dxin, w→x_coord); number_add(dyin, w→y_coord);
      }
    }
  }
  pyth_add(tmp, dxin, dyin);
  if (number_zero(tmp)) {
    join_type ← 2;
  }
  else {
    mp_number r1;
    new_fraction(r1); make_fraction(r1, dxin, tmp); number_clone(dxin, r1);
    make_fraction(r1, dyin, tmp); number_clone(dyin, r1); free_number(r1);
    ⟨ Set the outgoing direction at q 601 ⟩;
  }
}
```

This code is used in section 585.

601. If $q \leftarrow c$ then the coordinates of r and the control points between q and r have already been offset by h.

⟨Set the outgoing direction at q 601⟩ ≡

```
{
  set_number_from_substraction(dxout, q->right_x, q->x_coord);
  set_number_from_substraction(dyout, q->right_y, q->y_coord);
  if (number_zero(dxout) ∧ number_zero(dyout)) {
    r ← mp_next_knot(q); set_number_from_substraction(dxout, r->left_x, q->x_coord);
    set_number_from_substraction(dyout, r->left_y, q->y_coord);
    if (number_zero(dxout) ∧ number_zero(dyout)) {
      set_number_from_substraction(dxout, r->x_coord, q->x_coord);
      set_number_from_substraction(dyout, r->y_coord, q->y_coord);
    }
  }
  if (q ≡ c) {
    number_substract(dxout, h->x_coord); number_substract(dyout, h->y_coord);
  }
  pyth_add(tmp, dxout, dyout);
  if (number_zero(tmp)) {    ▷ mp_confusion(mp, "degenerate␣spec"); ◁
    ▷ But apparently, it actually can happen. The test case is this: path p; linejoin := mitered; p:=
      (10,0)..(0,10)..(-10,0)..(0,-10)..cycle; addto currentpicture contour p withpen pensquare; The reason
      for failure here is the addition of r ≠ q in revision 1757 in “Advance p to node q, removing any “dead”
      cubics”, which itself was needed to fix a bug with disappearing knots in a path that was rotated exactly
      45 degrees (luatex.org bug 530). ◁
  }
  else {
    mp_number r1;
    new_fraction(r1); make_fraction(r1, dxout, tmp); number_clone(dxout, r1);
    make_fraction(r1, dyout, tmp); number_clone(dyout, r1); free_number(r1);
  }
}
```

This code is used in section 600.

602. Direction and intersection times. A path of length n is defined parametrically by functions $x(t)$ and $y(t)$, for $0 \le t \le n$; we can regard t as the "time" at which the path reaches the point $\bigl(x(t), y(t)\bigr)$. In this section of the program we shall consider operations that determine special times associated with given paths: the first time that a path travels in a given direction, and a pair of times at which two paths cross each other.

603. Let's start with the easier task. The function *find_direction_time* is given a direction (x,y) and a path starting at h. If the path never travels in direction (x,y), the direction time will be -1; otherwise it will be nonnegative.

Certain anomalous cases can arise: If $(x,y) \leftarrow (0,0)$, so that the given direction is undefined, the direction time will be 0. If $\bigl(x'(t),y'(t)\bigr) = (0,0)$, so that the path direction is undefined, it will be assumed to match any given direction at time t.

The routine solves this problem in nondegenerate cases by rotating the path and the given direction so that $(x,y) \leftarrow (1,0)$; i.e., the main task will be to find when a given path first travels "due east."

```
static void mp_find_direction_time(MP mp, mp_number *ret, mp_number x_orig, mp_number
        y_orig, mp_knot h)
{
  mp_number max;    ▷ max(|x|, |y|) ◁
  mp_knot p, q;    ▷ for list traversal ◁
  mp_number n;    ▷ the direction time at knot p ◁
  mp_number tt;    ▷ the direction time within a cubic ◁
  mp_number x, y;
  mp_number abs_x, abs_y;    ▷ Other local variables for find_direction_time ◁
  mp_number x1, x2, x3, y1, y2, y3;    ▷ multiples of rotated derivatives ◁
  mp_number phi;    ▷ angles of exit and entry at a knot ◁
  mp_number t;    ▷ temp storage ◁
  mp_number ab_vs_cd;
  new_number(max); new_number(x1); new_number(x2); new_number(x3); new_number(y1);
  new_number(y2); new_number(y3); new_fraction(t); new_angle(phi); new_number(ab_vs_cd);
  set_number_to_zero(*ret);    ▷ just in case ◁
  new_number(x); new_number(y); new_number(abs_x); new_number(abs_y); new_number(n);
  new_fraction(tt); number_clone(x, x_orig); number_clone(y, y_orig); number_clone(abs_x, x_orig);
  number_clone(abs_y, y_orig); number_abs(abs_x); number_abs(abs_y);
    ▷ Normalize the given direction for better accuracy; but return with zero result if it's zero ◁
  if (number_less(abs_x, abs_y)) {
    mp_number r1;
    new_fraction(r1); make_fraction(r1, x, abs_y); number_clone(x, r1); free_number(r1);
    if (number_positive(y)) {
      number_clone(y, fraction_one_t);
    }
    else {
      number_clone(y, fraction_one_t); number_negate(y);
    }
  }
  else if (number_zero(x)) {
    goto FREE;
  }
  else {
    mp_number r1;
    new_fraction(r1); make_fraction(r1, y, abs_x); number_clone(y, r1); free_number(r1);
    if (number_positive(x)) {
      number_clone(x, fraction_one_t);
    }
    else {
      number_clone(x, fraction_one_t); number_negate(x);
    }
  }
```

$p \leftarrow h$;
while (1) {
  if (*mp_right_type*(p) $\equiv$ *mp_endpoint*) **break**;
  $q \leftarrow$ *mp_next_knot*(p); ⟨ Rotate the cubic between p and q; then **goto** *found* if the rotated cubic travels due east at some time tt; but **break** if an entire cyclic path has been traversed 604 ⟩;
  $p \leftarrow q$; *number_add*(n, *unity_t*);
}
set_number_to_unity(∗*ret*); *number_negate*(∗*ret*); **goto** `FREE`;
`FOUND`: *set_number_from_addition*(∗*ret*, n, tt); **goto** `FREE`;
`FREE`: *free_number*(x); *free_number*(y); *free_number*(*abs_x*); *free_number*(*abs_y*);
  ▷ Free local variables for *find_direction_time* ◁
free_number(*x1*); *free_number*(*x2*); *free_number*(*x3*); *free_number*(*y1*); *free_number*(*y2*);
free_number(*y3*); *free_number*(t); *free_number*(*phi*); *free_number*(*ab_vs_cd*); *free_number*(n);
free_number(*max*); *free_number*(*tt*);
}

604. Since we're interested in the tangent directions, we work with the derivative

$$\frac{1}{3}B'(x_0,x_1,x_2,x_3;t) = B(x_1 - x_0, x_2 - x_1, x_3 - x_2; t)$$

instead of $B(x_0,x_1,x_2,x_3;t)$ itself. The derived coefficients are also scale-d up in order to achieve better accuracy.

The given path may turn abruptly at a knot, and it might pass the critical tangent direction at such a time. Therefore we remember the direction *phi* in which the previous rotated cubic was traveling. (The value of *phi* will be undefined on the first cubic, i.e., when $n \leftarrow 0$.)

```
#define we_found_it
  {
    number_clone(tt, t); fraction_to_round_scaled(tt); goto FOUND;
  }
```

⟨ Rotate the cubic between p and q; then **goto** *found* if the rotated cubic travels due east at some time *tt*; but **break** if an entire cyclic path has been traversed 604 ⟩ ≡

```
set_number_to_zero(tt);   ▷ Set local variables x1, x2, x3 and y1, y2, y3 to multiples of the control points
    of the rotated derivatives ◁
{
  mp_number absval;
  new_number(absval); set_number_from_substraction(x1, p→right_x, p→x_coord);
  set_number_from_substraction(x2, q→left_x, p→right_x);
  set_number_from_substraction(x3, q→x_coord, q→left_x);
  set_number_from_substraction(y1, p→right_y, p→y_coord);
  set_number_from_substraction(y2, q→left_y, p→right_y);
  set_number_from_substraction(y3, q→y_coord, q→left_y); number_clone(absval, x2); number_abs(absval);
  number_clone(max, x1); number_abs(max);
  if (number_greater(absval, max)) {
    number_clone(max, absval);
  }
  number_clone(absval, x3); number_abs(absval);
  if (number_greater(absval, max)) {
    number_clone(max, absval);
  }
  number_clone(absval, y1); number_abs(absval);
  if (number_greater(absval, max)) {
    number_clone(max, absval);
  }
  number_clone(absval, y2); number_abs(absval);
  if (number_greater(absval, max)) {
    number_clone(max, absval);
  }
  number_clone(absval, y3); number_abs(absval);
  if (number_greater(absval, max)) {
    number_clone(max, absval);
  }
  free_number(absval);
  if (number_zero(max)) goto FOUND;
  while (number_less(max, fraction_half_t)) {
    number_double(max); number_double(x1); number_double(x2); number_double(x3);
    number_double(y1); number_double(y2); number_double(y3);
  }
```

```
  number_clone(t, x1);
  {
    mp_number r1, r2;
    new_fraction(r1); new_fraction(r2); take_fraction(r1, x1, x); take_fraction(r2, y1, y);
    set_number_from_addition(x1, r1, r2); take_fraction(r1, y1, x); take_fraction(r2, t, y);
    set_number_from_substraction(y1, r1, r2); number_clone(t, x2); take_fraction(r1, x2, x);
    take_fraction(r2, y2, y); set_number_from_addition(x2, r1, r2); take_fraction(r1, y2, x);
    take_fraction(r2, t, y); set_number_from_substraction(y2, r1, r2); number_clone(t, x3);
    take_fraction(r1, x3, x); take_fraction(r2, y3, y); set_number_from_addition(x3, r1, r2);
    take_fraction(r1, y3, x); take_fraction(r2, t, y); set_number_from_substraction(y3, r1, r2);
    free_number(r1); free_number(r2);
  }
}
if (number_zero(y1))
  if (number_zero(x1) ∨ number_positive(x1)) goto FOUND;
if (number_positive(n)) {    ▷ Exit to found if an eastward direction occurs at knot p ◁
  mp_number theta;
  mp_number tmp;
  new_angle(theta); n_arg(theta, x1, y1); new_angle(tmp);
  set_number_from_substraction(tmp, theta, one_eighty_deg_t);
  if (number_nonnegative(theta) ∧ number_nonpositive(phi) ∧ number_greaterequal(phi, tmp)) {
    free_number(tmp); free_number(theta); goto FOUND;
  }
  set_number_from_addition(tmp, theta, one_eighty_deg_t);
  if (number_nonpositive(theta) ∧ number_nonnegative(phi) ∧ number_lessequal(phi, tmp)) {
    free_number(tmp); free_number(theta); goto FOUND;
  }
  free_number(tmp); free_number(theta);
  if (p ≡ h) break;
}
if (number_nonzero(x3) ∨ number_nonzero(y3)) {
  n_arg(phi, x3, y3);
}    ▷ Exit to found if the curve whose derivatives are specified by x1, x2, x3, y1, y2, y3 travels eastward at
       some time tt. ◁    ▷ In this step we want to use the crossing_point routine to find the roots of the
       quadratic equation B(y_1, y_2, y_3; t) = 0. Several complications arise: If the quadratic equation has a
       double root, the curve never crosses zero, and crossing_point will find nothing; this case occurs iff
       y_1 y_3 = y_2^2 and y_1 y_2 < 0. If the quadratic equation has simple roots, or only one root, we may have to
       negate it so that B(y_1, y_2, y_3; t) crosses from positive to negative at its first root. And finally, we need
       to do special things if B(y_1, y_2, y_3; t) is identically zero. ◁
if (number_negative(x1))
  if (number_negative(x2))
    if (number_negative(x3)) goto DONE;
{
  ab_vs_cd(ab_vs_cd, y1, y3, y2, y2);
  if (number_zero(ab_vs_cd)) {
      ▷ Handle the test for eastward directions when y_1 y_3 = y_2^2; either goto found or goto done ◁
    {
      ab_vs_cd(ab_vs_cd, y1, y2, zero_t, zero_t);
      if (number_negative(ab_vs_cd)) {
        mp_number tmp, arg2;
```

```
        new_number(tmp); new_number(arg2); set_number_from_substraction(arg2, y1, y2);
        make_fraction(t, y1, arg2); free_number(arg2); set_number_from_of_the_way(x1, t, x1, x2);
        set_number_from_of_the_way(x2, t, x2, x3); set_number_from_of_the_way(tmp, t, x1, x2);
        if (number_zero(tmp) ∨ number_positive(tmp)) {
          free_number(tmp); we_found_it;
        }
        free_number(tmp);
      }
      else if (number_zero(y3)) {
        if (number_zero(y1)) {     ▷ Exit to found if the derivative B(x1, x2, x3; t) becomes ≥ 0 ◁
            ▷ At this point we know that the derivative of y(t) is identically zero, and that x1 < 0; but
              either x2 ≥ 0 or x3 ≥ 0, so there's some hope of traveling east. ◁
          {
            mp_number arg1, arg2, arg3;
            new_number(arg1); new_number(arg2); new_number(arg3); number_clone(arg1, x1);
            number_negate(arg1); number_clone(arg2, x2); number_negate(arg2);
            number_clone(arg3, x3); number_negate(arg3); crossing_point(t, arg1, arg2, arg3);
            free_number(arg1); free_number(arg2); free_number(arg3);
            if (number_lessequal(t, fraction_one_t)) we_found_it;
            ab_vs_cd(ab_vs_cd, x1, x3, x2, x2);
            if (number_nonpositive(ab_vs_cd)) {
              mp_number arg2;
              new_number(arg2); set_number_from_substraction(arg2, x1, x2);
              make_fraction(t, x1, arg2); free_number(arg2); we_found_it;
            }
          }
        }
        else if (number_zero(x3) ∨ number_positive(x3)) {
          set_number_to_unity(tt); goto FOUND;
        }
      }
      goto DONE;
    }
  }
}
if (number_zero(y1) ∨ number_negative(y1)) {
  if (number_negative(y1)) {
    number_negate(y1); number_negate(y2); number_negate(y3);
  }
  else if (number_positive(y2)) {
    number_negate(y2); number_negate(y3);
  }
}    ▷ Check the places where B(y1, y2, y3; t) = 0 to see if B(x1, x2, x3; t) ≥ 0 ◁    ▷ The quadratic
       polynomial B(y1, y2, y3; t) begins ≥ 0 and has at most two roots, because we know that it isn't
       identically zero. It must be admitted that the crossing_point routine is not perfectly accurate; rounding
       errors might cause it to find a root when y1y3 > y2^2, or to miss the roots when y1y3 < y2^2. The rotation
       process is itself subject to rounding errors. Yet this code optimistically tries to do the right thing. ◁
crossing_point(t, y1, y2, y3);
if (number_greater(t, fraction_one_t)) goto DONE;
set_number_from_of_the_way(y2, t, y2, y3); set_number_from_of_the_way(x1, t, x1, x2);
set_number_from_of_the_way(x2, t, x2, x3); set_number_from_of_the_way(x1, t, x1, x2);
if (number_zero(x1) ∨ number_positive(x1)) we_found_it;
```

```
if (number_positive(y2)) set_number_to_zero(y2);
number_clone(tt, t);
{
  mp_number arg1, arg2, arg3;
  new_number(arg1); new_number(arg2); new_number(arg3); number_clone(arg2, y2);
  number_negate(arg2); number_clone(arg3, y3); number_negate(arg3);
  crossing_point(t, arg1, arg2, arg3); free_number(arg1); free_number(arg2); free_number(arg3);
}
if (number_greater(t, fraction_one_t)) goto DONE;
{
  mp_number tmp;
  new_number(tmp); set_number_from_of_the_way(x1, t, x1, x2);
  set_number_from_of_the_way(x2, t, x2, x3); set_number_from_of_the_way(tmp, t, x1, x2);
  if (number_nonnegative(tmp)) {
    free_number(tmp); set_number_from_of_the_way(t, t, tt, fraction_one_t); we_found_it;
  }
  free_number(tmp);
}
DONE:
```

This code is used in section 603.

605. The intersection of two cubics can be found by an interesting variant of the general bisection scheme described in the introduction to *crossing_point*. Given $w(t) = B(w_0, w_1, w_2, w_3; t)$ and $z(t) = B(z_0, z_1, z_2, z_3; t)$, we wish to find a pair of times (t_1, t_2) such that $w(t_1) = z(t_2)$, if an intersection exists. First we find the smallest rectangle that encloses the points $\{w_0, w_1, w_2, w_3\}$ and check that it overlaps the smallest rectangle that encloses $\{z_0, z_1, z_2, z_3\}$; if not, the cubics certainly don't intersect. But if the rectangles do overlap, we bisect the intervals, getting new cubics w' and w'', z' and z''; the intersection routine first tries for an intersection between w' and z', then (if unsuccessful) between w' and z'', then (if still unsuccessful) between w'' and z', finally (if thrice unsuccessful) between w'' and z''. After l successful levels of bisection we will have determined the intersection times t_1 and t_2 to l bits of accuracy.

As before, it is better to work with the numbers $W_k = 2^l(w_k - w_{k-1})$ and $Z_k = 2^l(z_k - z_{k-1})$ rather than the coefficients w_k and z_k themselves. We also need one other quantity, $\Delta = 2^l(w_0 - z_0)$, to determine when the enclosing rectangles overlap. Here's why: The x coordinates of $w(t)$ are between $u_{\min}$ and $u_{\max}$, and the x coordinates of $z(t)$ are between $x_{\min}$ and $x_{\max}$, if we write $w_k = (u_k, v_k)$ and $z_k = (x_k, y_k)$ and $u_{\min} = \min(u_0, u_1, u_2, u_3)$, etc. These intervals of x coordinates overlap if and only if $u_{\min}\text{Ł}x_{\max}$ and $x_{\min}\text{Ł}u_{\max}$. Letting

$$U_{\min} = \min(0, U_1, U_1 + U_2, U_1 + U_2 + U_3),\ U_{\max} = \max(0, U_1, U_1 + U_2, U_1 + U_2 + U_3),$$

we have $2^l u_{\min} = 2^l u_0 + U_{\min}$, etc.; the condition for overlap reduces to

$$X_{\min} - U_{\max}\text{Ł}2^l(u_0 - x_0)\text{Ł}X_{\max} - U_{\min}.$$

Thus we want to maintain the quantity $2^l(u_0 - x_0)$; similarly, the quantity $2^l(v_0 - y_0)$ accounts for the y coordinates. The coordinates of $\Delta = 2^l(w_0 - z_0)$ must stay bounded as l increases, because of the overlap condition; i.e., we know that $X_{\min}$, $X_{\max}$, and their relatives are bounded, hence $X_{\max} - U_{\min}$ and $X_{\min} - U_{\max}$ are bounded.

606. Incidentally, if the given cubics intersect more than once, the process just sketched will not necessarily find the lexicographically smallest pair (t_1, t_2). The solution actually obtained will be smallest in "shuffled order"; i.e., if $t_1 = (.a_1 a_2 \ldots a_{16})_2$ and $t_2 = (.b_1 b_2 \ldots b_{16})_2$, then we will minimize $a_1 b_1 a_2 b_2 \ldots a_{16} b_{16}$, not $a_1 a_2 \ldots a_{16} b_1 b_2 \ldots b_{16}$. Shuffled order agrees with lexicographic order if all pairs of solutions (t_1, t_2) and (t_1', t_2') have the property that $t_1 < t_1'$ iff $t_2 < t_2'$; but in general, lexicographic order can be quite different, and the bisection algorithm would be substantially less efficient if it were constrained by lexicographic order.

For example, suppose that an overlap has been found for $l = 3$ and $(t_1, t_2) = (.101, .011)$ in binary, but that no overlap is produced by either of the alternatives $(.1010, .0110)$, $(.1010, .0111)$ at level 4. Then there is probably an intersection in one of the subintervals $(.1011, .011x)$; but lexicographic order would require us to explore $(.1010, .1xxx)$ and $(.1011, .00xx)$ and $(.1011, .010x)$ first. We wouldn't want to store all of the subdivision data for the second path, so the subdivisions would have to be regenerated many times. Such inefficiencies would be associated with every '1' in the binary representation of t_1.

607. The subdivision process introduces rounding errors, hence we need to make a more liberal test for overlap. It is not hard to show that the computed values of U_i differ from the truth by at most l, on level l, hence $U_{\min}$ and $U_{\max}$ will be at most $3l$ in error. If β is an upper bound on the absolute error in the computed components of $\Delta = (\mathit{delx}, \mathit{dely})$ on level l, we will replace the test '$X_{\min} - U_{\max}$Łdelx' by the more liberal test '$X_{\min} - U_{\max}$Ł$\mathit{delx} + \mathit{tol}$', where $\mathit{tol} = 6l + \beta$.

More accuracy is obtained if we try the algorithm first with $\mathit{tol} \leftarrow 0$; the more liberal tolerance is used only if an exact approach fails. It is convenient to do this double-take by letting '3' in the preceding paragraph be a parameter, which is first 0, then 3.

⟨ Global variables 18 ⟩ +≡
unsigned int *tol_step*; ▷ either 0 or 3, usually ◁

608. We shall use an explicit stack to implement the recursive bisection method described above. The *bisect_stack* array will contain numerous 5-word packets like $(U_1, U_2, U_3, U_{\min}, U_{\max})$, as well as 20-word packets comprising the 5-word packets for U, V, X, and Y.

The following macros define the allocation of stack positions to the quantities needed for bisection-intersection.

#define *stack_1*(*A*) *mp*→*bisect_stack*[(*A*)] ▷ U_1, V_1, X_1, or Y_1 ◁
#define *stack_2*(*A*) *mp*→*bisect_stack*[(*A*) + 1] ▷ U_2, V_2, X_2, or Y_2 ◁
#define *stack_3*(*A*) *mp*→*bisect_stack*[(*A*) + 2] ▷ U_3, V_3, X_3, or Y_3 ◁
#define *stack_min*(*A*) *mp*→*bisect_stack*[(*A*) + 3] ▷ $U_{\min}$, $V_{\min}$, $X_{\min}$, or $Y_{\min}$ ◁
#define *stack_max*(*A*) *mp*→*bisect_stack*[(*A*) + 4] ▷ $U_{\max}$, $V_{\max}$, $X_{\max}$, or $Y_{\max}$ ◁
#define *int_packets* 20 ▷ number of words to represent U_k, V_k, X_k, and Y_k ◁

#define *u_packet*(*A*) ((*A*) − 5)
#define *v_packet*(*A*) ((*A*) − 10)
#define *x_packet*(*A*) ((*A*) − 15)
#define *y_packet*(*A*) ((*A*) − 20)
#define *l_packets* (*mp*→*bisect_ptr* − *int_packets*)
#define *r_packets* *mp*→*bisect_ptr*
#define *ul_packet* *u_packet*(*l_packets*) ▷ base of U'_k variables ◁
#define *vl_packet* *v_packet*(*l_packets*) ▷ base of V'_k variables ◁
#define *xl_packet* *x_packet*(*l_packets*) ▷ base of X'_k variables ◁
#define *yl_packet* *y_packet*(*l_packets*) ▷ base of Y'_k variables ◁
#define *ur_packet* *u_packet*(*r_packets*) ▷ base of U''_k variables ◁
#define *vr_packet* *v_packet*(*r_packets*) ▷ base of V''_k variables ◁
#define *xr_packet* *x_packet*(*r_packets*) ▷ base of X''_k variables ◁
#define *yr_packet* *y_packet*(*r_packets*) ▷ base of Y''_k variables ◁

#define *u1l* *stack_1*(*ul_packet*) ▷ U'_1 ◁
#define *u2l* *stack_2*(*ul_packet*) ▷ U'_2 ◁
#define *u3l* *stack_3*(*ul_packet*) ▷ U'_3 ◁
#define *v1l* *stack_1*(*vl_packet*) ▷ V'_1 ◁
#define *v2l* *stack_2*(*vl_packet*) ▷ V'_2 ◁
#define *v3l* *stack_3*(*vl_packet*) ▷ V'_3 ◁
#define *x1l* *stack_1*(*xl_packet*) ▷ X'_1 ◁
#define *x2l* *stack_2*(*xl_packet*) ▷ X'_2 ◁
#define *x3l* *stack_3*(*xl_packet*) ▷ X'_3 ◁
#define *y1l* *stack_1*(*yl_packet*) ▷ Y'_1 ◁
#define *y2l* *stack_2*(*yl_packet*) ▷ Y'_2 ◁
#define *y3l* *stack_3*(*yl_packet*) ▷ Y'_3 ◁
#define *u1r* *stack_1*(*ur_packet*) ▷ U''_1 ◁
#define *u2r* *stack_2*(*ur_packet*) ▷ U''_2 ◁
#define *u3r* *stack_3*(*ur_packet*) ▷ U''_3 ◁
#define *v1r* *stack_1*(*vr_packet*) ▷ V''_1 ◁
#define *v2r* *stack_2*(*vr_packet*) ▷ V''_2 ◁
#define *v3r* *stack_3*(*vr_packet*) ▷ V''_3 ◁
#define *x1r* *stack_1*(*xr_packet*) ▷ X''_1 ◁
#define *x2r* *stack_2*(*xr_packet*) ▷ X''_2 ◁
#define *x3r* *stack_3*(*xr_packet*) ▷ X''_3 ◁
#define *y1r* *stack_1*(*yr_packet*) ▷ Y''_1 ◁
#define *y2r* *stack_2*(*yr_packet*) ▷ Y''_2 ◁
#define *y3r* *stack_3*(*yr_packet*) ▷ Y''_3 ◁

#define *stack_dx* *mp*→*bisect_stack*[*mp*→*bisect_ptr*] ▷ stacked value of *delx* ◁
#define *stack_dy* *mp*→*bisect_stack*[*mp*→*bisect_ptr* + 1] ▷ stacked value of *dely* ◁

#define *stack_tol* $mp\rightarrow bisect\_stack[mp\rightarrow bisect\_ptr + 2]$ ▷ stacked value of *tol* ◁
#define *stack_uv* $mp\rightarrow bisect\_stack[mp\rightarrow bisect\_ptr + 3]$ ▷ stacked value of *uv* ◁
#define *stack_xy* $mp\rightarrow bisect\_stack[mp\rightarrow bisect\_ptr + 4]$ ▷ stacked value of *xy* ◁
#define *int_increment* $(int\_packets + int\_packets + 5)$ ▷ number of stack words per level ◁

⟨ Global variables 18 ⟩ +≡
  mp_number **bisect_stack*;
  integer *bisect_ptr*;

609. ⟨ Allocate or initialize variables 32 ⟩ +≡

```
mp→bisect_stack ← xmalloc((bistack_size + 1), sizeof(mp_number));
{
  int i;
  for (i ← 0; i < bistack_size + 1; i++) {
    new_number(mp→bisect_stack[i]);
  }
}
```

610. ⟨ Dealloc variables 31 ⟩ +≡

```
{
  int i;
  for (i ← 0; i < bistack_size + 1; i++) {
    free_number(mp→bisect_stack[i]);
  }
}
xfree(mp→bisect_stack);
```

611. ⟨ Check the "constant" values for consistency 34 ⟩ +≡

```
if (int_packets + (17 + 2) * int_increment > bistack_size) mp→bad ← 19;
```

612. Computation of the min and max is a tedious but fairly fast sequence of instructions; exactly four comparisons are made in each branch.

```
#define set_min_max(A)
        debug_number(stack_1(A)); debug_number(stack_3(A)); debug_number(stack_2(A));
        debug_number(stack_min(A)); debug_number(stack_max(A));
        if (number_negative(stack_1((A)))) {
          if (number_nonnegative(stack_3((A)))) {
            if (number_negative(stack_2((A))))
              set_number_from_addition(stack_min((A)), stack_1((A)), stack_2((A)));
            else number_clone(stack_min((A)), stack_1((A)));
            set_number_from_addition(stack_max((A)), stack_1((A)), stack_2((A)));
            number_add(stack_max((A)), stack_3((A)));
            if (number_negative(stack_max((A)))) set_number_to_zero(stack_max((A)));
          }
          else {
            set_number_from_addition(stack_min((A)), stack_1((A)), stack_2((A)));
            number_add(stack_min((A)), stack_3((A)));
            if (number_greater(stack_min((A)), stack_1((A))))
              number_clone(stack_min((A)), stack_1((A)));
            set_number_from_addition(stack_max((A)), stack_1((A)), stack_2((A)));
            if (number_negative(stack_max((A)))) set_number_to_zero(stack_max((A)));
          }
        }
        else if (number_nonpositive(stack_3((A)))) {
          if (number_positive(stack_2((A))))
            set_number_from_addition(stack_max((A)), stack_1((A)), stack_2((A)));
          else number_clone(stack_max((A)), stack_1((A)));
          set_number_from_addition(stack_min((A)), stack_1((A)), stack_2((A)));
          number_add(stack_min((A)), stack_3((A)));
          if (number_positive(stack_min((A)))) set_number_to_zero(stack_min((A)));
        }
        else {
          set_number_from_addition(stack_max((A)), stack_1((A)), stack_2((A)));
          number_add(stack_max((A)), stack_3((A)));
          if (number_less(stack_max((A)), stack_1((A)))) number_clone(stack_max((A)), stack_1((A)));
          set_number_from_addition(stack_min((A)), stack_1((A)), stack_2((A)));
          if (number_positive(stack_min((A)))) set_number_to_zero(stack_min((A)));
        }
```

613. It's convenient to keep the current values of l, t_1, and t_2 in the integer form $2^l+2^lt_1$ and $2^l+2^lt_2$. The *cubic_intersection* routine uses global variables *cur_t* and *cur_tt* for this purpose; after successful completion, *cur_t* and *cur_tt* will contain *unity* plus the *scaled* values of t_1 and t_2.

The values of *cur_t* and *cur_tt* will be set to zero if *cubic_intersection* finds no intersection. The routine gives up and gives an approximate answer if it has backtracked more than 5000 times (otherwise there are cases where several minutes of fruitless computation would be possible).

```
#define max_patience 5000
⟨Global variables 18⟩ +≡
  mp_number cur_t;
  mp_number cur_tt;    ▷ controls and results of cubic_intersection ◁
  integer time_to_go;    ▷ this many backtracks before giving up ◁
  mp_number max_t;    ▷ maximum of 2^{l+1} so far achieved ◁
```

614. ⟨ Initialize table entries 186 ⟩ +≡
$new\_number(mp\rightarrow cur\_t)$; $new\_number(mp\rightarrow cur\_tt)$; $new\_number(mp\rightarrow max\_t)$;

615. ⟨ Dealloc variables 31 ⟩ +≡
$free\_number(mp\rightarrow cur\_t)$; $free\_number(mp\rightarrow cur\_tt)$; $free\_number(mp\rightarrow max\_t)$;

616. The given cubics $B(w_0, w_1, w_2, w_3; t)$ and $B(z_0, z_1, z_2, z_3; t)$ are specified in adjacent knot nodes $(p, mp\_link(p))$ and $(pp, mp\_link(pp))$, respectively.

```
#define half(A) ((A)/2)
  static void mp_cubic_intersection(MP mp, mp_knot p, mp_knot pp)
  {
    mp_knot q, qq;     ▷ mp_link(p), mp_link(pp) ◁
    mp_number x_two_t;     ▷ increment bit precision ◁
    mp_number x_two_t_low_precision;     ▷ check for low precision ◁

    mp→time_to_go ← max_patience; set_number_from_scaled(mp→max_t, 2); new_number(x_two_t);
    new_number(x_two_t_low_precision); number_clone(x_two_t, two_t); number_double(x_two_t);
    number_double(x_two_t);     ▷ added 2 bit of precision ◁
    set_number_from_double(x_two_t_low_precision, −0.5); number_add(x_two_t_low_precision, x_two_t);
    ⟨Initialize for intersections at level zero 620⟩;
  CONTINUE:
    while (1) {     ▷ When we are in arbitrary precision math, low precisions can ◁     ▷ lead to access
          locations beyond the stack_size: in this case ◁     ▷ we say that there is no intersection. ◁
      if (((x_packet(mp→xy)) + 4) > bistack_size ∨ ((u_packet(mp→uv)) + 4) > bistack_size ∨
            ((y_packet(mp→xy)) + 4) > bistack_size ∨ ((v_packet(mp→uv)) + 4) > bistack_size) {
        set_number_from_scaled(mp→cur_t, 1); set_number_from_scaled(mp→cur_tt, 1); goto NOT_FOUND;
      }     ▷ Also, low precision can lead to wrong result in comparing ◁
          ▷ so we check that the level of bisection stay low, and later ◁
          ▷ we will also check that the bisection level are safe from ◁     ▷ approximations. ◁
      if (number_greater(mp→max_t, x_two_t)) {
        set_number_from_scaled(mp→cur_t, 1); set_number_from_scaled(mp→cur_tt, 1); goto NOT_FOUND;
      }
      if (number_to_scaled(mp→delx) − mp→tol ≤ number_to_scaled(stack_max(x_packet(mp→xy))) −
            number_to_scaled(stack_min(u_packet(mp→uv))))
        if (number_to_scaled(mp→delx) + mp→tol ≥ number_to_scaled(stack_min(x_packet(mp→xy))) −
              number_to_scaled(stack_max(u_packet(mp→uv))))
          if (number_to_scaled(mp→dely) − mp→tol ≤ number_to_scaled(stack_max(y_packet(mp→xy))) −
                number_to_scaled(stack_min(v_packet(mp→uv))))
            if (number_to_scaled(mp→dely) + mp→tol ≥ number_to_scaled(stack_min(y_packet(mp→xy))) −
                  number_to_scaled(stack_max(v_packet(mp→uv)))) {
              if (number_to_scaled(mp→cur_t) ≥ number_to_scaled(mp→max_t)) {
                if (number_equal(mp→max_t, x_two_t) ∨ number_greater(mp→max_t, x_two_t_low_precision))
                  {     ▷ we've done 17+2 bisections ◁
                  number_divide_int(mp→cur_t, 1 ≪ 2); number_divide_int(mp→cur_tt, 1 ≪ 2);
                    ▷ restore values due bit precision ◁
                  set_number_from_scaled(mp→cur_t, ((number_to_scaled(mp→cur_t) + 1)/2));
                  set_number_from_scaled(mp→cur_tt, ((number_to_scaled(mp→cur_tt) + 1)/2)); return;
                }
                number_double(mp→max_t); number_clone(mp→appr_t, mp→cur_t);
                number_clone(mp→appr_tt, mp→cur_tt);
              }
              ⟨Subdivide for a new level of intersection 621⟩;
              goto CONTINUE;
            }
      if (mp→time_to_go > 0) {
        decr(mp→time_to_go);
      }
      else {     ▷ we have added 2 bit of precision ◁
```

```
        number_divide_int(mp→appr_t, 1 ≪ 2); number_divide_int(mp→appr_tt, 1 ≪ 2);
        while (number_less(mp→appr_t, unity_t)) {
          number_double(mp→appr_t); number_double(mp→appr_tt);
        }
        number_clone(mp→cur_t, mp→appr_t); number_clone(mp→cur_tt, mp→appr_tt); return;
      }
    NOT_FOUND:    ▷ Advance to the next pair (cur_t, cur_tt) ◁
      if (odd(number_to_scaled(mp→cur_tt))) {
        if (odd(number_to_scaled(mp→cur_t))) {    ▷ Descend to the previous level and goto not_found ◁
          set_number_from_scaled(mp→cur_t, half(number_to_scaled(mp→cur_t)));
          set_number_from_scaled(mp→cur_tt, half(number_to_scaled(mp→cur_tt)));
          if (number_to_scaled(mp→cur_t) ≡ 0) return;
          mp→bisect_ptr −= int_increment; mp→three_l −= (integer) mp→tol_step;
          number_clone(mp→delx, stack_dx); number_clone(mp→dely, stack_dy);
          mp→tol ← number_to_scaled(stack_tol); mp→uv ← number_to_scaled(stack_uv);
          mp→xy ← number_to_scaled(stack_xy); goto NOT_FOUND;
        }
        else {
          set_number_from_scaled(mp→cur_t, number_to_scaled(mp→cur_t) + 1);
          number_add(mp→delx, stack_1(u_packet(mp→uv)));
          number_add(mp→delx, stack_2(u_packet(mp→uv)));
          number_add(mp→delx, stack_3(u_packet(mp→uv)));
          number_add(mp→dely, stack_1(v_packet(mp→uv)));
          number_add(mp→dely, stack_2(v_packet(mp→uv)));
          number_add(mp→dely, stack_3(v_packet(mp→uv))); mp→uv ← mp→uv + int_packets;
            ▷ switch from l_packets to r_packets ◁
          set_number_from_scaled(mp→cur_tt, number_to_scaled(mp→cur_tt) − 1);
          mp→xy ← mp→xy − int_packets; number_add(mp→delx, stack_1(x_packet(mp→xy)));
          number_add(mp→delx, stack_2(x_packet(mp→xy)));
          number_add(mp→delx, stack_3(x_packet(mp→xy)));
          number_add(mp→dely, stack_1(y_packet(mp→xy)));
          number_add(mp→dely, stack_2(y_packet(mp→xy)));
          number_add(mp→dely, stack_3(y_packet(mp→xy)));
        }
      }
      else {
        set_number_from_scaled(mp→cur_tt, number_to_scaled(mp→cur_tt) + 1);
        mp→tol ← mp→tol + mp→three_l; number_substract(mp→delx, stack_1(x_packet(mp→xy)));
        number_substract(mp→delx, stack_2(x_packet(mp→xy)));
        number_substract(mp→delx, stack_3(x_packet(mp→xy)));
        number_substract(mp→dely, stack_1(y_packet(mp→xy)));
        number_substract(mp→dely, stack_2(y_packet(mp→xy)));
        number_substract(mp→dely, stack_3(y_packet(mp→xy))); mp→xy ← mp→xy + int_packets;
          ▷ switch from l_packets to r_packets ◁
      }
    }
}
```

617. The following variables are global, although they are used only by *cubic_intersection*, because it is necessary on some machines to split *cubic_intersection* up into two procedures.

⟨ Global variables 18 ⟩ +≡
mp_number *delx*;
mp_number *dely*; ▷ the components of $\Delta = 2^l(w_0 - z_0)$ ◁
integer *tol*; ▷ bound on the uncertainty in the overlap test ◁
integer *uv*;
integer *xy*; ▷ pointers to the current packets of interest ◁
integer *three_l*; ▷ *tol_step* times the bisection level ◁
mp_number *appr_t*;
mp_number *appr_tt*; ▷ best approximations known to the answers ◁

618. ⟨ Initialize table entries 186 ⟩ +≡
new_number(*mp→delx*); *new_number*(*mp→dely*); *new_number*(*mp→appr_t*); *new_number*(*mp→appr_tt*);

619. ⟨ Dealloc variables 31 ⟩ +≡
free_number(*mp→delx*); *free_number*(*mp→dely*); *free_number*(*mp→appr_t*); *free_number*(*mp→appr_tt*);

620. We shall assume that the coordinates are sufficiently non-extreme that integer overflow will not occur.

⟨ Initialize for intersections at level zero 620 ⟩ ≡
q ← *mp_next_knot*(*p*); *qq* ← *mp_next_knot*(*pp*); *mp→bisect_ptr* ← *int_packets*;
set_number_from_substraction(*u1r*, *p→right_x*, *p→x_coord*);
set_number_from_substraction(*u2r*, *q→left_x*, *p→right_x*);
set_number_from_substraction(*u3r*, *q→x_coord*, *q→left_x*); *set_min_max*(*ur_packet*);
set_number_from_substraction(*v1r*, *p→right_y*, *p→y_coord*);
set_number_from_substraction(*v2r*, *q→left_y*, *p→right_y*);
set_number_from_substraction(*v3r*, *q→y_coord*, *q→left_y*); *set_min_max*(*vr_packet*);
set_number_from_substraction(*x1r*, *pp→right_x*, *pp→x_coord*);
set_number_from_substraction(*x2r*, *qq→left_x*, *pp→right_x*);
set_number_from_substraction(*x3r*, *qq→x_coord*, *qq→left_x*); *set_min_max*(*xr_packet*);
set_number_from_substraction(*y1r*, *pp→right_y*, *pp→y_coord*);
set_number_from_substraction(*y2r*, *qq→left_y*, *pp→right_y*);
set_number_from_substraction(*y3r*, *qq→y_coord*, *qq→left_y*); *set_min_max*(*yr_packet*);
set_number_from_substraction(*mp→delx*, *p→x_coord*, *pp→x_coord*);
set_number_from_substraction(*mp→dely*, *p→y_coord*, *pp→y_coord*); *mp→tol* ← 0; *mp→uv* ← *r_packets*;
mp→xy ← *r_packets*; *mp→three_l* ← 0; *set_number_from_scaled*(*mp→cur_t*, 1);
set_number_from_scaled(*mp→cur_tt*, 1)

This code is used in section 616.

621. ⟨ Subdivide for a new level of intersection 621 ⟩ ≡

number_clone(*stack_dx*, *mp*→*delx*); *number_clone*(*stack_dy*, *mp*→*dely*);
set_number_from_scaled(*stack_tol*, *mp*→*tol*); *set_number_from_scaled*(*stack_uv*, *mp*→*uv*);
set_number_from_scaled(*stack_xy*, *mp*→*xy*); *mp*→*bisect_ptr* ← *mp*→*bisect_ptr* + *int_increment*;
number_double(*mp*→*cur_t*); *number_double*(*mp*→*cur_tt*); *number_clone*(*u1l*, *stack_1*(*u_packet*(*mp*→*uv*)));
number_clone(*u3r*, *stack_3*(*u_packet*(*mp*→*uv*)));
set_number_from_addition(*u2l*, *u1l*, *stack_2*(*u_packet*(*mp*→*uv*))); *number_half*(*u2l*);
set_number_from_addition(*u2r*, *u3r*, *stack_2*(*u_packet*(*mp*→*uv*))); *number_half*(*u2r*);
set_number_from_addition(*u3l*, *u2l*, *u2r*); *number_half*(*u3l*); *number_clone*(*u1r*, *u3l*);
set_min_max(*ul_packet*); *set_min_max*(*ur_packet*); *number_clone*(*v1l*, *stack_1*(*v_packet*(*mp*→*uv*)));
number_clone(*v3r*, *stack_3*(*v_packet*(*mp*→*uv*)));
set_number_from_addition(*v2l*, *v1l*, *stack_2*(*v_packet*(*mp*→*uv*))); *number_half*(*v2l*);
set_number_from_addition(*v2r*, *v3r*, *stack_2*(*v_packet*(*mp*→*uv*))); *number_half*(*v2r*);
set_number_from_addition(*v3l*, *v2l*, *v2r*); *number_half*(*v3l*); *number_clone*(*v1r*, *v3l*);
set_min_max(*vl_packet*); *set_min_max*(*vr_packet*); *number_clone*(*x1l*, *stack_1*(*x_packet*(*mp*→*xy*)));
number_clone(*x3r*, *stack_3*(*x_packet*(*mp*→*xy*)));
set_number_from_addition(*x2l*, *x1l*, *stack_2*(*x_packet*(*mp*→*xy*))); *number_half*(*x2l*);
set_number_from_addition(*x2r*, *x3r*, *stack_2*(*x_packet*(*mp*→*xy*))); *number_half*(*x2r*);
set_number_from_addition(*x3l*, *x2l*, *x2r*); *number_half*(*x3l*); *number_clone*(*x1r*, *x3l*);
set_min_max(*xl_packet*); *set_min_max*(*xr_packet*); *number_clone*(*y1l*, *stack_1*(*y_packet*(*mp*→*xy*)));
number_clone(*y3r*, *stack_3*(*y_packet*(*mp*→*xy*)));
set_number_from_addition(*y2l*, *y1l*, *stack_2*(*y_packet*(*mp*→*xy*))); *number_half*(*y2l*);
set_number_from_addition(*y2r*, *y3r*, *stack_2*(*y_packet*(*mp*→*xy*))); *number_half*(*y2r*);
set_number_from_addition(*y3l*, *y2l*, *y2r*); *number_half*(*y3l*); *number_clone*(*y1r*, *y3l*);
set_min_max(*yl_packet*); *set_min_max*(*yr_packet*); *mp*→*uv* ← *l_packets*; *mp*→*xy* ← *l_packets*;
number_double(*mp*→*delx*); *number_double*(*mp*→*dely*);
mp→*tol* ← *mp*→*tol* − *mp*→*three_l* + (**integer**) *mp*→*tol_step*; *mp*→*tol* += *mp*→*tol*;
mp→*three_l* ← *mp*→*three_l* + (**integer**) *mp*→*tol_step*

This code is used in section 616.

622. The *path_intersection* procedure is much simpler. It invokes *cubic_intersection* in lexicographic order until finding a pair of cubics that intersect. The final intersection times are placed in *cur_t* and *cur_tt*.

```
static void mp_path_intersection(MP mp, mp_knot h, mp_knot hh)
{
  mp_knot p, pp;    ▷ link registers that traverse the given paths ◁
  mp_number n, nn;    ▷ integer parts of intersection times, minus unity ◁
  ⟨Change one-point paths into dead cycles 623⟩;
  new_number(n); new_number(nn); mp→tol_step ← 0;
  do {
    set_number_to_unity(n); number_negate(n); p ← h;
    do {
      if (mp_right_type(p) ≠ mp_endpoint) {
        set_number_to_unity(nn); number_negate(nn); pp ← hh;
        do {
          if (mp_right_type(pp) ≠ mp_endpoint) {
            mp_cubic_intersection(mp, p, pp);
            if (number_positive(mp→cur_t)) {
              number_add(mp→cur_t, n); number_add(mp→cur_tt, nn); goto DONE;
            }
          }
          number_add(nn, unity_t); pp ← mp_next_knot(pp);
        } while (pp ≠ hh);
      }
      number_add(n, unity_t); p ← mp_next_knot(p);
    } while (p ≠ h);
    mp→tol_step ← mp→tol_step + 3;
  } while (mp→tol_step ≤ 3);
  number_clone(mp→cur_t, unity_t); number_negate(mp→cur_t); number_clone(mp→cur_tt, unity_t);
  number_negate(mp→cur_tt);
DONE: free_number(n); free_number(nn);
}
```

623. ⟨Change one-point paths into dead cycles 623⟩ ≡

```
if (mp_right_type(h) ≡ mp_endpoint) {
  number_clone(h→right_x, h→x_coord); number_clone(h→left_x, h→x_coord);
  number_clone(h→right_y, h→y_coord); number_clone(h→left_y, h→y_coord);
  mp_right_type(h) ← mp_explicit;
}
if (mp_right_type(hh) ≡ mp_endpoint) {
  number_clone(hh→right_x, hh→x_coord); number_clone(hh→left_x, hh→x_coord);
  number_clone(hh→right_y, hh→y_coord); number_clone(hh→left_y, hh→y_coord);
  mp_right_type(hh) ← mp_explicit;
}
```

This code is used in section 622.

624. Dynamic linear equations. METAPOST users define variables implicitly by stating equations that should be satisfied; the computer is supposed to be smart enough to solve those equations. And indeed, the computer tries valiantly to do so, by distinguishing five different types of numeric values:

type(p) ← *mp_known* is the nice case, when *value*(p) is the *scaled* value of the variable whose address is p.

type(p) ← *mp_dependent* means that *value*(p) is not present, but *dep_list*(p) points to a *dependency list* that expresses the value of variable p as a *scaled* number plus a sum of independent variables with *fraction* coefficients.

type(p) ← *mp_independent* means that *indep_value*(p) ← s, where $s > 0$ is a "serial number" reflecting the time this variable was first used in an equation; and there is an extra field *indep_scale*(p) ← m, with $0 \le m < 64$, each dependent variable that refers to this one is actually referring to the future value of this variable times 2^m. (Usually $m \leftarrow 0$, but higher degrees of scaling are sometimes needed to keep the coefficients in dependency lists from getting too large. The value of m will always be even.)

type(p) ← *mp_numeric_type* means that variable p hasn't appeared in an equation before, but it has been explicitly declared to be numeric.

type(p) ← *undefined* means that variable p hasn't appeared before.

We have actually discussed these five types in the reverse order of their history during a computation: Once *known*, a variable never again becomes *dependent*; once *dependent*, it almost never again becomes *mp_independent*; once *mp_independent*, it never again becomes *mp_numeric_type*; and once *mp_numeric_type*, it never again becomes *undefined* (except of course when the user specifically decides to scrap the old value and start again). A backward step may, however, take place: Sometimes a *dependent* variable becomes *mp_independent* again, when one of the independent variables it depends on is reverting to *undefined*.

```
#define indep_scale(A) ((mp_value_node)(A))→data.indep.scale
#define set_indep_scale(A, B) ((mp_value_node)(A))→data.indep.scale ← (B)
#define indep_value(A) ((mp_value_node)(A))→data.indep.serial
#define set_indep_value(A, B) ((mp_value_node)(A))→data.indep.serial ← (B)

  void mp_new_indep(MP mp, mp_node p)
  {    ▷ create a new independent variable ◁
    if (mp→serial_no ≥ max_integer) {
      mp_fatal_error(mp, "variable␣instance␣identifiers␣exhausted");
    }
    mp_type(p) ← mp_independent; mp→serial_no ← mp→serial_no + 1; set_indep_scale(p, 0);
    set_indep_value(p, mp→serial_no);
  }
```

625. ⟨ Declarations 10 ⟩ +≡

```
  void mp_new_indep(MP mp, mp_node p);
```

626. ⟨ Global variables 18 ⟩ +≡

```
  integer serial_no;    ▷ the most recent serial number ◁
```

627. But how are dependency lists represented? It's simple: The linear combination $\alpha_1 v_1 + \cdots + \alpha_k v_k + \beta$ appears in $k+1$ value nodes. If $q \leftarrow dep\_list(p)$ points to this list, and if $k > 0$, then $dep\_value(q) \leftarrow \alpha_1$ (which is a *fraction*); $dep\_info(q)$ points to the location of α_1; and $mp\_link(p)$ points to the dependency list $\alpha_2 v_2 + \cdots + \alpha_k v_k + \beta$. On the other hand if $k \leftarrow 0$, then $dep\_value(q) \leftarrow \beta$ (which is *scaled*) and $dep\_info(q) \leftarrow \Lambda$. The independent variables $v_1, \ldots, v_k$ have been sorted so that they appear in decreasing order of their *value* fields (i.e., of their serial numbers). (It is convenient to use decreasing order, since $value(\Lambda) \leftarrow 0$. If the independent variables were not sorted by serial number but by some other criterion, such as their location in *mem*, the equation-solving mechanism would be too system-dependent, because the ordering can affect the computed results.)

The *link* field in the node that contains the constant term β is called the *final link* of the dependency list. METAPOST maintains a doubly-linked master list of all dependency lists, in terms of a permanently allocated node in *mem* called *dep_head*. If there are no dependencies, we have $mp\_link(dep\_head) \leftarrow dep\_head$ and $prev\_dep(dep\_head) \leftarrow dep\_head$; otherwise $mp\_link(dep\_head)$ points to the first dependent variable, say p, and $prev\_dep(p) \leftarrow dep\_head$. We have $type(p) \leftarrow mp\_dependent$, and $dep\_list(p)$ points to its dependency list. If the final link of that dependency list occurs in location q, then $mp\_link(q)$ points to the next dependent variable (say r); and we have $prev\_dep(r) \leftarrow q$, etc.

Dependency nodes sometimes mutate into value nodes and vice versa, so their structures have to match.

```
#define dep_value(A) ((mp_value_node)(A))→data.n
#define set_dep_value(A, B) do_set_dep_value(mp, (A), (B))
#define dep_info(A) get_dep_info(mp, (A))
#define set_dep_info(A, B)
        do {
          mp_value_node d ← (mp_value_node)(B);
          FUNCTION_TRACE4("set_dep_info(%p,%p)␣on␣%d\n", (A), d, __LINE__);
          ((mp_value_node)(A))→parent_ ← (mp_node) d;
        } while (0)
#define dep_list(A) ((mp_value_node)(A))→attr_head_
          ▷ half of the value field in a dependent variable ◁
#define set_dep_list(A, B)
        do {
          mp_value_node d ← (mp_value_node)(B);
          FUNCTION_TRACE4("set_dep_list(%p,%p)␣on␣%d\n", (A), d, __LINE__);
          dep_list((A)) ← (mp_node) d;
        } while (0)
#define prev_dep(A) ((mp_value_node)(A))→subscr_head_
          ▷ the other half; makes a doubly linked list ◁
#define set_prev_dep(A, B)
        do {
          mp_value_node d ← (mp_value_node)(B);
          FUNCTION_TRACE4("set_prev_dep(%p,%p)␣on␣%d\n", (A), d, __LINE__);
          prev_dep((A)) ← (mp_node) d;
        } while (0)

  static mp_node get_dep_info(MP mp, mp_value_node p)
  {
    mp_node d;
    d ← p→parent_;   ▷ half of the value field in a dependent variable ◁
    FUNCTION_TRACE3("%p␣=␣dep_info(%p)\n", d, p); return d;
  }

  static void do_set_dep_value(MP mp, mp_value_node p, mp_number q)
  {
```

$number\_clone(p\rightarrow data.n, q)$; ▷ half of the *value* field in a *dependent* variable ◁
FUNCTION_TRACE3("set_dep_value(%p,%d)\n", p, q); $p\rightarrow attr\_head\_ \leftarrow \Lambda$; $p\rightarrow subscr\_head\_ \leftarrow \Lambda$;
}

628. ⟨ Declarations 10 ⟩ +≡
static mp_node *get_dep_info*(**MP** *mp*, **mp_value_node** *p*);

629. **static mp_value_node** *mp_get_dep_node*(**MP** *mp*)
{
mp_value_node $p \leftarrow$ (**mp_value_node**) *mp_get_value_node*(*mp*);
mp_type(*p*) $\leftarrow$ *mp_dep_node_type*; **return** *p*;
}
static void *mp_free_dep_node*(**MP** *mp*, **mp_value_node** *p*)
{
mp_free_value_node(*mp*, (**mp_node**) *p*);
}

630. ⟨ Declarations 10 ⟩ +≡
static void *mp_free_dep_node*(**MP** *mp*, **mp_value_node** *p*);

631. ⟨ Initialize table entries 186 ⟩ +≡
$mp\rightarrow serial\_no \leftarrow 0$; $mp\rightarrow dep\_head \leftarrow mp\_get\_dep\_node(mp)$;
set_mp_link($mp\rightarrow dep\_head$, (**mp_node**) $mp\rightarrow dep\_head$);
set_prev_dep($mp\rightarrow dep\_head$, (**mp_node**) $mp\rightarrow dep\_head$); *set_dep_info*($mp\rightarrow dep\_head, \Lambda$);
set_dep_list($mp\rightarrow dep\_head, \Lambda$);

632. ⟨ Free table entries 187 ⟩ +≡
mp_free_dep_node(*mp*, $mp\rightarrow dep\_head$);

633. Actually the description above contains a little white lie. There's another kind of variable called *mp_proto_dependent*, which is just like a *dependent* one except that the α coefficients in its dependency list are *scaled* instead of being fractions. Proto-dependency lists are mixed with dependency lists in the nodes reachable from *dep_head*.

634. Here is a procedure that prints a dependency list in symbolic form. The second parameter should be either *dependent* or *mp_proto_dependent*, to indicate the scaling of the coefficients.

⟨ Declarations 10 ⟩ +≡
static void *mp_print_dependency*(**MP** *mp*, **mp_value_node** *p*, **quarterword** *t*);

635. **void** *mp_print_dependency*(**MP** *mp*, **mp_value_node** *p*, **quarterword** *t*)

```
{
  mp_number v;    ▷ a coefficient ◁
  mp_value_node pp;    ▷ for list manipulation ◁
  mp_node q;
  pp ← p; new_number(v);
  while (true) {
    number_clone(v, dep_value(p)); number_abs(v); q ← dep_info(p);
    if (q ≡ Λ) {    ▷ the constant term ◁
      if (number_nonzero(v) ∨ (p ≡ pp)) {
        if (number_positive(dep_value(p)))
          if (p ≠ pp) mp_print_char(mp, xord('+'));
        print_number(dep_value(p));
      }
      return;
    }    ▷ Print the coefficient, unless it's ±1.0 ◁
    if (number_negative(dep_value(p))) mp_print_char(mp, xord('-'));
    else if (p ≠ pp) mp_print_char(mp, xord('+'));
    if (t ≡ mp_dependent) {
      fraction_to_round_scaled(v);
    }
    if (¬number_equal(v, unity_t)) print_number(v);
    if (mp_type(q) ≠ mp_independent) mp_confusion(mp, "dep");
    mp_print_variable_name(mp, q); set_number_from_scaled(v, indep_scale(q));
    while (number_positive(v)) {
      mp_print(mp, "*4"); number_add_scaled(v, −2);
    }
    p ← (mp_value_node) mp_link(p);
  }
}
```

636. The maximum absolute value of a coefficient in a given dependency list is returned by the following simple function.

```
static void mp_max_coef(MP mp, mp_number *x, mp_value_node p)
{
  mp_number(absv); new_number(absv); set_number_to_zero(*x);
  while (dep_info(p) ≠ Λ) {
    number_clone(absv, dep_value(p)); number_abs(absv);
    if (number_greater(absv, *x)) {
      number_clone(*x, absv);
    }
    p ← (mp_value_node) mp_link(p);
  }
  free_number(absv);
}
```

637. One of the main operations needed on dependency lists is to add a multiple of one list to the other; we call this *p_plus_fq*, where p and q point to dependency lists and f is a fraction.

If the coefficient of any independent variable becomes *coef_bound* or more, in absolute value, this procedure changes the type of that variable to '*independent_needing_fix*', and sets the global variable *fix_needed* to *true*. The value of *coef_bound* $= \mu$ is chosen so that $\mu^2 + \mu < 8$; this means that the numbers we deal with won't get too large. (Instead of the "optimum" $\mu = (\sqrt{33} - 1)/2 \approx 2.3723$, the safer value 7/3 is taken as the threshold.)

The changes mentioned in the preceding paragraph are actually done only if the global variable *watch_coefs* is *true*. But it usually is; in fact, it is *false* only when METAPOST is making a dependency list that will soon be equated to zero.

Several procedures that act on dependency lists, including *p_plus_fq*, set the global variable *dep_final* to the final (constant term) node of the dependency list that they produce.

#**define** *independent_needing_fix* 0

⟨ Global variables 18 ⟩ +≡
 boolean *fix_needed*; ▷ does at least one *independent* variable need scaling? ◁
 boolean *watch_coefs*; ▷ should we scale coefficients that exceed *coef_bound*? ◁
 mp_value_node *dep_final*; ▷ location of the constant term and final link ◁

638. ⟨ Set initial values of key variables 42 ⟩ +≡
 mp→*fix_needed* ← *false*; *mp*→*watch_coefs* ← *true*;

639. The *p_plus_fq* procedure has a fourth parameter, t, that should be set to *mp_proto_dependent* if p is a proto-dependency list. In this case f will be *scaled*, not a *fraction*. Similarly, the fifth parameter *tt* should be *mp_proto_dependent* if q is a proto-dependency list.

List q is unchanged by the operation; but list p is totally destroyed.

The final link of the dependency list or proto-dependency list returned by *p_plus_fq* is the same as the original final link of p. Indeed, the constant term of the result will be located in the same *mem* location as the original constant term of p.

Coefficients of the result are assumed to be zero if they are less than a certain threshold. This compensates for inevitable rounding errors, and tends to make more variables '*known*'. The threshold is approximately 10^{-5} in the case of normal dependency lists, 10^{-4} for proto-dependencies.

#**define** *fraction_threshold_k* ((**math_data** ∗) *mp*→*math*)→*fraction_threshold_t*
#**define** *half_fraction_threshold_k* ((**math_data** ∗) *mp*→*math*)→*half_fraction_threshold_t*
#**define** *scaled_threshold_k* ((**math_data** ∗) *mp*→*math*)→*scaled_threshold_t*
#**define** *half_scaled_threshold_k* ((**math_data** ∗) *mp*→*math*)→*half_scaled_threshold_t*

⟨ Declarations 10 ⟩ +≡
 static mp_value_node *mp_p_plus_fq*(**MP** *mp*, **mp_value_node** *p*, **mp_number** *f*, **mp_value_node** *q*, **mp_variable_type** *t*, **mp_variable_type** *tt*);

640. **static mp_value_node** *mp_p_plus_fq*(**MP** *mp*, **mp_value_node** *p*, **mp_number** *f*, **mp_value_node** *q*, **mp_variable_type** *t*, **mp_variable_type** *tt*)

```
{
  mp_node pp, qq;   ▷ dep_info(p) and dep_info(q), respectively ◁
  mp_value_node r, s;   ▷ for list manipulation ◁
  mp_number threshold, half_threshold;   ▷ defines a neighborhood of zero ◁
  mp_number v, vv;   ▷ temporary registers ◁
  new_number(v); new_number(vv); new_number(threshold); new_number(half_threshold);
  if (t ≡ mp_dependent) {
    number_clone(threshold, fraction_threshold_k);
    number_clone(half_threshold, half_fraction_threshold_k);
  }
  else {
    number_clone(threshold, scaled_threshold_k); number_clone(half_threshold, half_scaled_threshold_k);
  }
  r ← (mp_value_node) mp→temp_head; pp ← dep_info(p); qq ← dep_info(q);
  while (1) {
    if (pp ≡ qq) {
      if (pp ≡ Λ) {
        break;
      }
      else {   ▷ Contribute a term from p, plus f times the corresponding term from q ◁
        mp_number r1;
        mp_number absv;
        new_fraction(r1); new_number(absv);
        if (tt ≡ mp_dependent) {
          take_fraction(r1, f, dep_value(q));
        }
        else {
          take_scaled(r1, f, dep_value(q));
        }
        set_number_from_addition(v, dep_value(p), r1); free_number(r1); set_dep_value(p, v); s ← p;
        p ← (mp_value_node) mp_link(p); number_clone(absv, v); number_abs(absv);
        if (number_less(absv, threshold)) {
          mp_free_dep_node(mp, s);
        }
        else {
          if (number_greaterequal(absv, coef_bound_k) ∧ mp→watch_coefs) {
            mp_type(qq) ← independent_needing_fix;
              ▷ If we set this , then we can drop (mp_type(pp) ≡ independent_needing_fix ∧ mp→fix_needed)
                later ◁   ▷ set_number_from_scaled(value_number(qq), indep_value(qq)); ◁
            mp→fix_needed ← true;
          }
          set_mp_link(r, (mp_node) s); r ← s;
        }
        free_number(absv); pp ← dep_info(p); q ← (mp_value_node) mp_link(q); qq ← dep_info(q);
      }
    }
    else {
      if (pp ≡ Λ) set_number_to_neg_inf(v);
      else if (mp_type(pp) ≡ mp_independent ∨ (mp_type(pp) ≡ independent_needing_fix ∧ mp→fix_needed))
        set_number_from_scaled(v, indep_value(pp));
```

```
    else number_clone(v, value_number(pp));
    if (qq ≡ Λ) set_number_to_neg_inf(vv);
    else if (mp_type(qq) ≡ mp_independent ∨ (mp_type(qq) ≡ independent_needing_fix ∧ mp→fix_needed))
      set_number_from_scaled(vv, indep_value(qq));
    else number_clone(vv, value_number(qq));
    if (number_less(v, vv)) {    ▷ Contribute a term from q, multiplied by f ◁
      mp_number absv;

      new_number(absv);
      {
        mp_number r1;
        mp_number arg1, arg2;

        new_fraction(r1); new_number(arg1); new_number(arg2); number_clone(arg1, f);
        number_clone(arg2, dep_value(q));
        if (tt ≡ mp_dependent) {
          take_fraction(r1, arg1, arg2);
        }
        else {
          take_scaled(r1, arg1, arg2);
        }
        number_clone(v, r1); free_number(r1); free_number(arg1); free_number(arg2);
      }
      number_clone(absv, v); number_abs(absv);
      if (number_greater(absv, half_threshold)) {
        s ← mp_get_dep_node(mp); set_dep_info(s, qq); set_dep_value(s, v);
        if (number_greaterequal(absv, coef_bound_k) ∧ mp→watch_coefs) {
            ▷ clang: dereference of a null pointer ('qq') ◁
          assert(qq); mp_type(qq) ← independent_needing_fix; mp→fix_needed ← true;
        }
        set_mp_link(r, (mp_node) s); r ← s;
      }
      q ← (mp_value_node) mp_link(q); qq ← dep_info(q); free_number(absv);
    }
    else {
      set_mp_link(r, (mp_node) p); r ← p; p ← (mp_value_node) mp_link(p); pp ← dep_info(p);
    }
  }
}
{
  mp_number r1;
  mp_number arg1, arg2;

  new_fraction(r1); new_number(arg1); new_number(arg2); number_clone(arg1, dep_value(q));
  number_clone(arg2, f);
  if (t ≡ mp_dependent) {
    take_fraction(r1, arg1, arg2);
  }
  else {
    take_scaled(r1, arg1, arg2);
  }
  slow_add(arg1, dep_value(p), r1); set_dep_value(p, arg1); free_number(r1); free_number(arg1);
  free_number(arg2);
}
```

$set\_mp\_link(r, (\textbf{mp\_node})\, p)$; $mp\rightarrow dep\_final \leftarrow p$; $free\_number(threshold)$; $free\_number(half\_threshold)$;
$free\_number(v)$; $free\_number(vv)$; **return** $(\textbf{mp\_value\_node})\, mp\_link(mp\rightarrow temp\_head)$;
}

641. It is convenient to have another subroutine for the special case of *p_plus_fq* when $f \leftarrow 1.0$. In this routine lists p and q are both of the same type t (either *dependent* or *mp_proto_dependent*).

```
static mp_value_node mp_p_plus_q(MP mp, mp_value_node p, mp_value_node
        q, mp_variable_type t)
{
  mp_node pp, qq;    ▷ dep_info(p) and dep_info(q), respectively ◁
  mp_value_node s;    ▷ for list manipulation ◁
  mp_value_node r;    ▷ for list manipulation ◁
  mp_number threshold;    ▷ defines a neighborhood of zero ◁
  mp_number v, vv;    ▷ temporary register ◁
  new_number(v); new_number(vv); new_number(threshold);
  if (t ≡ mp_dependent) number_clone(threshold, fraction_threshold_k);
  else number_clone(threshold, scaled_threshold_k);
  r ← (mp_value_node) mp→temp_head; pp ← dep_info(p); qq ← dep_info(q);
  while (1) {
    if (pp ≡ qq) {
      if (pp ≡ Λ) {
        break;
      }
      else {    ▷ Contribute a term from p, plus the corresponding term from q ◁
        mp_number test;
        new_number(test); set_number_from_addition(v, dep_value(p), dep_value(q));
        set_dep_value(p, v); s ← p; p ← (mp_value_node) mp_link(p); pp ← dep_info(p);
        number_clone(test, v); number_abs(test);
        if (number_less(test, threshold)) {
          mp_free_dep_node(mp, s);
        }
        else {
          if (number_greaterequal(test, coef_bound_k) ∧ mp→watch_coefs) {
            mp_type(qq) ← independent_needing_fix;
              ▷ If we set this , then we can drop (mp_type(pp) ≡ independent_needing_fix ∧ mp→fix_needed)
                later ◁    ▷ set_number_from_scaled(value_number(qq), indep_value(qq)); ◁
            mp→fix_needed ← true;
          }
          set_mp_link(r, (mp_node) s); r ← s;
        }
        free_number(test); q ← (mp_value_node) mp_link(q); qq ← dep_info(q);
      }
    }
    else {
      if (pp ≡ Λ) set_number_to_zero(v);
      else if (mp_type(pp) ≡ mp_independent ∨ (mp_type(pp) ≡ independent_needing_fix ∧ mp→fix_needed))
        set_number_from_scaled(v, indep_value(pp));
      else number_clone(v, value_number(pp));
      if (qq ≡ Λ) set_number_to_zero(vv);
      else if (mp_type(qq) ≡ mp_independent ∨ (mp_type(qq) ≡ independent_needing_fix ∧ mp→fix_needed))
        set_number_from_scaled(vv, indep_value(qq));
      else number_clone(vv, value_number(qq));
      if (number_less(v, vv)) {
        s ← mp_get_dep_node(mp); set_dep_info(s, qq); set_dep_value(s, dep_value(q));
        q ← (mp_value_node) mp_link(q); qq ← dep_info(q); set_mp_link(r, (mp_node) s); r ← s;
```

$\}$
else $\{$
$\mathit{set\_mp\_link}(r, (\mathbf{mp\_node})\, p)$; $r \leftarrow p$; $p \leftarrow (\mathbf{mp\_value\_node})\, \mathit{mp\_link}(p)$; $\mathit{pp} \leftarrow \mathit{dep\_info}(p)$;
$\}$
$\}$
$\}$
$\{$
mp_number $\mathit{r1}$;
$\mathit{new\_number}(\mathit{r1})$; $\mathit{slow\_add}(\mathit{r1}, \mathit{dep\_value}(p), \mathit{dep\_value}(q))$; $\mathit{set\_dep\_value}(p, \mathit{r1})$; $\mathit{free\_number}(\mathit{r1})$;
$\}$
$\mathit{set\_mp\_link}(r, (\mathbf{mp\_node})\, p)$; $\mathit{mp}{\rightarrow}\mathit{dep\_final} \leftarrow p$; $\mathit{free\_number}(v)$; $\mathit{free\_number}(\mathit{vv})$;
$\mathit{free\_number}(\mathit{threshold})$; **return** $(\mathbf{mp\_value\_node})\, \mathit{mp\_link}(\mathit{mp}{\rightarrow}\mathit{temp\_head})$;
$\}$

642. A somewhat simpler routine will multiply a dependency list by a given constant v. The constant is either a *fraction* less than *fraction_one*, or it is *scaled*. In the latter case we might be forced to convert a dependency list to a proto-dependency list. Parameters *t0* and *t1* are the list types before and after; they should agree unless *t0* ← *mp_dependent* and *t1* ← *mp_proto_dependent* and *v_is_scaled* ← *true*.

```
static mp_value_node mp_p_times_v(MP mp, mp_value_node p, mp_number v, quarterword
        t0, quarterword t1, boolean v_is_scaled)
{
  mp_value_node r, s;    ▷ for list manipulation ◁
  mp_number w;    ▷ tentative coefficient ◁
  mp_number threshold;
  boolean scaling_down;
  new_number(threshold); new_number(w);
  if (t0 ≠ t1) scaling_down ← true;
  else scaling_down ← (¬v_is_scaled);
  if (t1 ≡ mp_dependent) number_clone(threshold, half_fraction_threshold_k);
  else number_clone(threshold, half_scaled_threshold_k);
  r ← (mp_value_node) mp→temp_head;
  while (dep_info(p) ≠ Λ) {
    mp_number test;
    new_number(test);
    if (scaling_down) {
      take_fraction(w, v, dep_value(p));
    }
    else {
      take_scaled(w, v, dep_value(p));
    }
    number_clone(test, w); number_abs(test);
    if (number_lessequal(test, threshold)) {
      s ← (mp_value_node) mp_link(p); mp_free_dep_node(mp, p); p ← s;
    }
    else {
      if (number_greaterequal(test, coef_bound_k)) {
        mp→fix_needed ← true; mp_type(dep_info(p)) ← independent_needing_fix;
      }
      set_mp_link(r, (mp_node) p); r ← p; set_dep_value(p, w); p ← (mp_value_node) mp_link(p);
    }
    free_number(test);
  }
  set_mp_link(r, (mp_node) p);
  {
    mp_number r1;
    new_number(r1);
    if (v_is_scaled) {
      take_scaled(r1, dep_value(p), v);
    }
    else {
      take_fraction(r1, dep_value(p), v);
    }
    set_dep_value(p, r1); free_number(r1);
  }
  free_number(w); free_number(threshold); return (mp_value_node) mp_link(mp→temp_head);
```

}

643. Similarly, we sometimes need to divide a dependency list by a given *scaled* constant.

⟨ Declarations 10 ⟩ +≡

static mp_value_node *mp_p_over_v*(**MP** *mp*, **mp_value_node** *p*, **mp_number** *v*, **quarterword** *t0*, **quarterword** *t1*);

644. #define $p\_over\_v\_threshold\_k$ ((**math_data** ∗) $mp\rightarrow math$)→$p\_over\_v\_threshold\_t$

```
mp_value_node mp_p_over_v(MP mp, mp_value_node p, mp_number v_orig, quarterword
        t0, quarterword t1)
{
  mp_value_node r, s;   ▷ for list manipulation ◁
  mp_number w;   ▷ tentative coefficient ◁
  mp_number threshold;
  mp_number v;
  boolean scaling_down;

  new_number(v); new_number(w); new_number(threshold); number_clone(v, v_orig);
  if (t0 ≠ t1) scaling_down ← true;
  else scaling_down ← false;
  if (t1 ≡ mp_dependent) number_clone(threshold, half_fraction_threshold_k);
  else number_clone(threshold, half_scaled_threshold_k);
  r ← (mp_value_node) mp→temp_head;
  while (dep_info(p) ≠ Λ) {
    if (scaling_down) {
      mp_number x, absv;

      new_number(x); new_number(absv); number_clone(absv, v); number_abs(absv);
      if (number_less(absv, p_over_v_threshold_k)) {
        number_clone(x, v); convert_scaled_to_fraction(x); make_scaled(w, dep_value(p), x);
      }
      else {
        number_clone(x, dep_value(p)); fraction_to_round_scaled(x); make_scaled(w, x, v);
      }
      free_number(x); free_number(absv);
    }
    else {
      make_scaled(w, dep_value(p), v);
    }
    {
      mp_number test;

      new_number(test); number_clone(test, w); number_abs(test);
      if (number_lessequal(test, threshold)) {
        s ← (mp_value_node) mp_link(p); mp_free_dep_node(mp, p); p ← s;
      }
      else {
        if (number_greaterequal(test, coef_bound_k)) {
          mp→fix_needed ← true; mp_type(dep_info(p)) ← independent_needing_fix;
        }
        set_mp_link(r, (mp_node) p); r ← p; set_dep_value(p, w); p ← (mp_value_node) mp_link(p);
      }
      free_number(test);
    }
  }
  set_mp_link(r, (mp_node) p);
  {
    mp_number ret;

    new_number(ret); make_scaled(ret, dep_value(p), v); set_dep_value(p, ret); free_number(ret);
  }
```

```
    free_number(v); free_number(w); free_number(threshold);
    return (mp_value_node) mp_link(mp→temp_head);
  }
```

645. Here's another utility routine for dependency lists. When an independent variable becomes dependent, we want to remove it from all existing dependencies. The *p_with_x_becoming_q* function computes the dependency list of p after variable x has been replaced by q.

This procedure has basically the same calling conventions as *p_plus_fq*: List q is unchanged; list p is destroyed; the constant node and the final link are inherited from p; and the fourth parameter tells whether or not p is *mp_proto_dependent*. However, the global variable *dep_final* is not altered if x does not occur in list p.

```
  static mp_value_node mp_p_with_x_becoming_q(MP mp, mp_value_node p, mp_node x, mp_node
        q, quarterword t)
  {
    mp_value_node r, s;    ▷ for list manipulation ◁
    integer sx;    ▷ serial number of x ◁
    s ← p; r ← (mp_value_node) mp→temp_head; sx ← indep_value(x);
    while (dep_info(s) ≠ Λ ∧ indep_value(dep_info(s)) > sx) {
      r ← s; s ← (mp_value_node) mp_link(s);
    }
    if (dep_info(s) ≡ Λ ∨ dep_info(s) ≠ x) {
      return p;
    }
    else {
      mp_value_node ret;
      mp_number v1;
      new_number(v1); set_mp_link(mp→temp_head, (mp_node) p); set_mp_link(r, mp_link(s));
      number_clone(v1, dep_value(s)); mp_free_dep_node(mp, s); ret ← mp_p_plus_fq(mp,
          (mp_value_node) mp_link(mp→temp_head), v1, (mp_value_node) q, t, mp_dependent);
      free_number(v1); return ret;
    }
  }
```

646. Here's a simple procedure that reports an error when a variable has just received a known value that's out of the required range.

```
⟨ Declarations 10 ⟩ +≡
  static void mp_val_too_big(MP mp, mp_number x);
```

647.
```
  static void mp_val_too_big(MP mp, mp_number x)
  {
    if (number_positive(internal_value(mp_warning_check))) {
      char msg[256];
      const char *hlp[] ← {"The␣equation␣I␣just␣processed␣has␣given␣some␣variable␣a",
          "value␣outside␣of␣the␣safety␣range.␣Continue␣and␣I'll␣try",
          "to␣cope␣with␣that␣big␣value;␣but␣it␣might␣be␣dangerous.",
          "(Set␣warningcheck:=0␣to␣suppress␣this␣message.)", Λ};
      mp_snprintf(msg, 256, "Value␣is␣too␣large␣(%s)", number_tostring(x));
      mp_error(mp, msg, hlp, true);
    }
  }
```

648. When a dependent variable becomes known, the following routine removes its dependency list. Here p points to the variable, and q points to the dependency list (which is one node long).

⟨ Declarations 10 ⟩ +≡
static void *mp_make_known*(**MP** *mp*, **mp_value_node** *p*, **mp_value_node** *q*);

649. void *mp_make_known*(**MP** *mp*, **mp_value_node** *p*, **mp_value_node** *q*)

```
{
  mp_variable_type t;    ▷ the previous type ◁
  mp_number absp;
  new_number(absp); set_prev_dep(mp_link(q), prev_dep(p)); set_mp_link(prev_dep(p), mp_link(q));
  t ← mp_type(p); mp_type(p) ← mp_known; set_value_number(p, dep_value(q));
  mp_free_dep_node(mp, q); number_clone(absp, value_number(p)); number_abs(absp);
  if (number_greaterequal(absp, warning_limit_t)) mp_val_too_big(mp, value_number(p));
  if ((number_positive(internal_value(mp_tracing_equations))) ∧ mp_interesting(mp, (mp_node) p)) {
    mp_begin_diagnostic(mp); mp_print_nl(mp, "####␣"); mp_print_variable_name(mp, (mp_node) p);
    mp_print_char(mp, xord('=')); print_number(value_number(p)); mp_end_diagnostic(mp, false);
  }
  if (cur_exp_node() ≡ (mp_node) p ∧ mp→cur_exp.type ≡ t) {
    mp→cur_exp.type ← mp_known; set_cur_exp_value_number(value_number(p));
    mp_free_value_node(mp, (mp_node) p);
  }
  free_number(absp);
}
```

650. The *fix_dependencies* routine is called into action when *fix_needed* has been triggered. The program keeps a list s of independent variables whose coefficients must be divided by 4.

In unusual cases, this fixup process might reduce one or more coefficients to zero, so that a variable will become known more or less by default.

⟨ Declarations 10 ⟩ +≡
static void *mp_fix_dependencies*(**MP** *mp*);

651. **#define** *independent_being_fixed* 1 ▷ this variable already appears in s ◁

```
static void mp_fix_dependencies(MP mp)
{
  mp_value_node p, q, r, s, t;   ▷ list manipulation registers ◁
  mp_node x;   ▷ an independent variable ◁
  r ← (mp_value_node) mp_link(mp→dep_head);  s ← Λ;
  while (r ≠ mp→dep_head) {
    t ← r;   ▷ Run through the dependency list for variable t, fixing all nodes, and ending with final link q ◁
    while (1) {
      if (t ≡ r) {
        q ← (mp_value_node) dep_list(t);
      }
      else {
        q ← (mp_value_node) mp_link(r);
      }
      x ← dep_info(q);
      if (x ≡ Λ) break;
      if (mp_type(x) ≤ independent_being_fixed) {
        if (mp_type(x) < independent_being_fixed) {
          p ← mp_get_dep_node(mp);  set_mp_link(p, (mp_node) s);  s ← p;  set_dep_info(s, x);
          mp_type(x) ← independent_being_fixed;
        }
        set_dep_value(q, dep_value(q));  number_divide_int(dep_value(q), 4);
        if (number_zero(dep_value(q))) {
          set_mp_link(r, mp_link(q));  mp_free_dep_node(mp, q);  q ← r;
        }
      }
      r ← q;
    }
    r ← (mp_value_node) mp_link(q);
    if (q ≡ (mp_value_node) dep_list(t)) mp_make_known(mp, t, q);
  }
  while (s ≠ Λ) {
    p ← (mp_value_node) mp_link(s);  x ← dep_info(s);  mp_free_dep_node(mp, s);  s ← p;
    mp_type(x) ← mp_independent;  set_indep_scale(x, indep_scale(x) + 2);
  }
  mp→fix_needed ← false;
}
```

652. The *new_dep* routine installs a dependency list p based on the value node q, linking it into the list of all known dependencies. It replaces q with the new dependency node. We assume that *dep_final* points to the final node of list p.

```
static void mp_new_dep(MP mp, mp_node q, mp_variable_type newtype, mp_value_node p)
{
  mp_node r;   ▷ what used to be the first dependency ◁
  FUNCTION_TRACE4("mp_new_dep(%p,%d,%p)\n", q, newtype, p);  mp_type(q) ← newtype;
  set_dep_list(q, p);  set_prev_dep(q, (mp_node) mp→dep_head);  r ← mp_link(mp→dep_head);
  set_mp_link(mp→dep_final, r);  set_prev_dep(r, (mp_node) mp→dep_final);
  set_mp_link(mp→dep_head, q);
}
```

653. Here is one of the ways a dependency list gets started. The *const_dependency* routine produces a list that has nothing but a constant term.

```
static mp_value_node mp_const_dependency(MP mp, mp_number v)
{
  mp→dep_final ← mp_get_dep_node(mp); set_dep_value(mp→dep_final, v); set_dep_info(mp→dep_final, Λ);
  FUNCTION_TRACE3("%p␣=␣mp_const_dependency(%d)\n", mp→dep_final, number_to_scaled(v));
  return mp→dep_final;
}
```

654. And here's a more interesting way to start a dependency list from scratch: The parameter to *single_dependency* is the location of an independent variable x, and the result is the simple dependency list '$x + 0$'.

In the unlikely event that the given independent variable has been doubled so often that we can't refer to it with a nonzero coefficient, *single_dependency* returns the simple list '0'. This case can be recognized by testing that the returned list pointer is equal to *dep_final*.

```
#define two_to_the(A) (1 ≪ (unsigned)(A))
static mp_value_node mp_single_dependency(MP mp, mp_node p)
{
  mp_value_node q, rr;    ▷ the new dependency list ◁
  integer m;    ▷ the number of doublings ◁
  m ← indep_scale(p);
  if (m > 28) {
    q ← mp_const_dependency(mp, zero_t);
  }
  else {
    q ← mp_get_dep_node(mp); set_dep_value(q, zero_t);
    set_number_from_scaled(dep_value(q), (integer) two_to_the(28 − m)); set_dep_info(q, p);
    rr ← mp_const_dependency(mp, zero_t); set_mp_link(q, (mp_node) rr);
  }
  FUNCTION_TRACE3("%p␣=␣mp_single_dependency(%p)\n", q, p); return q;
}
```

655. We sometimes need to make an exact copy of a dependency list.

```
static mp_value_node mp_copy_dep_list(MP mp, mp_value_node p)
{
  mp_value_node q;    ▷ the new dependency list ◁
  FUNCTION_TRACE2("mp_copy_dep_list(%p)\n", p); q ← mp_get_dep_node(mp); mp→dep_final ← q;
  while (1) {
    set_dep_info(mp→dep_final, dep_info(p)); set_dep_value(mp→dep_final, dep_value(p));
    if (dep_info(mp→dep_final) ≡ Λ) break;
    set_mp_link(mp→dep_final, (mp_node) mp_get_dep_node(mp));
    mp→dep_final ← (mp_value_node) mp_link(mp→dep_final); p ← (mp_value_node) mp_link(p);
  }
  return q;
}
```

656. But how do variables normally become known? Ah, now we get to the heart of the equation-solving mechanism. The *linear_eq* procedure is given a *dependent* or *mp_proto_dependent* list, *p*, in which at least one independent variable appears. It equates this list to zero, by choosing an independent variable with the largest coefficient and making it dependent on the others. The newly dependent variable is eliminated from all current dependencies, thereby possibly making other dependent variables known.

The given list *p* is, of course, totally destroyed by all this processing.

```
static mp_value_node find_node_with_largest_coefficient(MP mp, mp_value_node p, mp_number
      *v);
static void display_new_dependency(MP mp, mp_value_node p, mp_node x, integer n);
static void change_to_known(MP mp, mp_value_node p, mp_node x, mp_value_node
      final_node, integer n);
static mp_value_node divide_p_by_minusv_removing_q(MP mp, mp_value_node p, mp_value_node
      q, mp_value_node *final_node, mp_number v, quarterword t);
static mp_value_node divide_p_by_2_n(MP mp, mp_value_node p, integer n);

static void mp_linear_eq(MP mp, mp_value_node p, quarterword t)
{
  mp_value_node r;   ▷ for link manipulation ◁
  mp_node x;   ▷ the variable that loses its independence ◁
  integer n;   ▷ the number of times x had been halved ◁
  mp_number v;   ▷ the coefficient of x in list p ◁
  mp_value_node prev_r;   ▷ lags one step behind r ◁
  mp_value_node final_node;   ▷ the constant term of the new dependency list ◁
  mp_value_node qq;

  new_number(v); FUNCTION_TRACE3("mp_linear_eq(%p,%d)\n", p, t);
  qq ← find_node_with_largest_coefficient(mp, p, &v); x ← dep_info(qq); n ← indep_scale(x);
  p ← divide_p_by_minusv_removing_q(mp, p, qq, &final_node, v, t);
  if (number_positive(internal_value(mp_tracing_equations))) {
    display_new_dependency(mp, p, (mp_node) x, n);
  }
  prev_r ← (mp_value_node) mp→dep_head; r ← (mp_value_node) mp_link(mp→dep_head);
  while (r ≠ mp→dep_head) {
    mp_value_node s ← (mp_value_node) dep_list(r);
    mp_value_node q ← mp_p_with_x_becoming_q(mp, s, x, (mp_node) p, mp_type(r));
    if (dep_info(q) ≡ Λ) {
      mp_make_known(mp, r, q);
    }
    else {
      set_dep_list(r, q);
      do {
        q ← (mp_value_node) mp_link(q);
      } while (dep_info(q) ≠ Λ);
      prev_r ← q;
    }
    r ← (mp_value_node) mp_link(prev_r);
  }
  if (n > 0) {
    p ← divide_p_by_2_n(mp, p, n);
  }
  change_to_known(mp, p, (mp_node) x, final_node, n);
  if (mp→fix_needed) mp_fix_dependencies(mp);
  free_number(v);
```

```
}
```

657. **static mp_value_node** *find_node_with_largest_coefficient*(**MP** *mp*, **mp_value_node** *p*, **mp_number** $*v$)

```
{
  mp_number vabs;    ▷ its absolute value of v ◁
  mp_number rabs;    ▷ the absolute value of dep_value(r) ◁
  mp_value_node q ← p;
  mp_value_node r ← (mp_value_node) mp_link(p);
  new_number(vabs); new_number(rabs); number_clone(*v, dep_value(q));
  while (dep_info(r) ≠ Λ) {
    number_clone(vabs, *v); number_abs(vabs); number_clone(rabs, dep_value(r)); number_abs(rabs);
    if (number_greater(rabs, vabs)) {
      q ← r; number_clone(*v, dep_value(r));
    }
    r ← (mp_value_node) mp_link(r);
  }
  free_number(vabs); free_number(rabs); return q;
}
```

658. Here we want to change the coefficients from *scaled* to *fraction*, except in the constant term. In the common case of a trivial equation like '`x=3.14`', we will have $v \leftarrow -fraction\_one$, $q \leftarrow p$, and $t \leftarrow mp\_dependent$.

```
static mp_value_node divide_p_by_minusv_removing_q(MP mp, mp_value_node p, mp_value_node
        q, mp_value_node *final_node, mp_number v, quarterword t)
{
  mp_value_node r;    ▷ for link manipulation ◁
  mp_value_node s;
  s ← (mp_value_node) mp→temp_head; set_mp_link(s, (mp_node) p); r ← p;
  do {
    if (r ≡ q) {
      set_mp_link(s, mp_link(r)); mp_free_dep_node(mp, r);
    }
    else {
      mp_number w;    ▷ a tentative coefficient ◁
      mp_number absw;
      new_number(w); new_number(absw); make_fraction(w, dep_value(r), v); number_clone(absw, w);
      number_abs(absw);
      if (number_lessequal(absw, half_fraction_threshold_k)) {
        set_mp_link(s, mp_link(r)); mp_free_dep_node(mp, r);
      }
      else {
        number_negate(w); set_dep_value(r, w); s ← r;
      }
      free_number(w); free_number(absw);
    }
    r ← (mp_value_node) mp_link(s);
  } while (dep_info(r) ≠ Λ);
  if (t ≡ mp_proto_dependent) {
    mp_number ret;
    new_number(ret); make_scaled(ret, dep_value(r), v); number_negate(ret); set_dep_value(r, ret);
    free_number(ret);
  }
  else if (number_to_scaled(v) ≠ −number_to_scaled(fraction_one_t)) {
    mp_number ret;
    new_fraction(ret); make_fraction(ret, dep_value(r), v); number_negate(ret); set_dep_value(r, ret);
    free_number(ret);
  }
  *final_node ← r; return (mp_value_node) mp_link(mp→temp_head);
}
```

659. **static void** *display_new_dependency*(**MP** *mp*, **mp_value_node** *p*, **mp_node** *x*, **integer** *n*)

```
{
  if (mp_interesting(mp, x)) {
    int w0;
    mp_begin_diagnostic(mp); mp_print_nl(mp, "##␣"); mp_print_variable_name(mp, x); w0 ← n;
    while (w0 > 0) {
      mp_print(mp, "*4"); w0 ← w0 − 2;
    }
    mp_print_char(mp, xord('=')); mp_print_dependency(mp, p, mp_dependent);
    mp_end_diagnostic(mp, false);
  }
}
```

660. The $n > 0$ test is repeated here because it is of vital importance to the function's functioning.

```
static mp_value_node divide_p_by_2_n(MP mp, mp_value_node p, integer n)
{
  mp_value_node pp ← Λ;
  if (n > 0) {    ▷ Divide list p by 2^n ◁
    mp_value_node r;
    mp_value_node s;
    mp_number absw;
    mp_number w;    ▷ a tentative coefficient ◁
    new_number(w); new_number(absw); s ← (mp_value_node) mp→temp_head;
    set_mp_link(mp→temp_head, (mp_node) p); r ← p;
    do {
      if (n > 30) {
        set_number_to_zero(w);
      }
      else {
        number_clone(w, dep_value(r)); number_divide_int(w, two_to_the(n));
      }
      number_clone(absw, w); number_abs(absw);
      if (number_lessequal(absw, half_fraction_threshold_k) ∧ (dep_info(r) ≠ Λ)) {
        set_mp_link(s, mp_link(r)); mp_free_dep_node(mp, r);
      }
      else {
        set_dep_value(r, w); s ← r;
      }
      r ← (mp_value_node) mp_link(s);
    } while (dep_info(s) ≠ Λ);
    pp ← (mp_value_node) mp_link(mp→temp_head); free_number(absw); free_number(w);
  }
  return pp;
}
```

661. **static void** *change_to_known*(**MP** *mp*, **mp_value_node** *p*, **mp_node** *x*, **mp_value_node** *final_node*, **integer** *n*)

```
{
  if (dep_info(p) ≡ Λ) {
    mp_number absx;
    new_number(absx); mp_type(x) ← mp_known; set_value_number(x, dep_value(p));
    number_clone(absx, value_number(x)); number_abs(absx);
    if (number_greaterequal(absx, warning_limit_t)) mp_val_too_big(mp, value_number(x));
    free_number(absx); mp_free_dep_node(mp, p);
    if (cur_exp_node() ≡ x ∧ mp→cur_exp.type ≡ mp_independent) {
      set_cur_exp_value_number(value_number(x)); mp→cur_exp.type ← mp_known;
      mp_free_value_node(mp, x);
    }
  }
  else {
    mp→dep_final ← final_node; mp_new_dep(mp, x, mp_dependent, p);
    if (cur_exp_node() ≡ x ∧ mp→cur_exp.type ≡ mp_independent) {
      mp→cur_exp.type ← mp_dependent;
    }
  }
}
```

662. Dynamic nonlinear equations. Variables of numeric type are maintained by the general scheme of independent, dependent, and known values that we have just studied; and the components of pair and transform variables are handled in the same way. But METAPOST also has five other types of values: **boolean**, **string**, **pen**, **path**, and **picture**; what about them?

Equations are allowed between nonlinear quantities, but only in a simple form. Two variables that haven't yet been assigned values are either equal to each other, or they're not.

Before a boolean variable has received a value, its type is *mp_unknown_boolean*; similarly, there are variables whose type is *mp_unknown_string*, *mp_unknown_pen*, *mp_unknown_path*, and *mp_unknown_picture*. In such cases the value is either Λ (which means that no other variables are equivalent to this one), or it points to another variable of the same undefined type. The pointers in the latter case form a cycle of nodes, which we shall call a "ring." Rings of undefined variables may include capsules, which arise as intermediate results within expressions or as **expr** parameters to macros.

When one member of a ring receives a value, the same value is given to all the other members. In the case of paths and pictures, this implies making separate copies of a potentially large data structure; users should restrain their enthusiasm for such generality, unless they have lots and lots of memory space.

663. The following procedure is called when a capsule node is being added to a ring (e.g., when an unknown variable is mentioned in an expression).

```
static mp_node mp_new_ring_entry(MP mp, mp_node p)
{
  mp_node q;    ▷ the new capsule node ◁
  q ← mp_get_value_node(mp); mp_name_type(q) ← mp_capsule; mp_type(q) ← mp_type(p);
  if (value_node(p) ≡ Λ) set_value_node(q, p);
  else set_value_node(q, value_node(p));
  set_value_node(p, q); return q;
}
```

664. Conversely, we might delete a capsule or a variable before it becomes known. The following procedure simply detaches a quantity from its ring, without recycling the storage.

⟨ Declarations 10 ⟩ +≡

```
static void mp_ring_delete(MP mp, mp_node p);
```

665.

```
void mp_ring_delete(MP mp, mp_node p)
{
  mp_node q;
  (void) mp; q ← value_node(p);
  if (q ≠ Λ ∧ q ≠ p) {
    while (value_node(q) ≠ p) q ← value_node(q);
    set_value_node(q, value_node(p));
  }
}
```

666. Eventually there might be an equation that assigns values to all of the variables in a ring. The *nonlinear_eq* subroutine does the necessary propagation of values.

If the parameter *flush_p* is *true*, node *p* itself needn't receive a value, it will soon be recycled.

```
static void mp_nonlinear_eq(MP mp, mp_value v, mp_node p, boolean flush_p)
{
  mp_variable_type t;    ▷ the type of ring p ◁
  mp_node q, r;    ▷ link manipulation registers ◁
  t ← (mp_type(p) − unknown_tag); q ← value_node(p);
  if (flush_p) mp_type(p) ← mp_vacuous;
  else p ← q;
  do {
    r ← value_node(q); mp_type(q) ← t;
    switch (t) {
    case mp_boolean_type: set_value_number(q, v.data.n); break;
    case mp_string_type: set_value_str(q, v.data.str); add_str_ref(v.data.str); break;
    case mp_pen_type: set_value_knot(q, copy_pen(v.data.p)); break;
    case mp_path_type: set_value_knot(q, mp_copy_path(mp, v.data.p)); break;
    case mp_picture_type: set_value_node(q, v.data.node); add_edge_ref(v.data.node); break;
    default: break;
    }    ▷ there ain't no more cases ◁
    q ← r;
  } while (q ≠ p);
}
```

667. If two members of rings are equated, and if they have the same type, the *ring_merge* procedure is called on to make them equivalent.

```
static void mp_ring_merge(MP mp, mp_node p, mp_node q)
{
  mp_node r;    ▷ traverses one list ◁
  r ← value_node(p);
  while (r ≠ p) {
    if (r ≡ q) {
      exclaim_redundant_equation(mp); return;
    }
    r ← value_node(r);
  }
  r ← value_node(p); set_value_node(p, value_node(q)); set_value_node(q, r);
}
```

668.
```
static void exclaim_redundant_equation(MP mp)
{
  const char *hlp[] ← {"I already knew that this equation was true.",
      "But perhaps no harm has been done; let's continue.", Λ};
  mp_back_error(mp, "Redundant equation", hlp, true); mp_get_x_next(mp);
}
```

669. ⟨ Declarations 10 ⟩ +≡
```
static void exclaim_redundant_equation(MP mp);
```

670. Introduction to the syntactic routines. Let's pause a moment now and try to look at the Big Picture. The METAPOST program consists of three main parts: syntactic routines, semantic routines, and output routines. The chief purpose of the syntactic routines is to deliver the user's input to the semantic routines, while parsing expressions and locating operators and operands. The semantic routines act as an interpreter responding to these operators, which may be regarded as commands. And the output routines are periodically called on to produce compact font descriptions that can be used for typesetting or for making interim proof drawings. We have discussed the basic data structures and many of the details of semantic operations, so we are good and ready to plunge into the part of METAPOST that actually controls the activities.

Our current goal is to come to grips with the *get_next* procedure, which is the keystone of METAPOST's input mechanism. Each call of *get_next* sets the value of three variables *cur_cmd*, *cur_mod*, and *cur_sym*, representing the next input token.

> *cur_cmd* denotes a command code from the long list of codes given earlier;
> *cur_mod* denotes a modifier or operand of the command code;
> *cur_sym* is the hash address of the symbolic token that was just scanned,
> or zero in the case of a numeric or string or capsule token.

Underlying this external behavior of *get_next* is all the machinery necessary to convert from character files to tokens. At a given time we may be only partially finished with the reading of several files (for which **input** was specified), and partially finished with the expansion of some user-defined macros and/or some macro parameters, and partially finished reading some text that the user has inserted online, and so on. When reading a character file, the characters must be converted to tokens; comments and blank spaces must be removed, numeric and string tokens must be evaluated.

To handle these situations, which might all be present simultaneously, METAPOST uses various stacks that hold information about the incomplete activities, and there is a finite state control for each level of the input mechanism. These stacks record the current state of an implicitly recursive process, but the *get_next* procedure is not recursive.

```
#define cur_cmd() (unsigned)(mp→cur_mod_→type)
#define set_cur_cmd(A) mp→cur_mod_→type ← (A)
#define cur_mod_int() number_to_int(mp→cur_mod_→data.n)   ▷ operand of current command ◁
#define cur_mod() number_to_scaled(mp→cur_mod_→data.n)   ▷ operand of current command ◁
#define cur_mod_number() mp→cur_mod_→data.n   ▷ operand of current command ◁
#define set_cur_mod(A) set_number_from_scaled(mp→cur_mod_→data.n, (A))
#define set_cur_mod_number(A) number_clone(mp→cur_mod_→data.n, (A))
#define cur_mod_node() mp→cur_mod_→data.node
#define set_cur_mod_node(A) mp→cur_mod_→data.node ← (A)
#define cur_mod_str() mp→cur_mod_→data.str
#define set_cur_mod_str(A) mp→cur_mod_→data.str ← (A)
#define cur_sym() mp→cur_mod_→data.sym
#define set_cur_sym(A) mp→cur_mod_→data.sym ← (A)
#define cur_sym_mod() mp→cur_mod_→name_type
#define set_cur_sym_mod(A) mp→cur_mod_→name_type ← (A)
```

⟨Global variables 18⟩ +≡

```
mp_node cur_mod_;   ▷ current command, symbol, and its operands ◁
```

671. ⟨Initialize table entries 186⟩ +≡

```
mp→cur_mod_ ← mp_get_symbolic_node(mp);
```

672. ⟨Free table entries 187⟩ +≡

```
mp_free_symbolic_node(mp, mp→cur_mod_);
```

673. The *print_cmd_mod* routine prints a symbolic interpretation of a command code and its modifier. It consists of a rather tedious sequence of print commands, and most of it is essentially an inverse to the *primitive* routine that enters a METAPOST primitive into *hash* and *eqtb*. Therefore almost all of this procedure appears elsewhere in the program, together with the corresponding *primitive* calls.

⟨ Declarations 10 ⟩ +≡

```
static void mp_print_cmd_mod(MP mp, integer c, integer m);
```

674.

```
void mp_print_cmd_mod(MP mp, integer c, integer m)
{
  switch (c) {
  ⟨ Cases of print_cmd_mod for symbolic printing of primitives 239 ⟩
  default: mp_print(mp, "[unknown␣command␣code!]"); break;
  }
}
```

675. Here is a procedure that displays a given command in braces, in the user's transcript file.

```
#define show_cur_cmd_mod mp_show_cmd_mod(mp, cur_cmd(), cur_mod())
static void mp_show_cmd_mod(MP mp, integer c, integer m)
{
  mp_begin_diagnostic(mp); mp_print_nl(mp, "{"); mp_print_cmd_mod(mp, c, m);
  mp_print_char(mp, xord('}')); mp_end_diagnostic(mp, false);
}
```

676. Input stacks and states. The state of METAPOST's input mechanism appears in the input stack, whose entries are records with five fields, called *index*, *start*, *loc*, *limit*, and *name*. The top element of this stack is maintained in a global variable for which no subscripting needs to be done; the other elements of the stack appear in an array. Hence the stack is declared thus:

⟨ Types in the outer block 37 ⟩ +≡
```
typedef struct {
  char *long_name_field;
  halfword start_field, loc_field, limit_field;
  mp_node nstart_field, nloc_field;
  mp_string name_field;
  quarterword index_field;
} in_state_record;
```

677. ⟨ Global variables 18 ⟩ +≡
```
in_state_record *input_stack;
integer input_ptr;   ▷ first unused location of input_stack ◁
integer max_in_stack;   ▷ largest value of input_ptr when pushing ◁
in_state_record cur_input;   ▷ the "top" input state ◁
int stack_size;   ▷ maximum number of simultaneous input sources ◁
```

678. ⟨ Allocate or initialize variables 32 ⟩ +≡
```
mp→stack_size ← 16; mp→input_stack ← xmalloc((mp→stack_size + 1), sizeof(in_state_record));
```

679. ⟨ Dealloc variables 31 ⟩ +≡
```
xfree(mp→input_stack);
```

680. We've already defined the special variable $loc \equiv cur\_input.loc\_field$ in our discussion of basic input-output routines. The other components of *cur_input* are defined in the same way:

```
#define iindex mp→cur_input.index_field   ▷ reference for buffer information ◁
#define start mp→cur_input.start_field   ▷ starting position in buffer ◁
#define limit mp→cur_input.limit_field   ▷ end of current line in buffer ◁
#define name mp→cur_input.name_field   ▷ name of the current file ◁
```

681. Let's look more closely now at the five control variables (*index*, *start*, *loc*, *limit*, *name*), assuming that METAPOST is reading a line of characters that have been input from some file or from the user's terminal. There is an array called *buffer* that acts as a stack of all lines of characters that are currently being read from files, including all lines on subsidiary levels of the input stack that are not yet completed. METAPOST will return to the other lines when it is finished with the present input file.

(Incidentally, on a machine with byte-oriented addressing, it would be appropriate to combine *buffer* with the *str_pool* array, letting the buffer entries grow downward from the top of the string pool and checking that these two tables don't bump into each other.)

The line we are currently working on begins in position *start* of the buffer; the next character we are about to read is *buffer*[*loc*]; and *limit* is the location of the last character present. We always have $loc \le limit$. For convenience, *buffer*[*limit*] has been set to `"%"`, so that the end of a line is easily sensed.

The *name* variable is a string number that designates the name of the current file, if we are reading an ordinary text file. Special codes *is_term* .. *max_spec_src* indicate other sources of input text.

```
#define is_term (mp_string) 0   ▷ name value when reading from the terminal for normal input ◁
#define is_read (mp_string) 1   ▷ name value when executing a readstring or readfrom ◁
#define is_scantok (mp_string) 2   ▷ name value when reading text generated by scantokens ◁
#define max_spec_src is_scantok
```

682. Additional information about the current line is available via the *index* variable, which counts how many lines of characters are present in the buffer below the current level. We have $index \leftarrow 0$ when reading from the terminal and prompting the user for each line; then if the user types, e.g., '`input figs`', we will have $index \leftarrow 1$ while reading the file `figs.mp`. However, it does not follow that *index* is the same as the input stack pointer, since many of the levels on the input stack may come from token lists and some *index* values may correspond to `MPX` files that are not currently on the stack.

The global variable *in_open* is equal to the highest *index* value counting `MPX` files but excluding token-list input levels. Thus, the number of partially read lines in the buffer is $in\_open + 1$ and we have $in\_open \geq index$ when we are not reading a token list.

If we are not currently reading from the terminal, we are reading from the file variable *input_file*[*index*]. We use the notation *terminal_input* as a convenient abbreviation for $name \leftarrow is\_term$, and *cur_file* as an abbreviation for *input_file*[*index*].

When METAPOST is not reading from the terminal, the global variable *line* contains the line number in the current file, for use in error messages. More precisely, *line* is a macro for *line_stack*[*index*] and the *line_stack* array gives the line number for each file in the *input_file* array.

When an `MPX` file is opened the file name is stored in the *mpx_name* array so that the name doesn't get lost when the file is temporarily removed from the input stack. Thus when *input_file*[k] is an `MPX` file, its name is *mpx_name*[k] and it contains translated TEX pictures for *input_file*[$k-1$]. Since this is not an `MPX` file, we have

$$mpx\_name[k-1] \leq absent.$$

This *name* field is set to *finished* when *input_file*[k] is completely read.

If more information about the input state is needed, it can be included in small arrays like those shown here. For example, the current page or segment number in the input file might be put into a variable *page*, that is really a macro for the current entry in '*page_stack*: *array*[0..*max_in_open*] *of* **integer**' by analogy with *line_stack*.

```
#define terminal_input (name ≡ is_term)   ▷ are we reading from the terminal? ◁
#define cur_file mp→input_file[iindex]   ▷ the current void * variable ◁
#define line mp→line_stack[iindex]   ▷ current line number in the current source file ◁
#define in_ext mp→inext_stack[iindex]   ▷ a string used to construct MPX file names ◁
#define in_name mp→iname_stack[iindex]   ▷ a string used to construct MPX file names ◁
#define in_area mp→iarea_stack[iindex]   ▷ another string for naming MPX files ◁
#define absent (mp_string) 1   ▷ name_field value for unused mpx_in_stack entries ◁
#define mpx_reading (mp→mpx_name[iindex] > absent)   ▷ when reading a file, is it an MPX file? ◁
#define mpx_finished 0   ▷ name_field value when the corresponding MPX file is finished ◁

⟨ Global variables 18 ⟩ +≡
  integer in_open;   ▷ the number of lines in the buffer, less one ◁
  integer in_open_max;   ▷ highest value of in_open ever seen ◁
  unsigned int open_parens;   ▷ the number of open text files ◁
  void **input_file;
  integer *line_stack;   ▷ the line number for each file ◁
  char **inext_stack;   ▷ used for naming MPX files ◁
  char **iname_stack;   ▷ used for naming MPX files ◁
  char **iarea_stack;   ▷ used for naming MPX files ◁
  mp_string *mpx_name;
```

683. ⟨ Declarations 10 ⟩ +≡

```
  static void mp_reallocate_input_stack(MP mp, int newsize);
```

684. **static void** *mp_reallocate_input_stack*(**MP** *mp*, **int** *newsize*)

```
{
  int k;
  int n ← newsize + 1;
  XREALLOC(mp→input_file, n, void *); XREALLOC(mp→line_stack, n, integer);
  XREALLOC(mp→inext_stack, n, char *); XREALLOC(mp→iname_stack, n, char *);
  XREALLOC(mp→iarea_stack, n, char *); XREALLOC(mp→mpx_name, n, mp_string);
  for (k ← mp→max_in_open; k ≤ n; k++) {
    mp→input_file[k] ← Λ; mp→line_stack[k] ← 0; mp→inext_stack[k] ← Λ; mp→iname_stack[k] ← Λ;
    mp→iarea_stack[k] ← Λ; mp→mpx_name[k] ← Λ;
  }
  mp→max_in_open ← newsize;
}
```

685. This has to be more than *file_bottom*, so:

⟨ Allocate or initialize variables 32 ⟩ +≡
mp_reallocate_input_stack(*mp*, *file_bottom* + 4);

686. ⟨ Dealloc variables 31 ⟩ +≡

```
{
  int l;
  for (l ← 0; l ≤ mp→max_in_open; l++) {
    xfree(mp→inext_stack[l]); xfree(mp→iname_stack[l]); xfree(mp→iarea_stack[l]);
  }
}
xfree(mp→input_file); xfree(mp→line_stack); xfree(mp→inext_stack); xfree(mp→iname_stack);
xfree(mp→iarea_stack); xfree(mp→mpx_name);
```

687. However, all this discussion about input state really applies only to the case that we are inputting from a file. There is another important case, namely when we are currently getting input from a token list. In this case $iindex > max\_in\_open$, and the conventions about the other state variables are different:

nloc is a pointer to the current node in the token list, i.e., the node that will be read next. If $nloc \leftarrow \Lambda$, the token list has been fully read.

start points to the first node of the token list; this node may or may not contain a reference count, depending on the type of token list involved.

token_type, which takes the place of *iindex* in the discussion above, is a code number that explains what kind of token list is being scanned.

name points to the *eqtb* address of the control sequence being expanded, if the current token list is a macro not defined by **vardef**. Macros defined by **vardef** have $name \leftarrow \Lambda$; their name can be deduced by looking at their first two parameters.

param_start, which takes the place of *limit*, tells where the parameters of the current macro or loop text begin in the *param_stack*.

The *token_type* can take several values, depending on where the current token list came from:

forever_text, if the token list being scanned is the body of a **forever** loop;
loop_text, if the token list being scanned is the body of a **for** or **forsuffixes** loop;
parameter, if a **text** or **suffix** parameter is being scanned;
backed_up, if the token list being scanned has been inserted as 'to be read again'.
inserted, if the token list being scanned has been inserted as part of error recovery;
macro, if the expansion of a user-defined symbolic token is being scanned.

The token list begins with a reference count if and only if $token\_type \leftarrow macro$.

#**define** *nloc* *mp→cur_input.nloc_field* ▷ location of next node node ◁
#**define** *nstart* *mp→cur_input.nstart_field* ▷ location of next node node ◁
#**define** *token_type* *iindex* ▷ type of current token list ◁
#**define** *token_state* $(iindex \le macro)$ ▷ are we scanning a token list? ◁
#**define** *file_state* $(iindex > macro)$ ▷ are we scanning a file line? ◁
#**define** *param_start* *limit* ▷ base of macro parameters in *param_stack* ◁
#**define** *forever_text* 0 ▷ *token_type* code for loop texts ◁
#**define** *loop_text* 1 ▷ *token_type* code for loop texts ◁
#**define** *parameter* 2 ▷ *token_type* code for parameter texts ◁
#**define** *backed_up* 3 ▷ *token_type* code for texts to be reread ◁
#**define** *inserted* 4 ▷ *token_type* code for inserted texts ◁
#**define** *macro* 5 ▷ *token_type* code for macro replacement texts ◁
#**define** *file_bottom* 6 ▷ lowest file code ◁

688. The *param_stack* is an auxiliary array used to hold pointers to the token lists for parameters at the current level and subsidiary levels of input. This stack grows at a different rate from the others, and is dynamically reallocated when needed.

⟨ Global variables 18 ⟩ +≡
mp_node **param_stack*; ▷ token list pointers for parameters ◁
integer *param_ptr*; ▷ first unused entry in *param_stack* ◁
integer *max_param_stack*; ▷ largest value of *param_ptr* ◁

689. ⟨ Allocate or initialize variables 32 ⟩ +≡
mp→param_stack ← *xmalloc*((*mp→param_size* + 1), **sizeof**(**mp_node**));

690. **static void** *mp_check_param_size*(**MP** *mp*, **int** *k*)

```
{
  while (k ≥ mp→param_size) {
    XREALLOC(mp→param_stack, (k + k/4), mp_node);  mp→param_size ← k + k/4;
  }
}
```

691. ⟨ Dealloc variables 31 ⟩ +≡

```
xfree(mp→param_stack);
```

692. Notice that the *line* isn't valid when *token_state* is true because it depends on *iindex*. If we really need to know the line number for the topmost file in the iindex stack we use the following function. If a page number or other information is needed, this routine should be modified to compute it as well.

⟨ Declarations 10 ⟩ +≡

```
static integer mp_true_line(MP mp);
```

693. **integer** *mp_true_line*(**MP** *mp*)

```
{
  int k;    ▷ an index into the input stack ◁
  if (file_state ∧ (name > max_spec_src)) {
    return line;
  }
  else {
    k ← mp→input_ptr;
    while ((k > 0) ∧ ((mp→input_stack[(k − 1)].index_field < file_bottom) ∨
          (mp→input_stack[(k − 1)].name_field ≤ max_spec_src))) {
      decr(k);
    }
    return (k > 0 ? mp→line_stack[(k − 1) + file_bottom] : 0);
  }
}
```

694. Thus, the "current input state" can be very complicated indeed; there can be many levels and each level can arise in a variety of ways. The *show_context* procedure, which is used by METAPOST's error-reporting routine to print out the current input state on all levels down to the most recent line of characters from an input file, illustrates most of these conventions. The global variable *file_ptr* contains the lowest level that was displayed by this procedure.

⟨ Global variables 18 ⟩ +≡

```
integer file_ptr;    ▷ shallowest level shown by show_context ◁
```

695. The status at each level is indicated by printing two lines, where the first line indicates what was read so far and the second line shows what remains to be read. The context is cropped, if necessary, so that the first line contains at most *half_error_line* characters, and the second contains at most *error_line*. Non-current input levels whose *token_type* is '*backed_up*' are shown only if they have not been fully read.

```
void mp_show_context(MP mp)
{   ▷ prints where the scanner is ◁
  unsigned old_setting;   ▷ saved selector setting ◁
  ⟨Local variables for formatting calculations 701⟩;
  mp→file_ptr ← mp→input_ptr; mp→input_stack[mp→file_ptr] ← mp→cur_input;   ▷ store current state ◁
  while (1) {
    mp→cur_input ← mp→input_stack[mp→file_ptr];   ▷ enter into the context ◁
    ⟨Display the current context 696⟩;
    if (file_state)
      if ((name > max_spec_src) ∨ (mp→file_ptr ≡ 0)) break;
    decr(mp→file_ptr);
  }
  mp→cur_input ← mp→input_stack[mp→input_ptr];   ▷ restore original state ◁
}
```

696. ⟨Display the current context 696⟩ ≡

```
if ((mp→file_ptr ≡ mp→input_ptr) ∨ file_state ∨ (token_type ≠ backed_up) ∨ (nloc ≠ Λ)) {
      ▷ we omit backed-up token lists that have already been read ◁
  mp→tally ← 0;   ▷ get ready to count characters ◁
  old_setting ← mp→selector;
  if (file_state) {
    ⟨Print location of current line 697⟩;
    ⟨Pseudoprint the line 704⟩;
  }
  else {
    ⟨Print type of token list 698⟩;
    ⟨Pseudoprint the token list 705⟩;
  }
  mp→selector ← old_setting;   ▷ stop pseudoprinting ◁
  ⟨Print two lines using the tricky pseudoprinted information 703⟩;
}
```

This code is used in section 695.

697. This routine should be changed, if necessary, to give the best possible indication of where the current line resides in the input file. For example, on some systems it is best to print both a page and line number.

⟨ Print location of current line 697 ⟩ ≡

```
if (name > max_spec_src) {
  mp_print_nl(mp, "l."); mp_print_int(mp, mp_true_line(mp));
}
else if (terminal_input) {
  if (mp→file_ptr ≡ 0) mp_print_nl(mp, "<*>");
  else mp_print_nl(mp, "<insert>");
}
else if (name ≡ is_scantok) {
  mp_print_nl(mp, "<scantokens>");
}
else {
  mp_print_nl(mp, "<read>");
}
mp_print_char(mp, xord('␣'))
```

This code is used in section 696.

698. Can't use case statement here because the *token_type* is not a constant expression.

⟨ Print type of token list 698 ⟩ ≡

```
{
  if (token_type ≡ forever_text) {
    mp_print_nl(mp, "<forever>␣");
  }
  else if (token_type ≡ loop_text) {
    ⟨ Print the current loop value 699 ⟩;
  }
  else if (token_type ≡ parameter) {
    mp_print_nl(mp, "<argument>␣");
  }
  else if (token_type ≡ backed_up) {
    if (nloc ≡ Λ) mp_print_nl(mp, "<recently␣read>␣");
    else mp_print_nl(mp, "<to␣be␣read␣again>␣");
  }
  else if (token_type ≡ inserted) {
    mp_print_nl(mp, "<inserted␣text>␣");
  }
  else if (token_type ≡ macro) {
    mp_print_ln(mp);
    if (name ≠ Λ) mp_print_str(mp, name);
    else ⟨ Print the name of a vardef'd macro 700 ⟩;
    mp_print(mp, "->");
  }
  else {
    mp_print_nl(mp, "?");    ▷ this should never happen ◁
  }
}
```

This code is used in section 696.

699. The parameter that corresponds to a loop text is either a token list (in the case of **forsuffixes**) or a "capsule" (in the case of **for**). We'll discuss capsules later; for now, all we need to know is that the *link* field in a capsule parameter is **void** and that *print_exp*$(p, 0)$ displays the value of capsule p in abbreviated form.

⟨ Print the current loop value 699 ⟩ ≡

```
{
  mp_node pp;
  mp_print_nl(mp, "<for("); pp ← mp→param_stack[param_start];
  if (pp ≠ Λ) {
    if (mp_link(pp) ≡ MP_VOID) mp_print_exp(mp, pp, 0);    ▷ we're in a for loop ◁
    else mp_show_token_list(mp, pp, Λ, 20, mp→tally);
  }
  mp_print(mp, ")>␣");
}
```

This code is used in section 698.

700. The first two parameters of a macro defined by **vardef** will be token lists representing the macro's prefix and "at point." By putting these together, we get the macro's full name.

⟨ Print the name of a **vardef**'d macro 700 ⟩ ≡

```
{
  mp_node pp ← mp→param_stack[param_start];
  if (pp ≡ Λ) {
    mp_show_token_list(mp, mp→param_stack[param_start + 1], Λ, 20, mp→tally);
  }
  else {
    mp_node qq ← pp;
    while (mp_link(qq) ≠ Λ) qq ← mp_link(qq);
    mp_link(qq) ← mp→param_stack[param_start + 1]; mp_show_token_list(mp, pp, Λ, 20, mp→tally);
    mp_link(qq) ← Λ;
  }
}
```

This code is used in section 698.

701. Now it is necessary to explain a little trick. We don't want to store a long string that corresponds to a token list, because that string might take up lots of memory; and we are printing during a time when an error message is being given, so we dare not do anything that might overflow one of METAPOST's tables. So 'pseudoprinting' is the answer: We enter a mode of printing that stores characters into a buffer of length *error_line*, where character $k+1$ is placed into *trick_buf* [k mod *error_line*] if $k <$ *trick_count*, otherwise character k is dropped. Initially we set *tally*: $\leftarrow 0$ and *trick_count*: $\leftarrow 1000000$; then when we reach the point where transition from line 1 to line 2 should occur, we set *first_count*: $\leftarrow$ *tally* and *trick_count*: $\leftarrow$ max(*error_line*, *tally* $+ 1 +$ *error_line* $-$ *half_error_line*). At the end of the pseudoprinting, the values of *first_count*, *tally*, and *trick_count* give us all the information we need to print the two lines, and all of the necessary text is in *trick_buf*.

Namely, let l be the length of the descriptive information that appears on the first line. The length of the context information gathered for that line is $k \leftarrow$ *first_count*, and the length of the context information gathered for line 2 is $m = \min(tally, trick\_count) - k$. If $l + k \le h$, where $h \leftarrow$ *half_error_line*, we print *trick_buf* $[0..k-1]$ after the descriptive information on line 1, and set n: $\leftarrow l + k$; here n is the length of line 1. If $l + k > h$, some cropping is necessary, so we set n: $\leftarrow h$ and print '...' followed by

$$trick\_buf[(l+k-h+3) \mathinner{..} k-1],$$

where subscripts of *trick_buf* are circular modulo *error_line*. The second line consists of n spaces followed by *trick_buf* $[k \mathinner{..} (k+m-1)]$, unless $n + m >$ *error_line*; in the latter case, further cropping is done. This is easier to program than to explain.

⟨ Local variables for formatting calculations 701 ⟩ ≡
  int i; ▷ index into *buffer* ◁
  integer l; ▷ length of descriptive information on line 1 ◁
  integer m; ▷ context information gathered for line 2 ◁
  int n; ▷ length of line 1 ◁
  integer p; ▷ starting or ending place in *trick_buf* ◁
  integer q; ▷ temporary index ◁

This code is used in section 695.

702. The following code tells the print routines to gather the desired information.

```
#define begin_pseudoprint
        {
          l ← mp→tally; mp→tally ← 0; mp→selector ← pseudo; mp→trick_count ← 1000000;
        }
#define set_trick_count()
        {
          mp→first_count ← mp→tally;
          mp→trick_count ← mp→tally + 1 + mp→error_line − mp→half_error_line;
          if (mp→trick_count < mp→error_line) mp→trick_count ← mp→error_line;
        }
```

703. And the following code uses the information after it has been gathered.

⟨ Print two lines using the tricky pseudoprinted information 703 ⟩ ≡
```
if (mp→trick_count ≡ 1000000) set_trick_count( );   ▷ set_trick_count must be performed ◁
if (mp→tally < mp→trick_count) m ← mp→tally − mp→first_count;
else m ← mp→trick_count − mp→first_count;   ▷ context on line 2 ◁
if (l + mp→first_count ≤ mp→half_error_line) {
  p ← 0; n ← l + mp→first_count;
}
else {
  mp_print(mp, "..."); p ← l + mp→first_count − mp→half_error_line + 3; n ← mp→half_error_line;
}
for (q ← p; q ≤ mp→first_count − 1; q++) {
  mp_print_char(mp, mp→trick_buf[q % mp→error_line]);
}
mp_print_ln(mp);
for (q ← 1; q ≤ n; q++) {
  mp_print_char(mp, xord('␣'));   ▷ print n spaces to begin line 2 ◁
}
if (m + n ≤ mp→error_line) p ← mp→first_count + m;
else p ← mp→first_count + (mp→error_line − n − 3);
for (q ← mp→first_count; q ≤ p − 1; q++) {
  mp_print_char(mp, mp→trick_buf[q % mp→error_line]);
}
if (m + n > mp→error_line) mp_print(mp, "...")
```
This code is used in section 696.

704. But the trick is distracting us from our current goal, which is to understand the input state. So let's concentrate on the data structures that are being pseudoprinted as we finish up the *show_context* procedure.

⟨ Pseudoprint the line 704 ⟩ ≡
```
begin_pseudoprint;
if (limit > 0) {
  for (i ← start; i ≤ limit − 1; i++) {
    if (i ≡ loc) set_trick_count( );
    mp_print_char(mp, mp→buffer[i]);
  }
}
```
This code is used in section 696.

705. ⟨ Pseudoprint the token list 705 ⟩ ≡
```
begin_pseudoprint;
if (token_type ≠ macro) mp_show_token_list(mp, nstart, nloc, 100000, 0);
else mp_show_macro(mp, nstart, nloc, 100000)
```
This code is used in section 696.

706. Maintaining the input stacks. The following subroutines change the input status in commonly needed ways.

First comes *push_input*, which stores the current state and creates a new level (having, initially, the same properties as the old).

```
#define push_input
        {   ▷ enter a new input level, save the old ◁
          if (mp→input_ptr > mp→max_in_stack) {
            mp→max_in_stack ← mp→input_ptr;
            if (mp→input_ptr ≡ mp→stack_size) {
              int l ← (mp→stack_size + (mp→stack_size/4));   ▷ The mp→stack_size < 1001 condition is
                  necessary to prevent C stack overflow due infinite recursion. ◁
              if (l > 1000) {
                fprintf(stderr, "input␣stack␣overflow\n"); exit(EXIT_FAILURE);
              }
              XREALLOC(mp→input_stack, l, in_state_record); mp→stack_size ← l;
            }
          }
          mp→input_stack[mp→input_ptr] ← mp→cur_input;   ▷ stack the record ◁
          incr(mp→input_ptr);
        }
```

707. And of course what goes up must come down.

```
#define pop_input
        {   ▷ leave an input level, re-enter the old ◁
          decr(mp→input_ptr); mp→cur_input ← mp→input_stack[mp→input_ptr];
        }
```

708. Here is a procedure that starts a new level of token-list input, given a token list p and its type t. If $t \leftarrow macro$, the calling routine should set *name*, reset *loc*, and increase the macro's reference count.

```
#define back_list(A) mp_begin_token_list(mp, (A), (quarterword) backed_up)
          ▷ backs up a simple token list ◁

  static void mp_begin_token_list(MP mp, mp_node p, quarterword t)
  {
    push_input; nstart ← p; token_type ← t; param_start ← mp→param_ptr; nloc ← p;
  }
```

709. When a token list has been fully scanned, the following computations should be done as we leave that level of input.

```
static void mp_end_token_list(MP mp)
{    ▷ leave a token-list input level ◁
  mp_node p;    ▷ temporary register ◁
  if (token_type ≥ backed_up) {    ▷ token list to be deleted ◁
    if (token_type ≤ inserted) {
      mp_flush_token_list(mp, nstart); goto DONE;
    }
    else {
      mp_delete_mac_ref(mp, nstart);    ▷ update reference count ◁
    }
  }
  while (mp→param_ptr > param_start) {    ▷ parameters must be flushed ◁
    decr(mp→param_ptr); p ← mp→param_stack[mp→param_ptr];
    if (p ≠ Λ) {
      if (mp_link(p) ≡ MP_VOID) {    ▷ it's an expr parameter ◁
        mp_recycle_value(mp, p); mp_free_value_node(mp, p);
      }
      else {
        mp_flush_token_list(mp, p);    ▷ it's a suffix or text parameter ◁
      }
    }
  }
DONE: pop_input; check_interrupt;
}
```

710. The contents of *cur_cmd*, *cur_mod*, *cur_sym* are placed into an equivalent token by the *cur_tok* routine.

⟨ Declare the procedure called *make_exp_copy* 942 ⟩;

```
static mp_node mp_cur_tok(MP mp)
{
  mp_node p;    ▷ a new token node ◁
  if (cur_sym() ≡ Λ ∧ (cur_sym_mod() ≡ 0 ∨ cur_sym_mod() ≡ mp_normal_sym)) {
    if (cur_cmd() ≡ mp_capsule_token) {
      mp_number save_exp_num;    ▷ possible cur_exp numerical to be restored ◁
      mp_value save_exp ← mp→cur_exp;    ▷ cur_exp to be restored ◁
      new_number(save_exp_num); number_clone(save_exp_num, cur_exp_value_number());
      mp_make_exp_copy(mp, cur_mod_node()); p ← mp_stash_cur_exp(mp); mp_link(p) ← Λ;
      mp→cur_exp ← save_exp; number_clone(mp→cur_exp.data.n, save_exp_num);
      free_number(save_exp_num);
    }
    else {
      p ← mp_get_token_node(mp); mp_name_type(p) ← mp_token;
      if (cur_cmd() ≡ mp_numeric_token) {
        set_value_number(p, cur_mod_number()); mp_type(p) ← mp_known;
      }
      else {
        set_value_str(p, cur_mod_str()); mp_type(p) ← mp_string_type;
      }
    }
  }
  else {
    p ← mp_get_symbolic_node(mp); set_mp_sym_sym(p, cur_sym());
    mp_name_type(p) ← cur_sym_mod();
  }
  return p;
}
```

711. Sometimes METAPOST has read too far and wants to "unscan" what it has seen. The *back_input* procedure takes care of this by putting the token just scanned back into the input stream, ready to be read again. If *cur_sym* <> 0, the values of *cur_cmd* and *cur_mod* are irrelevant.

⟨ Declarations 10 ⟩ +≡

```
static void mp_back_input(MP mp);
```

712.

```
void mp_back_input(MP mp)
{    ▷ undoes one token of input ◁
  mp_node p;    ▷ a token list of length one ◁
  p ← mp_cur_tok(mp);
  while (token_state ∧ (nloc ≡ Λ)) mp_end_token_list(mp);    ▷ conserve stack space ◁
  back_list(p);
}
```

713. The *back_error* routine is used when we want to restore or replace an offending token just before issuing an error message. We disable interrupts during the call of *back_input* so that the help message won't be lost.

⟨ Declarations 10 ⟩ +≡

```
static void mp_back_error(MP mp, const char *msg, const char **hlp, boolean deletions_allowed);
```

714. **static void** *mp_back_error*(**MP** *mp*, **const char** **msg*, **const char** ***hlp*, **boolean** *deletions_allowed*)

```
{  ▷ back up one token and call error ◁
  mp→OK_to_interrupt ← false; mp_back_input(mp); mp→OK_to_interrupt ← true;
  mp_error(mp, msg, hlp, deletions_allowed);
}
static void mp_ins_error(MP mp, const char *msg, const char **hlp, boolean deletions_allowed)
{  ▷ back up one inserted token and call error ◁
  mp→OK_to_interrupt ← false; mp_back_input(mp); token_type ← (quarterword) inserted;
  mp→OK_to_interrupt ← true; mp_error(mp, msg, hlp, deletions_allowed);
}
```

715. The *begin_file_reading* procedure starts a new level of input for lines of characters to be read from a file, or as an insertion from the terminal. It does not take care of opening the file, nor does it set *loc* or *limit* or *line*.

```
void mp_begin_file_reading(MP mp)
{
  if (mp→in_open ≡ (mp→max_in_open − 1))
    mp_reallocate_input_stack(mp, (mp→max_in_open + mp→max_in_open/4));
  if (mp→first ≡ mp→buf_size) mp_reallocate_buffer(mp, (mp→buf_size + mp→buf_size/4));
  mp→in_open++; push_input; iindex ← (quarterword) mp→in_open;
  if (mp→in_open_max < mp→in_open) mp→in_open_max ← mp→in_open;
  mp→mpx_name[iindex] ← absent; start ← (halfword) mp→first; name ← is_term;
    ▷ terminal_input is now true ◁
}
```

716. Conversely, the variables must be downdated when such a level of input is finished. Any associated MPX file must also be closed and popped off the file stack. While finishing preloading, it is possible that the file does not actually end with 'dump', so we capture that case here as well.

```
static void mp_end_file_reading(MP mp)
{
  if (mp→reading_preload ∧ mp→input_ptr ≡ 0) {
    set_cur_sym(mp→frozen_dump); mp_back_input(mp); return;
  }
  if (mp→in_open > iindex) {
    if ((mp→mpx_name[mp→in_open] ≡ absent) ∨ (name ≤ max_spec_src)) {
      mp_confusion(mp, "endinput");
    }
    else {
      (mp→close_file)(mp, mp→input_file[mp→in_open]);  ▷ close an MPX file ◁
      delete_str_ref(mp→mpx_name[mp→in_open]); decr(mp→in_open);
    }
  }
  mp→first ← (size_t) start;
  if (iindex ≠ mp→in_open) mp_confusion(mp, "endinput");
  if (name > max_spec_src) {
    (mp→close_file)(mp, cur_file); xfree(in_ext); xfree(in_name); xfree(in_area);
  }
  pop_input; decr(mp→in_open);
}
```

717. Here is a function that tries to resume input from an MPX file already associated with the current input file. It returns *false* if this doesn't work.

```
static boolean mp_begin_mpx_reading(MP mp)
{
  if (mp→in_open ≠ iindex + 1) {
    return false;
  }
  else {
    if (mp→mpx_name[mp→in_open] ≤ absent) mp_confusion(mp, "mpx");
    if (mp→first ≡ mp→buf_size) mp_reallocate_buffer(mp, (mp→buf_size + (mp→buf_size/4)));
    push_input; iindex ← (quarterword) mp→in_open; start ← (halfword) mp→first;
    name ← mp→mpx_name[mp→in_open]; add_str_ref(name);     ▷ Put an empty line in the input buffer
        ◁    ▷ We want to make it look as though we have just read a blank line without really doing so. ◁
    mp→last ← mp→first; limit ← (halfword) mp→last;     ▷ simulate input_ln and firm_up_the_line ◁
    mp→buffer[limit] ← xord('%'); mp→first ← (size_t)(limit + 1); loc ← start; return true;
  }
}
```

718. This procedure temporarily stops reading an MPX file.

```
static void mp_end_mpx_reading(MP mp)
{
  if (mp→in_open ≠ iindex) mp_confusion(mp, "mpx");
  if (loc < limit) {     ▷ Complain that we are not at the end of a line in the MPX file ◁     ▷ Here we
        enforce a restriction that simplifies the input stacks considerably. This should not inconvenience the
        user because MPX files are generated by an auxiliary program called DVItoMP. ◁
    const char *hlp[] ← {"This␣file␣contains␣picture␣expressions␣for␣btex...etex",
        "blocks.␣␣Such␣files␣are␣normally␣generated␣automatically",
        "but␣this␣one␣seems␣to␣be␣messed␣up.␣␣I'm␣going␣to␣ignore",
        "the␣rest␣of␣this␣line.", Λ};
    mp_error(mp, "'mpxbreak'␣must␣be␣at␣the␣end␣of␣a␣line", hlp, true);
  }
  mp→first ← (size_t) start; pop_input;
}
```

719. In order to keep the stack from overflowing during a long sequence of inserted 'show' commands, the following routine removes completed error-inserted lines from memory.

```
void mp_clear_for_error_prompt(MP mp)
{
  while (file_state ∧ terminal_input ∧ (mp→input_ptr > 0) ∧ (loc ≡ limit)) mp_end_file_reading(mp);
  mp_print_ln(mp); clear_terminal();
}
```

720. To get METAPOST's whole input mechanism going, we perform the following actions.

⟨ Initialize the input routines 720 ⟩ ≡

{

$mp\rightarrow input\_ptr \leftarrow 0$; $mp\rightarrow max\_in\_stack \leftarrow file\_bottom$; $mp\rightarrow in\_open \leftarrow file\_bottom$;
$mp\rightarrow open\_parens \leftarrow 0$; $mp\rightarrow max\_buf\_stack \leftarrow 0$; $mp\rightarrow param\_ptr \leftarrow 0$; $mp\rightarrow max\_param\_stack \leftarrow 0$;
$mp\rightarrow first \leftarrow 0$; $start \leftarrow 0$; $iindex \leftarrow file\_bottom$; $line \leftarrow 0$; $name \leftarrow is\_term$;
$mp\rightarrow mpx\_name[file\_bottom] \leftarrow absent$; $mp\rightarrow force\_eof \leftarrow false$;
if $(\neg mp\_init\_terminal(mp))$ $mp\_jump\_out(mp)$;
$limit \leftarrow$ (**halfword**) $mp\rightarrow last$; $mp\rightarrow first \leftarrow mp\rightarrow last + 1$; ▷ *init_terminal* has set *loc* and *last* ◁

}

See also section 723.

This code is used in section 1292.

721. Getting the next token. The heart of METAPOST's input mechanism is the *get_next* procedure, which we shall develop in the next few sections of the program. Perhaps we shouldn't actually call it the "heart," however; it really acts as METAPOST's eyes and mouth, reading the source files and gobbling them up. And it also helps METAPOST to regurgitate stored token lists that are to be processed again.

The main duty of *get_next* is to input one token and to set *cur_cmd* and *cur_mod* to that token's command code and modifier. Furthermore, if the input token is a symbolic token, that token's *hash* address is stored in *cur_sym*; otherwise *cur_sym* is set to zero.

Underlying this simple description is a certain amount of complexity because of all the cases that need to be handled. However, the inner loop of *get_next* is reasonably short and fast.

722. Before getting into *get_next*, we need to consider a mechanism by which METAPOST helps keep errors from propagating too far. Whenever the program goes into a mode where it keeps calling *get_next* repeatedly until a certain condition is met, it sets *scanner_status* to some value other than *normal*. Then if an input file ends, or if an '**outer**' symbol appears, an appropriate error recovery will be possible.

The global variable *warning_info* helps in this error recovery by providing additional information. For example, *warning_info* might indicate the name of a macro whose replacement text is being scanned.

\#**define** *normal* 0 ▷ *scanner_status* at "quiet times" ◁
\#**define** *skipping* 1 ▷ *scanner_status* when false conditional text is being skipped ◁
\#**define** *flushing* 2 ▷ *scanner_status* when junk after a statement is being ignored ◁
\#**define** *absorbing* 3 ▷ *scanner_status* when a **text** parameter is being scanned ◁
\#**define** *var_defining* 4 ▷ *scanner_status* when a **vardef** is being scanned ◁
\#**define** *op_defining* 5 ▷ *scanner_status* when a macro **def** is being scanned ◁
\#**define** *loop_defining* 6 ▷ *scanner_status* when a **for** loop is being scanned ◁

⟨ Global variables 18 ⟩ +≡
\#**define** *tex_flushing* 7 ▷ *scanner_status* when skipping TEX material ◁
  integer *scanner_status*; ▷ are we scanning at high speed? ◁
  mp_sym *warning_info*; ▷ if so, what else do we need to know, in case an error occurs? ◁
  integer *warning_line*;
  mp_node *warning_info_node*;

723. ⟨ Initialize the input routines 720 ⟩ +≡
  mp→scanner_status ← *normal*;

724. The following subroutine is called when an '**outer**' symbolic token has been scanned or when the end of a file has been reached. These two cases are distinguished by *cur_sym*, which is zero at the end of a file.

```
static boolean mp_check_outer_validity(MP mp)
{
  mp_node p;    ▷ points to inserted token list ◁
  if (mp→scanner_status ≡ normal) {
    return true;
  }
  else if (mp→scanner_status ≡ tex_flushing) {
    ⟨Check if the file has ended while flushing TEX material and set the result value for
        check_outer_validity 725⟩;
  }
  else {
    ⟨Back up an outer symbolic token so that it can be reread 726⟩;
    if (mp→scanner_status > skipping) {
      ⟨Tell the user what has run away and try to recover 727⟩;
    }
    else {
      char msg[256];
      const char *hlp[] ← {"A␣forbidden␣'outer'␣token␣occurred␣in␣skipped␣text.",
          "This␣kind␣of␣error␣happens␣when␣you␣say␣'if...'␣and␣forget",
          "the␣matching␣'fi'.␣I've␣inserted␣a␣'fi';␣this␣might␣work.", Λ};
      mp_snprintf(msg, 256, "Incomplete␣if;␣all␣text␣was␣ignored␣after␣line␣%d",
          (int) mp→warning_line);
      if (cur_sym() ≡ Λ) {
        hlp[0] ← "The␣file␣ended␣while␣I␣was␣skipping␣conditional␣text.";
      }
      set_cur_sym(mp→frozen_fi); mp_ins_error(mp, msg, hlp, false);
    }
    return false;
  }
}
```

725. ⟨Check if the file has ended while flushing TEX material and set the result value for *check_outer_validity* 725⟩ ≡

```
if (cur_sym() ≠ Λ) {
  return true;
}
else {
  char msg[256];
  const char *hlp[] ← {"The␣file␣ended␣while␣I␣was␣looking␣for␣the␣'etex'␣to",
      "finish␣this␣TeX␣material.␣␣I've␣inserted␣'etex'␣now.", Λ};
  mp_snprintf(msg, 256, "TeX␣mode␣didn't␣end;␣all␣text␣was␣ignored␣after␣line␣%d",
      (int) mp→warning_line); set_cur_sym(mp→frozen_etex); mp_ins_error(mp, msg, hlp, false);
  return false;
}
```

This code is used in section 724.

726. ⟨ Back up an outer symbolic token so that it can be reread 726 ⟩ ≡

```
if (cur_sym() ≠ Λ) {
  p ← mp_get_symbolic_node(mp); set_mp_sym_sym(p, cur_sym());
  mp_name_type(p) ← cur_sym_mod(); back_list(p);   ▷ prepare to read the symbolic token again ◁
}
```

This code is used in section 724.

727. ⟨ Tell the user what has run away and try to recover 727 ⟩ ≡

```
{
  char msg[256];
  const char *msg_start ← Λ;
  const char *hlp[] ← {"I suspect you have forgotten an ‘enddef’,",
      "causing me to read past where you wanted me to stop.",
      "I’ll try to recover; but if the error is serious,",
      "you’d better type ‘E’ or ‘X’ now and fix your file.", Λ};
  mp_runaway(mp);   ▷ print the definition-so-far ◁
  if (cur_sym() ≡ Λ) {
    msg_start ← "File ended while scanning";
  }
  else {
    msg_start ← "Forbidden token found while scanning";
  }
  switch (mp→scanner_status) {
    ⟨ Complete the error message, and set cur_sym to a token that might help recover from the error 728 ⟩
  }   ▷ there are no other cases ◁
  mp_ins_error(mp, msg, hlp, true);
}
```

This code is used in section 724.

728. As we consider various kinds of errors, it is also appropriate to change the first line of the help message just given; *help_line*[3] points to the string that might be changed.

⟨ Complete the error message, and set *cur_sym* to a token that might help recover from the error 728 ⟩ ≡

```
case flushing: mp_snprintf(msg, 256, "%s to the end of the statement", msg_start);
  hlp[0] ← "A previous error seems to have propagated,"; set_cur_sym(mp→frozen_semicolon);
  break;
case absorbing: mp_snprintf(msg, 256, "%s a text argument", msg_start);
  hlp[0] ← "It seems that a right delimiter was left out,";
  if (mp→warning_info ≡ Λ) {
    set_cur_sym(mp→frozen_end_group);
  }
  else {
    set_cur_sym(mp→frozen_right_delimiter);
      ▷ the next line makes sure that the inserted delimiter will match the delimiter that already was read. ◁
    set_equiv_sym(cur_sym(), mp→warning_info);
  }
  break;
case var_defining:
  {
    mp_string s;
    int old_setting ← mp→selector;
    mp→selector ← new_string; mp_print_variable_name(mp, mp→warning_info_node);
    s ← mp_make_string(mp); mp→selector ← old_setting;
    mp_snprintf(msg, 256, "%s the definition of %s", msg_start, s→str); delete_str_ref(s);
  }
  set_cur_sym(mp→frozen_end_def); break;
case op_defining:
  {
    char *s ← mp_str(mp, text(mp→warning_info));
    mp_snprintf(msg, 256, "%s the definition of %s", msg_start, s);
  }
  set_cur_sym(mp→frozen_end_def); break;
case loop_defining:
  {
    char *s ← mp_str(mp, text(mp→warning_info));
    mp_snprintf(msg, 256, "%s the text of a %s loop", msg_start, s);
  }
  hlp[0] ← "I suspect you have forgotten an ‘endfor’,"; set_cur_sym(mp→frozen_end_for); break;
```

This code is used in section 727.

729. The *runaway* procedure displays the first part of the text that occurred when METAPOST began its special *scanner_status*, if that text has been saved.

⟨ Declarations 10 ⟩ +≡

```
static void mp_runaway(MP mp);
```

730. **void** *mp_runaway*(**MP** *mp*)

```
{
  if (mp→scanner_status > flushing) {
    mp_print_nl(mp, "Runaway␣");
    switch (mp→scanner_status) {
    case absorbing: mp_print(mp, "text?"); break;
    case var_defining: case op_defining: mp_print(mp, "definition?"); break;
    case loop_defining: mp_print(mp, "loop?"); break;
    }   ▷ there are no other cases ◁
    mp_print_ln(mp); mp_show_token_list(mp, mp_link(mp→hold_head), Λ, mp→error_line − 10, 0);
  }
}
```

731. We need to mention a procedure that may be called by *get_next*.

⟨ Declarations 10 ⟩ +≡

```
  static void mp_firm_up_the_line(MP mp);
```

732. And now we're ready to take the plunge into *get_next* itself. Note that the behavior depends on the *scanner_status* because percent signs and double quotes need to be passed over when skipping TEX material.

```
void mp_get_next(MP mp)
{     ▷ sets cur_cmd, cur_mod, cur_sym to next token ◁
  mp_sym cur_sym_;     ▷ speed up access ◁
RESTART: set_cur_sym(Λ); set_cur_sym_mod(0);
  if (file_state) {
    int k;     ▷ an index into buffer ◁
    ASCII_code c;     ▷ the current character in the buffer ◁
    int cclass;     ▷ its class number ◁     ▷ Input from external file; goto restart if no input found, or
        return if a non-symbolic token is found ◁     ▷ A percent sign appears in buffer[limit]; this makes
        it unnecessary to have a special test for end-of-line. ◁
  SWITCH: c ← mp→buffer[loc]; incr(loc); cclass ← mp→char_class[c];
    switch (cclass) {
    case digit_class: scan_numeric_token((c − '0')); return; break;
    case period_class: cclass ← mp→char_class[mp→buffer[loc]];
      if (cclass > period_class) {
        goto SWITCH;
      }
      else if (cclass < period_class) {     ▷ class ← digit_class ◁
        scan_fractional_token(0); return;
      }
      break;
    case space_class: goto SWITCH; break;
    case percent_class:
      if (mp→scanner_status ≡ tex_flushing) {
        if (loc < limit) goto SWITCH;
      }     ▷ Move to next line of file, or goto restart if there is no next line ◁
      switch (move_to_next_line(mp)) {
      case 1: goto RESTART; break;
      case 2: goto COMMON_ENDING; break;
      default: break;
      }
      check_interrupt; goto SWITCH; break;
    case string_class:
      if (mp→scanner_status ≡ tex_flushing) {
        goto SWITCH;
      }
      else {
        if (mp→buffer[loc] ≡ '"') {
          set_cur_mod_str(mp_rts(mp, ""));
        }
        else {
          k ← loc; mp→buffer[limit + 1] ← xord('"');
          do {
            incr(loc);
          } while (mp→buffer[loc] ≠ '"');
          if (loc > limit) {     ▷ Decry the missing string delimiter and goto restart ◁     ▷ We go to
                restart after this error message, not to SWITCH, because the clear_for_error_prompt
                routine might have reinstated token_state after error has finished. ◁
```

```
        const char *hlp[] ← {"Strings␣should␣finish␣on␣the␣same␣line␣as␣they␣began.",
            "I've␣deleted␣the␣partial␣string;␣you␣might␣want␣to",
            "insert␣another␣by␣typing,␣e.g.,␣`I\"new␣string\"'.", Λ};
        loc ← limit;   ▷ the next character to be read on this line will be "%" ◁
        mp_error(mp, "Incomplete␣string␣token␣has␣been␣flushed", hlp, false);
        goto RESTART;
      }
      str_room((size_t)(loc − k));
      do {
        append_char(mp→buffer[k]); incr(k);
      } while (k ≠ loc);
      set_cur_mod_str(mp_make_string(mp));
    }
    incr(loc); set_cur_cmd((mp_variable_type) mp_string_token); return;
  }
  break;
case isolated_classes: k ← loc − 1; goto FOUND; break;
case invalid_class:
  if (mp→scanner_status ≡ tex_flushing) {
    goto SWITCH;
  }
  else {   ▷ Decry the invalid character and goto restart ◁
      ▷ We go to restart instead of to SWITCH, because we might enter token_state after the error has
        been dealt with (cf. clear_for_error_prompt). ◁
    const char *hlp[] ← {"A␣funny␣symbol␣that␣I␣can\'t␣read␣has␣just␣been␣input.",
        "Continue,␣and␣I'll␣forget␣that␣it␣ever␣happened.", Λ};
    mp_error(mp, "Text␣line␣contains␣an␣invalid␣character", hlp, false); goto RESTART;
  }
  break;
default: break;   ▷ letters, etc. ◁
}
k ← loc − 1;
while (mp→char_class[mp→buffer[loc]] ≡ cclass) incr(loc);
FOUND: set_cur_sym(mp_id_lookup(mp, (char *)(mp→buffer + k), (size_t)(loc − k), true));
}
else {   ▷ Input from token list; goto restart if end of list or if a parameter needs to be expanded, or
      return if a non-symbolic token is found ◁
  if (nloc ≠ Λ ∧ mp_type(nloc) ≡ mp_symbol_node) {   ▷ symbolic token ◁
    int cur_sym_mod_ ← mp_name_type(nloc);
    halfword cur_info ← mp_sym_info(nloc);
    set_cur_sym(mp_sym_sym(nloc)); set_cur_sym_mod(cur_sym_mod_); nloc ← mp_link(nloc);
      ▷ move to next ◁
    if (cur_sym_mod_ ≡ mp_expr_sym) {
      set_cur_cmd((mp_variable_type) mp_capsule_token);
      set_cur_mod_node(mp→param_stack[param_start + cur_info]); set_cur_sym_mod(0);
      set_cur_sym(Λ); return;
    }
    else if (cur_sym_mod_ ≡ mp_suffix_sym ∨ cur_sym_mod_ ≡ mp_text_sym) {
      mp_begin_token_list(mp, mp→param_stack[param_start + cur_info], (quarterword) parameter);
      goto RESTART;
    }
```

```
      }
      else if (nloc ≠ Λ) {    ▷ Get a stored numeric or string or capsule token and return ◁
        if (mp_name_type(nloc) ≡ mp_token) {
          if (mp_type(nloc) ≡ mp_known) {
            set_cur_mod_number(value_number(nloc));
            set_cur_cmd((mp_variable_type) mp_numeric_token);
          }
          else {
            set_cur_mod_str(value_str(nloc)); set_cur_cmd((mp_variable_type) mp_string_token);
            add_str_ref(cur_mod_str());
          }
        }
        else {
          set_cur_mod_node(nloc); set_cur_cmd((mp_variable_type) mp_capsule_token);
        }
        nloc ← mp_link(nloc); return;
      }
      else {    ▷ we are done with this token list ◁
        mp_end_token_list(mp); goto RESTART;    ▷ resume previous level ◁
      }
    }
  COMMON_ENDING:
      ▷ When a symbolic token is declared to be 'outer', its command code is increased by outer_tag. ◁
    cur_sym_ ← cur_sym(); set_cur_cmd(eq_type(cur_sym_)); set_cur_mod(equiv(cur_sym_));
    set_cur_mod_node(equiv_node(cur_sym_));
    if (cur_cmd() ≥ mp_outer_tag) {
      if (mp_check_outer_validity(mp)) set_cur_cmd(cur_cmd() − mp_outer_tag);
      else goto RESTART;
    }
  }
```

733. The global variable *force_eof* is normally *false*; it is set *true* by an **endinput** command.

⟨ Global variables 18 ⟩ +≡

```
  boolean force_eof;    ▷ should the next input be aborted early? ◁
```

734. ⟨ Declarations 10 ⟩ +≡

```
  static int move_to_next_line(MP mp);
```

735. static int *move_to_next_line*(MP *mp*)

```
{
  if (name > max_spec_src) {    ▷ Read next line of file into buffer, or return 1 (goto restart) if the file
        has ended ◁    ▷ We must decrement loc in order to leave the buffer in a valid state when an error
        condition causes us to goto restart without calling end_file_reading. ◁
    {
      incr(line); mp→first ← (size_t) start;
      if (¬mp→force_eof) {
        if (mp_input_ln(mp, cur_file))    ▷ not end of file ◁
          mp_firm_up_the_line(mp);    ▷ this sets limit ◁
        else mp→force_eof ← true;
      }
      if (mp→force_eof) {
        mp→force_eof ← false; decr(loc);
        if (mpx_reading) {    ▷ Complain that the MPX file ended unexpectedly; then set cur_sym: ←
              mp→frozen_mpx_break and goto common_ending ◁
            ▷ We should never actually come to the end of an MPX file because such files should have an
              mpxbreak after the translation of the last btex ... etex block. ◁
          const char *hlp[] ← {"The␣file␣had␣too␣few␣picture␣expressions␣for␣btex...etex",
              "blocks.␣␣Such␣files␣are␣normally␣generated␣automatically",
              "but␣this␣one␣got␣messed␣up.␣␣You␣might␣want␣to␣insert␣a",
              "picture␣expression␣now.", Λ};
          mp→mpx_name[iindex] ← mpx_finished;
          mp_error(mp, "mpx␣file␣ended␣unexpectedly", hlp, false);
          set_cur_sym(mp→frozen_mpx_break); return 2;
        }
        else {
          mp_print_char(mp, xord(')')); decr(mp→open_parens); update_terminal();
            ▷ show user that file has been read ◁
          mp_end_file_reading(mp);    ▷ resume previous level ◁
          if (mp_check_outer_validity(mp)) return 1;
          else return 1;
        }
      }
      mp→buffer[limit] ← xord('%'); mp→first ← (size_t)(limit + 1); loc ← start;    ▷ ready to read ◁
    }
  }
  else {
    if (mp→input_ptr > 0) {    ▷ text was inserted during error recovery or by scantokens ◁
      mp_end_file_reading(mp);    ▷ goto RESTART ◁
      return 1;    ▷ resume previous level ◁
    }
    if (mp→job_name ≡ Λ ∧ (mp→selector < log_only ∨ mp→selector ≥ write_file)) mp_open_log_file(mp);
    if (mp→interaction > mp_nonstop_mode) {
      if (limit ≡ start)    ▷ previous line was empty ◁
        mp_print_nl(mp, "(Please␣type␣a␣command␣or␣say␣`end')");
      mp_print_ln(mp); mp→first ← (size_t) start; prompt_input("*");    ▷ input on-line into buffer ◁
      limit ← (halfword) mp→last; mp→buffer[limit] ← xord('%'); mp→first ← (size_t)(limit + 1);
      loc ← start;
    }
    else {
```

```
      mp_fatal_error(mp, "***␣(job␣aborted,␣no␣legal␣end␣found)");
        ▷ nonstop mode, which is intended for overnight batch processing, never waits for on-line input ◁
    }
  }
  return 0;
}
```

736. If the user has set the *mp_pausing* parameter to some positive value, and if nonstop mode has not been selected, each line of input is displayed on the terminal and the transcript file, followed by '=>'. METAPOST waits for a response. If the response is NULL (i.e., if nothing is typed except perhaps a few blank spaces), the original line is accepted as it stands; otherwise the line typed is used instead of the line in the file.

```
void mp_firm_up_the_line(MP mp)
{
  size_t k;    ▷ an index into buffer ◁
  limit ← (halfword) mp→last;
  if ((¬mp→noninteractive) ∧ (number_positive(internal_value(mp_pausing))) ∧ (mp→interaction >
        mp_nonstop_mode)) {
    wake_up_terminal(); mp_print_ln(mp);
    if (start < limit) {
      for (k ← (size_t) start; k < (size_t) limit; k++) {
        mp_print_char(mp, mp→buffer[k]);
      }
    }
    mp→first ← (size_t) limit; prompt_input("=>");    ▷ wait for user response ◁
    if (mp→last > mp→first) {
      for (k ← mp→first; k < mp→last; k++) {    ▷ move line down in buffer ◁
        mp→buffer[k + (size_t) start − mp→first] ← mp→buffer[k];
      }
      limit ← (halfword)((size_t) start + mp→last − mp→first);
    }
  }
}
```

737. Dealing with TEX material. The **btex** ... **etex** and **verbatimtex** ... **etex** features need to be implemented at a low level in the scanning process so that METAPOST can stay in sync with the a preprocessor that treats blocks of TEX material as they occur in the input file without trying to expand METAPOST macros. Thus we need a special version of *get_next* that does not expand macros and such but does handle **btex**, **verbatimtex**, etc.

The special version of *get_next* is called *get_t_next*. It works by flushing **btex** ... **etex** and **verbatimtex** ... **etex** blocks, switching to the `MPX` file when it sees **btex**, and switching back when it sees **mpxbreak**.

\#**define** *btex_code* 0
\#**define** *verbatim_code* 1

738. ⟨ Put each of METAPOST's primitives into the hash table 204 ⟩ +≡
mp_primitive(*mp*, "`btex`", *mp_start_tex*, *btex_code*);
mp_primitive(*mp*, "`verbatimtex`", *mp_start_tex*, *verbatim_code*);
mp_primitive(*mp*, "`etex`", *mp_etex_marker*, 0);
mp→frozen_etex ← *mp_frozen_primitive*(*mp*, "`etex`", *mp_etex_marker*, 0);
mp_primitive(*mp*, "`mpxbreak`", *mp_mpx_break*, 0);
mp→frozen_mpx_break ← *mp_frozen_primitive*(*mp*, "`mpxbreak`", *mp_mpx_break*, 0);

739. ⟨ Cases of *print_cmd_mod* for symbolic printing of primitives 239 ⟩ +≡
case *mp_start_tex*:
if ($m \equiv btex\_code$) *mp_print*(*mp*, "`btex`");
else *mp_print*(*mp*, "`verbatimtex`");
break;
case *mp_etex_marker*: *mp_print*(*mp*, "`etex`"); **break**;
case *mp_mpx_break*: *mp_print*(*mp*, "`mpxbreak`"); **break**;

740. Actually, *get_t_next* is a macro that avoids procedure overhead except in the unusual case where **btex**, **verbatimtex**, **etex**, or **mpxbreak** is encountered.

```
#define get_t_next(a)
        do {
          mp_get_next(mp);
          if (cur_cmd() ≤ mp_max_pre_command) mp_t_next(mp);
        } while (0)
```

741. ⟨ Declarations 10 ⟩ +≡
static void *mp_t_next*(**MP** *mp*);
static void *mp_start_mpx_input*(**MP** *mp*);

742. **static void** *mp_t_next*(**MP** *mp*)

```
{
  int old_status;    ▷ saves the scanner_status ◁
  integer old_info;    ▷ saves the warning_info ◁
  if ((mp→extensions ≡ 1) ∧ (cur_cmd() ≡ mp_start_tex)) ⟨Pass btex ... etex to script 784⟩
  else {
    while (cur_cmd() ≤ mp_max_pre_command) {
      if (cur_cmd() ≡ mp_mpx_break) {
        if (¬file_state ∨ (mp→mpx_name[iindex] ≡ absent))
          ⟨Complain about a misplaced mpxbreak 746⟩
        else {
          mp_end_mpx_reading(mp); goto TEX_FLUSH;
        }
      }
      else if (cur_cmd() ≡ mp_start_tex) {
        if (token_state ∨ (name ≤ max_spec_src)) ⟨Complain that we are not reading a file 745⟩
        else if (mpx_reading) ⟨Complain that MPX files cannot contain TeX material 744⟩
        else if ((cur_mod() ≠ verbatim_code) ∧ (mp→mpx_name[iindex] ≠ mpx_finished)) {
          if (¬mp_begin_mpx_reading(mp)) mp_start_mpx_input(mp);
        }
        else {
          goto TEX_FLUSH;
        }
      }
      else ⟨Complain about a misplaced etex 747⟩
      goto COMMON_ENDING;
    TEX_FLUSH: ⟨Flush the TeX material 743⟩;
    COMMON_ENDING: mp_get_next(mp);
    }
  }
}
```

743. We could be in the middle of an operation such as skipping false conditional text when TEX material is encountered, so we must be careful to save the *scanner_status*.

⟨Flush the TEX material 743⟩ ≡

```
  old_status ← mp→scanner_status; old_info ← mp→warning_line; mp→scanner_status ← tex_flushing;
  mp→warning_line ← line;
  do {
    mp_get_next(mp);
  } while (cur_cmd() ≠ mp_etex_marker);
  mp→scanner_status ← old_status; mp→warning_line ← old_info
```

This code is used in section 742.

744. ⟨ Complain that MPX files cannot contain TEX material 744 ⟩ ≡

```
{
  const char *hlp[] ← {"This␣file␣contains␣picture␣expressions␣for␣btex...etex",
      "blocks.␣␣Such␣files␣are␣normally␣generated␣automatically",
      "but␣this␣one␣seems␣to␣be␣messed␣up.␣␣I'll␣just␣keep␣going",
      "and␣hope␣for␣the␣best.", Λ};
  mp_error(mp, "An␣mpx␣file␣cannot␣contain␣btex␣or␣verbatimtex␣blocks", hlp, true);
}
```

This code is used in section 742.

745. ⟨ Complain that we are not reading a file 745 ⟩ ≡

```
{
  const char *hlp[] ← {"I'll␣have␣to␣ignore␣this␣preprocessor␣command␣because␣it",
      "only␣works␣when␣there␣is␣a␣file␣to␣preprocess.␣␣You␣might",
      "want␣to␣delete␣everything␣up␣to␣the␣next␣`etex`.", Λ};
  mp_error(mp, "You␣can␣only␣use␣`btex'␣or␣`verbatimtex'␣in␣a␣file", hlp, true);
}
```

This code is used in section 742.

746. ⟨ Complain about a misplaced **mpxbreak** 746 ⟩ ≡

```
{
  const char *hlp[] ← {"I'll␣ignore␣this␣preprocessor␣command␣because␣it",
      "doesn't␣belong␣here", Λ};
  mp_error(mp, "Misplaced␣mpxbreak", hlp, true);
}
```

This code is used in section 742.

747. ⟨ Complain about a misplaced **etex** 747 ⟩ ≡

```
{
  const char *hlp[] ← {"There␣is␣no␣btex␣or␣verbatimtex␣for␣this␣to␣match", Λ};
  mp_error(mp, "Extra␣etex␣will␣be␣ignored", hlp, true);
}
```

This code is used in section 742.

748. Scanning macro definitions. METAPOST has a variety of ways to tuck tokens away into token lists for later use: Macros can be defined with **def**, **vardef**, **primarydef**, etc.; repeatable code can be defined with **for**, **forever**, **forsuffixes**. All such operations are handled by the routines in this part of the program.

The modifier part of each command code is zero for the "ending delimiters" like **enddef** and **endfor**.

#define *start_def* 1 ▷ command modifier for **def** ◁
#define *var_def* 2 ▷ command modifier for **vardef** ◁
#define *end_def* 0 ▷ command modifier for **enddef** ◁
#define *start_forever* 1 ▷ command modifier for **forever** ◁
#define *start_for* 2 ▷ command modifier for **forever** ◁
#define *start_forsuffixes* 3 ▷ command modifier for **forever** ◁
#define *end_for* 0 ▷ command modifier for **endfor** ◁

⟨ Put each of METAPOST's primitives into the hash table 204 ⟩ +≡
```
mp_primitive(mp, "def", mp_macro_def, start_def);
mp_primitive(mp, "vardef", mp_macro_def, var_def);
mp_primitive(mp, "primarydef", mp_macro_def, mp_secondary_primary_macro);
mp_primitive(mp, "secondarydef", mp_macro_def, mp_tertiary_secondary_macro);
mp_primitive(mp, "tertiarydef", mp_macro_def, mp_expression_tertiary_macro);
mp_primitive(mp, "enddef", mp_macro_def, end_def);
mp→frozen_end_def ← mp_frozen_primitive(mp, "enddef", mp_macro_def, end_def);
mp_primitive(mp, "for", mp_iteration, start_for);
mp_primitive(mp, "forsuffixes", mp_iteration, start_forsuffixes);
mp_primitive(mp, "forever", mp_iteration, start_forever);
mp_primitive(mp, "endfor", mp_iteration, end_for);
mp→frozen_end_for ← mp_frozen_primitive(mp, "endfor", mp_iteration, end_for);
```

749. ⟨ Cases of *print_cmd_mod* for symbolic printing of primitives 239 ⟩ +≡
```
case mp_macro_def:
  if (m ≤ var_def) {
    if (m ≡ start_def) mp_print(mp, "def");
    else if (m < start_def) mp_print(mp, "enddef");
    else mp_print(mp, "vardef");
  }
  else if (m ≡ mp_secondary_primary_macro) {
    mp_print(mp, "primarydef");
  }
  else if (m ≡ mp_tertiary_secondary_macro) {
    mp_print(mp, "secondarydef");
  }
  else {
    mp_print(mp, "tertiarydef");
  }
  break;
case mp_iteration:
  if (m ≡ start_forever) mp_print(mp, "forever");
  else if (m ≡ end_for) mp_print(mp, "endfor");
  else if (m ≡ start_for) mp_print(mp, "for");
  else mp_print(mp, "forsuffixes");
  break;
```

750. Different macro-absorbing operations have different syntaxes, but they also have a lot in common. There is a list of special symbols that are to be replaced by parameter tokens; there is a special command code that ends the definition; the quotation conventions are identical. Therefore it makes sense to have most of the work done by a single subroutine. That subroutine is called *scan_toks*.

The first parameter to *scan_toks* is the command code that will terminate scanning (either *macro_def* or *iteration*).

The second parameter, *subst_list*, points to a (possibly empty) list of non-symbolic nodes whose *info* and *value* fields specify symbol tokens before and after replacement. The list will be returned to free storage by *scan_toks*.

The third parameter is simply appended to the token list that is built. And the final parameter tells how many of the special operations `#@!`, `@!`, and `@!#` are to be replaced by suffix parameters. When such parameters are present, they are called `(SUFFIX0)`, `(SUFFIX1)`, and `(SUFFIX2)`.

⟨ Types in the outer block 37 ⟩ +≡
  typedef struct mp_subst_list_item {
    mp_name_type_type *info_mod*;
    quarterword *value_mod*;
    mp_sym *info*;
    halfword *value_data*;
    struct mp_subst_list_item ∗*link*;
  } **mp_subst_list_item**;

751. **static mp_node** *mp_scan_toks*(**MP** *mp*, **mp_command_code** *terminator*, **mp_subst_list_item** **subst_list*, **mp_node** *tail_end*, **quarterword** *suffix_count*)

```
{
  mp_node p;    ▷ tail of the token list being built ◁
  mp_subst_list_item *q ← Λ;    ▷ temporary for link management ◁
  integer balance;    ▷ left delimiters minus right delimiters ◁
  halfword cur_data;
  quarterword cur_data_mod ← 0;
  p ← mp→hold_head; balance ← 1; mp_link(mp→hold_head) ← Λ;
  while (1) {
    get_t_next(mp); cur_data ← −1;
    if (cur_sym() ≠ Λ) {
      ⟨Substitute for cur_sym, if it's on the subst_list 754⟩;
      if (cur_cmd() ≡ terminator) ⟨Adjust the balance; break if it's zero 755⟩
      else if (cur_cmd() ≡ mp_macro_special) {    ▷ Handle quoted symbols, #@!, @!, or @!# ◁
        if (cur_mod() ≡ quote) {
          get_t_next(mp);
        }
        else if (cur_mod() ≤ suffix_count) {
          cur_data ← cur_mod() − 1; cur_data_mod ← mp_suffix_sym;
        }
      }
    }
    if (cur_data ≠ −1) {
      mp_node pp ← mp_get_symbolic_node(mp);
      set_mp_sym_info(pp, cur_data); mp_name_type(pp) ← cur_data_mod; mp_link(p) ← pp;
    }
    else {
      mp_link(p) ← mp_cur_tok(mp);
    }
    p ← mp_link(p);
  }
  mp_link(p) ← tail_end;
  while (subst_list) {
    q ← subst_list→link; xfree(subst_list); subst_list ← q;
  }
  return mp_link(mp→hold_head);
}
```

752. **void** *mp_print_sym*(**mp_sym** *sym*)

```
{
  printf("{type␣=␣%d,␣v␣=␣{type␣=␣%d,␣data␣=␣{indep␣=␣{scale␣=␣%d,␣serial␣=␣%d},␣n␣=␣%d,␣\
      str␣=␣%p,␣sym␣=␣%p,␣node␣=␣%p,␣p␣=␣%p}},␣text␣=␣%p}\n", sym→type, sym→v.type,
      (int) sym→v.data.indep.scale, (int) sym→v.data.indep.serial, sym→v.data.n.type, sym→v.data.str,
      sym→v.data.sym, sym→v.data.node, sym→v.data.p, sym→text);
  if (is_number(sym→v.data.n)) {
    mp_number n ← sym→v.data.n;
    printf("{data␣=␣{dval␣=␣%f,␣val␣=␣%d},␣type␣=␣%d}\n", n.data.dval, n.data.val, n.type);
  }
  if (sym→text ≠ Λ) {
    mp_string t ← sym→text;
    printf("{str␣=␣%p␣\"%s\",␣len␣=␣%d,␣refs␣=␣%d}\n", t→str, t→str, (int) t→len, t→refs);
  }
}
```

753. ⟨ Declarations 10 ⟩ +≡

```
void mp_print_sym(mp_sym sym);
```

754. ⟨ Substitute for *cur_sym*, if it's on the *subst_list* 754 ⟩ ≡

```
{
  q ← subst_list;
  while (q ≠ Λ) {
    if (q→info ≡ cur_sym() ∧ q→info_mod ≡ cur_sym_mod()) {
      cur_data ← q→value_data;  cur_data_mod ← q→value_mod;
      set_cur_cmd((mp_variable_type) mp_relax); break;
    }
    q ← q→link;
  }
}
```

This code is used in section 751.

755. ⟨ Adjust the balance; **break** if it's zero 755 ⟩ ≡

```
{
  if (cur_mod() > 0) {
    incr(balance);
  }
  else {
    decr(balance);
    if (balance ≡ 0) break;
  }
}
```

This code is used in section 751.

756. Four commands are intended to be used only within macro texts: **quote**, `#@!`, `@!`, and `@!#`. They are variants of a single command code called *macro_special*.

```
#define quote 0    ▷ macro_special modifier for quote ◁
#define macro_prefix 1    ▷ macro_special modifier for #@! ◁
#define macro_at 2    ▷ macro_special modifier for @! ◁
#define macro_suffix 3    ▷ macro_special modifier for @!# ◁
```

⟨ Put each of METAPOST's primitives into the hash table 204 ⟩ +≡

```
mp_primitive(mp, "quote", mp_macro_special, quote);
mp_primitive(mp, "#@", mp_macro_special, macro_prefix);
mp_primitive(mp, "@", mp_macro_special, macro_at);
mp_primitive(mp, "@#", mp_macro_special, macro_suffix);
```

757. ⟨ Cases of *print_cmd_mod* for symbolic printing of primitives 239 ⟩ +≡

```
case mp_macro_special:
  switch (m) {
  case macro_prefix: mp_print(mp, "#@"); break;
  case macro_at: mp_print_char(mp, xord('@')); break;
  case macro_suffix: mp_print(mp, "@#"); break;
  default: mp_print(mp, "quote"); break;
  }
  break;
```

758. Here is a routine that's used whenever a token will be redefined. If the user's token is unredefinable, the '*mp→frozen_inaccessible*' token is substituted; the latter is redefinable but essentially impossible to use, hence METAPOST's tables won't get fouled up.

```
static void mp_get_symbol(MP mp)
{    ▷ sets cur_sym to a safe symbol ◁
RESTART: get_t_next(mp);
  if ((cur_sym() ≡ Λ) ∨ mp_is_frozen(mp, cur_sym())) {
    const char *hlp[] ← {"Sorry:␣You␣can\'t␣redefine␣a␣number,␣string,␣or␣expr.",
        "I've␣inserted␣an␣inaccessible␣symbol␣so␣that␣your",
        "definition␣will␣be␣completed␣without␣mixing␣me␣up␣too␣badly.", Λ};
    if (cur_sym() ≠ Λ) hlp[0] ← "Sorry:␣You␣can\'t␣redefine␣my␣error-recovery␣tokens.";
    else if (cur_cmd() ≡ mp_string_token) delete_str_ref(cur_mod_str());
    set_cur_sym(mp→frozen_inaccessible);
    mp_ins_error(mp, "Missing␣symbolic␣token␣inserted", hlp, true); goto RESTART;
  }
}
```

759. Before we actually redefine a symbolic token, we need to clear away its former value, if it was a variable. The following stronger version of *get_symbol* does that.

```
static void mp_get_clear_symbol(MP mp)
{
  mp_get_symbol(mp); mp_clear_symbol(mp, cur_sym(), false);
}
```

760. Here's another little subroutine; it checks that an equals sign or assignment sign comes along at the proper place in a macro definition.

```
static void mp_check_equals(MP mp)
{
  if (cur_cmd() ≠ mp_equals)
    if (cur_cmd() ≠ mp_assignment) {
      const char *hlp[] ← {"The␣next␣thing␣in␣this␣‘def’␣should␣have␣been␣‘=’,",
          "because␣I’ve␣already␣looked␣at␣the␣definition␣heading.",
          "But␣don’t␣worry;␣I’ll␣pretend␣that␣an␣equals␣sign",
          "was␣present.␣Everything␣from␣here␣to␣‘enddef’",
          "will␣be␣the␣replacement␣text␣of␣this␣macro.", Λ};
      mp_back_error(mp, "Missing␣‘=’␣has␣been␣inserted", hlp, true);
    }
}
```

761. A **primarydef**, **secondarydef**, or **tertiarydef** is rather easily handled now that we have *scan_toks*. In this case there are two parameters, which will be EXPR0 and EXPR1.

```
static void mp_make_op_def(MP mp)
{
  mp_command_code m;    ▷ the type of definition ◁
  mp_node q, r;    ▷ for list manipulation ◁
  mp_subst_list_item *qm ← Λ, *qn ← Λ;
  m ← cur_mod(); mp_get_symbol(mp); qm ← xmalloc(1, sizeof(mp_subst_list_item));
  qm→link ← Λ; qm→info ← cur_sym(); qm→info_mod ← cur_sym_mod(); qm→value_data ← 0;
  qm→value_mod ← mp_expr_sym; mp_get_clear_symbol(mp); mp→warning_info ← cur_sym();
  mp_get_symbol(mp); qn ← xmalloc(1, sizeof(mp_subst_list_item)); qn→link ← qm;
  qn→info ← cur_sym(); qn→info_mod ← cur_sym_mod(); qn→value_data ← 1;
  qn→value_mod ← mp_expr_sym; get_t_next(mp); mp_check_equals(mp);
  mp→scanner_status ← op_defining; q ← mp_get_symbolic_node(mp); set_ref_count(q, 0);
  r ← mp_get_symbolic_node(mp); mp_link(q) ← r; set_mp_sym_info(r, mp_general_macro);
  mp_name_type(r) ← mp_macro_sym; mp_link(r) ← mp_scan_toks(mp, mp_macro_def, qn, Λ, 0);
  mp→scanner_status ← normal; set_eq_type(mp→warning_info, m); set_equiv_node(mp→warning_info, q);
  mp_get_x_next(mp);
}
```

762. Parameters to macros are introduced by the keywords **expr**, **suffix**, **text**, **primary**, **secondary**, and **tertiary**.

```
⟨Put each of METAPOST's primitives into the hash table 204⟩ +≡
  mp_primitive(mp, "expr", mp_param_type, mp_expr_param);
  mp_primitive(mp, "suffix", mp_param_type, mp_suffix_param);
  mp_primitive(mp, "text", mp_param_type, mp_text_param);
  mp_primitive(mp, "primary", mp_param_type, mp_primary_macro);
  mp_primitive(mp, "secondary", mp_param_type, mp_secondary_macro);
  mp_primitive(mp, "tertiary", mp_param_type, mp_tertiary_macro);
```

763. ⟨ Cases of *print_cmd_mod* for symbolic printing of primitives 239 ⟩ +≡

case *mp_param_type*:
  if $(m \equiv mp\_expr\_param)$ *mp_print*(*mp*, `"expr"`);
  else if $(m \equiv mp\_suffix\_param)$ *mp_print*(*mp*, `"suffix"`);
  else if $(m \equiv mp\_text\_param)$ *mp_print*(*mp*, `"text"`);
  else if $(m \equiv mp\_primary\_macro)$ *mp_print*(*mp*, `"primary"`);
  else if $(m \equiv mp\_secondary\_macro)$ *mp_print*(*mp*, `"secondary"`);
  else *mp_print*(*mp*, `"tertiary"`);
  break;

764. Let's turn next to the more complex processing associated with **def** and **vardef**. When the following procedure is called, *cur_mod* should be either *start_def* or *var_def*.

Note that although the macro scanner allows **def** = := **enddef** and **def** := = **enddef**; **def** = = **enddef** and **def** := := **enddef** will generate an error because by the time the second of the two identical tokens is seen, its meaning has already become undefined.

```
static void mp_scan_def(MP mp)
{
  int m;   ▷ the type of definition ◁
  int n;   ▷ the number of special suffix parameters ◁
  int k;   ▷ the total number of parameters ◁
  int c;   ▷ the kind of macro we're defining ◁
  mp_subst_list_item *r ← Λ, *rp ← Λ;   ▷ parameter-substitution list ◁
  mp_node q;   ▷ tail of the macro token list ◁
  mp_node p;   ▷ temporary storage ◁
  quarterword sym_type;   ▷ expr_sym, suffix_sym, or text_sym ◁
  mp_sym l_delim, r_delim;   ▷ matching delimiters ◁
  m ← cur_mod(); c ← mp_general_macro; mp_link(mp→hold_head) ← Λ;
  q ← mp_get_symbolic_node(mp); set_ref_count(q, 0); r ← Λ;
    ▷ Scan the token or variable to be defined; set n, scanner_status, and warning_info ◁
  if (m ≡ start_def) {
    mp_get_clear_symbol(mp); mp→warning_info ← cur_sym(); get_t_next(mp);
    mp→scanner_status ← op_defining; n ← 0; set_eq_type(mp→warning_info, mp_defined_macro);
    set_equiv_node(mp→warning_info, q);
  }
  else {   ▷ var_def ◁
    p ← mp_scan_declared_variable(mp);
    mp_flush_variable(mp, equiv_node(mp_sym_sym(p)), mp_link(p), true);
    mp→warning_info_node ← mp_find_variable(mp, p); mp_flush_node_list(mp, p);
    if (mp→warning_info_node ≡ Λ) {   ▷ Change to 'a bad variable' ◁
      const char *hlp[] ← {"After␣‘vardef␣a’␣you␣can\’t␣say␣‘vardef␣a.b’.",
          "So␣I’ll␣have␣to␣discard␣this␣definition.", Λ};
      mp_error(mp, "This␣variable␣already␣starts␣with␣a␣macro", hlp, true);
      mp→warning_info_node ← mp→bad_vardef;
    }
    mp→scanner_status ← var_defining; n ← 2;
    if (cur_cmd() ≡ mp_macro_special ∧ cur_mod() ≡ macro_suffix) {   ▷ @!# ◁
      n ← 3; get_t_next(mp);
    }
    mp_type(mp→warning_info_node) ← (quarterword)(mp_unsuffixed_macro − 2 + n);
      ▷ mp_suffixed_macro ← mp_unsuffixed_macro + 1 ◁
    set_value_node(mp→warning_info_node, q);
  }
  k ← n;
  if (cur_cmd() ≡ mp_left_delimiter) {   ▷ Absorb delimited parameters, putting them into lists q and r ◁
    do {
      l_delim ← cur_sym(); r_delim ← equiv_sym(cur_sym()); get_t_next(mp);
      if ((cur_cmd() ≡ mp_param_type) ∧ (cur_mod() ≡ mp_expr_param)) {
        sym_type ← mp_expr_sym;
      }
      else if ((cur_cmd() ≡ mp_param_type) ∧ (cur_mod() ≡ mp_suffix_param)) {
        sym_type ← mp_suffix_sym;
```

```
      }
      else if ((cur_cmd() ≡ mp_param_type) ∧ (cur_mod() ≡ mp_text_param)) {
        sym_type ← mp_text_sym;
      }
      else {
        const char *hlp[] ← {"You␣should've␣had␣'expr'␣or␣'suffix'␣or␣'text'␣here.", Λ};
        mp_back_error(mp, "Missing␣parameter␣type;␣'expr'␣will␣be␣assumed", hlp, true);
        sym_type ← mp_expr_sym;
      }    ▷ Absorb parameter tokens for type sym_type ◁
      do {
        mp_link(q) ← mp_get_symbolic_node(mp); q ← mp_link(q); mp_name_type(q) ← sym_type;
        set_mp_sym_info(q, k); mp_get_symbol(mp); rp ← xmalloc(1, sizeof(mp_subst_list_item));
        rp→link ← Λ; rp→value_data ← k; rp→value_mod ← sym_type; rp→info ← cur_sym();
        rp→info_mod ← cur_sym_mod(); mp_check_param_size(mp, k); incr(k); rp→link ← r; r ← rp;
        get_t_next(mp);
      } while (cur_cmd() ≡ mp_comma);
      mp_check_delimiter(mp, l_delim, r_delim); get_t_next(mp);
    } while (cur_cmd() ≡ mp_left_delimiter);
  }
  if (cur_cmd() ≡ mp_param_type) {    ▷ Absorb undelimited parameters, putting them into list r ◁
    rp ← xmalloc(1, sizeof(mp_subst_list_item)); rp→link ← Λ; rp→value_data ← k;
    if (cur_mod() ≡ mp_expr_param) {
      rp→value_mod ← mp_expr_sym; c ← mp_expr_macro;
    }
    else if (cur_mod() ≡ mp_suffix_param) {
      rp→value_mod ← mp_suffix_sym; c ← mp_suffix_macro;
    }
    else if (cur_mod() ≡ mp_text_param) {
      rp→value_mod ← mp_text_sym; c ← mp_text_macro;
    }
    else {
      c ← cur_mod(); rp→value_mod ← mp_expr_sym;
    }
    mp_check_param_size(mp, k); incr(k); mp_get_symbol(mp); rp→info ← cur_sym();
    rp→info_mod ← cur_sym_mod(); rp→link ← r; r ← rp; get_t_next(mp);
    if (c ≡ mp_expr_macro) {
      if (cur_cmd() ≡ mp_of_token) {
        c ← mp_of_macro; rp ← xmalloc(1, sizeof(mp_subst_list_item)); rp→link ← Λ;
        mp_check_param_size(mp, k); rp→value_data ← k; rp→value_mod ← mp_expr_sym;
        mp_get_symbol(mp); rp→info ← cur_sym(); rp→info_mod ← cur_sym_mod(); rp→link ← r;
        r ← rp; get_t_next(mp);
      }
    }
  }
  mp_check_equals(mp); p ← mp_get_symbolic_node(mp); set_mp_sym_info(p, c);
  mp_name_type(p) ← mp_macro_sym; mp_link(q) ← p;
    ▷ Attach the replacement text to the tail of node p ◁    ▷ We don't put 'mp→frozen_end_group' into
      the replacement text of a vardef, because the user may want to redefine 'endgroup'. ◁
  if (m ≡ start_def) {
    mp_link(p) ← mp_scan_toks(mp, mp_macro_def, r, Λ, (quarterword) n);
  }
  else {
```

```
      mp_node qq ← mp_get_symbolic_node(mp);
      set_mp_sym_sym(qq, mp→bg_loc); mp_link(p) ← qq; p ← mp_get_symbolic_node(mp);
      set_mp_sym_sym(p, mp→eg_loc);
      mp_link(qq) ← mp_scan_toks(mp, mp_macro_def, r, p, (quarterword) n);
    }
    if (mp→warning_info_node ≡ mp→bad_vardef) mp_flush_token_list(mp, value_node(mp→bad_vardef));
    mp→scanner_status ← normal; mp_get_x_next(mp);
  }
```

765. ⟨ Global variables 18 ⟩ +≡

```
  mp_sym bg_loc;
  mp_sym eg_loc;    ▷ hash addresses of 'begingroup' and 'endgroup' ◁
```

766. ⟨ Initialize table entries 186 ⟩ +≡

```
  mp→bad_vardef ← mp_get_value_node(mp); mp_name_type(mp→bad_vardef) ← mp_root;
  set_value_sym(mp→bad_vardef, mp→frozen_bad_vardef);
```

767. ⟨ Free table entries 187 ⟩ +≡

```
  mp_free_value_node(mp, mp→bad_vardef);
```

768. Expanding the next token. Only a few command codes $<$ *min_command* can possibly be returned by *get_t_next*; in increasing order, they are *if_test*, *fi_or_else*, *input*, *iteration*, *repeat_loop*, *exit_test*, *relax*, *scan_tokens*, *run_script*, *expand_after*, and *defined_macro*.

METAPOST usually gets the next token of input by saying *get_x_next*. This is like *get_t_next* except that it keeps getting more tokens until finding *cur_cmd* $\geq$ *min_command*. In other words, *get_x_next* expands macros and removes conditionals or iterations or input instructions that might be present.

It follows that *get_x_next* might invoke itself recursively. In fact, there is massive recursion, since macro expansion can involve the scanning of arbitrarily complex expressions, which in turn involve macro expansion and conditionals, etc.

Therefore it's necessary to declare a whole bunch of *forward* procedures at this point, and to insert some other procedures that will be invoked by *get_x_next*.

⟨ Declarations 10 ⟩ +≡
static void *mp_scan_primary*(**MP** *mp*);
static void *mp_scan_secondary*(**MP** *mp*);
static void *mp_scan_tertiary*(**MP** *mp*);
static void *mp_scan_expression*(**MP** *mp*);
static void *mp_scan_suffix*(**MP** *mp*);
static void *mp_pass_text*(**MP** *mp*);
static void *mp_conditional*(**MP** *mp*);
static void *mp_start_input*(**MP** *mp*);
static void *mp_begin_iteration*(**MP** *mp*);
static void *mp_resume_iteration*(**MP** *mp*);
static void *mp_stop_iteration*(**MP** *mp*);

769. A recursion depth counter is used to discover infinite recursions. (Near) infinite recursion is a problem because it translates into C function calls that eat up the available call stack. A better solution would be to depend on signal trapping, but that is problematic when METAPOST is used as a library.

⟨ Global variables 18 ⟩ +≡
int *expand_depth_count*; ▷ current expansion depth ◁
int *expand_depth*; ▷ current expansion depth ◁

770. The limit is set at 10000, which should be enough to allow normal usages of metapost while preventing the most obvious crashes on most all operating systems, but the value can be raised if the runtime system allows a larger C stack.

⟨ Set initial values of key variables 42 ⟩ +≡
mp→*expand_depth* ← 10000;

771. Even better would be if the system allows discovery of the amount of space available on the call stack.
In any case, when the limit is crossed, that is a fatal error.

#define *check_expansion_depth*()
  if (++*mp*→*expand_depth_count* ≥ *mp*→*expand_depth*) *mp_expansion_depth_error*(*mp*)

static void *mp_expansion_depth_error*(**MP** *mp*)
{
  const char **hlp*[ ] ← {"Recursive␣macro␣expansion␣cannot␣be␣unlimited␣because␣of␣runtime", "stack␣constraints.␣The␣limit␣is␣10000␣recursion␣levels␣in␣total.", Λ};
  if (*mp*→*interaction* ≡ *mp_error_stop_mode*) *mp*→*interaction* ← *mp_scroll_mode*; ▷ no more interaction ◁
  if (*mp*→*log_opened*) *mp_error*(*mp*, "Maximum␣expansion␣depth␣reached", *hlp*, *true*);
  mp→*history* ← *mp_fatal_error_stop*; *mp_jump_out*(*mp*);
}

772. An auxiliary subroutine called *expand* is used by *get_x_next* when it has to do exotic expansion commands.

```
static void mp_expand(MP mp)
{
  size_t k;     ▷ something that we hope is ≤ buf_size ◁
  size_t j;     ▷ index into str_pool ◁
  check_expansion_depth();
  if (number_greater(internal_value(mp_tracing_commands), unity_t))
    if (cur_cmd() ≠ mp_defined_macro) show_cur_cmd_mod;
  switch (cur_cmd()) {
  case mp_if_test: mp_conditional(mp);
      ▷ this procedure is discussed in Part "Conditional processing" below ◁
    break;
  case mp_fi_or_else: ⟨Terminate the current conditional and skip to fi 827⟩;
    break;
  case mp_input: ⟨Initiate or terminate input from a file 776⟩;
    break;
  case mp_iteration:
    if (cur_mod() ≡ end_for) ⟨Scold the user for having an extra endfor 773⟩
    else {
      mp_begin_iteration(mp);     ▷ this procedure is discussed in Part "Iterations" below ◁
    }
    break;
  case mp_repeat_loop: ⟨Repeat a loop 777⟩;
    break;
  case mp_exit_test: ⟨Exit a loop if the proper time has come 778⟩;
    break;
  case mp_relax: break;
  case mp_expand_after: ⟨Expand the token after the next token 780⟩;
    break;
  case mp_scan_tokens: ⟨Put a string into the input buffer 781⟩;
    break;
  case mp_runscript: ⟨Put a script result string into the input buffer 783⟩;
    break;
  case mp_maketext: ⟨Put a maketext result string into the input buffer 785⟩;
    break;
  case mp_defined_macro: mp_macro_call(mp, cur_mod_node(), Λ, cur_sym()); break;
  default: break;     ▷ make the compiler happy ◁
  }     ▷ there are no other cases ◁
  mp→expand_depth_count−−;
}
```

773. ⟨Scold the user for having an extra **endfor** 773⟩ ≡

```
{
  const char *hlp[] ← {"I'm␣not␣currently␣working␣on␣a␣for␣loop,",
      "so␣I␣had␣better␣not␣try␣to␣end␣anything.", Λ};
  mp_error(mp, "Extra␣`endfor'", hlp, true);
}
```

This code is used in section 772.

774. The processing of **input** involves the *mp_start_input* subroutine, which will be declared later; the processing of **endinput** is trivial.

⟨ Put each of METAPOST's primitives into the hash table 204 ⟩ +≡

```
mp_primitive(mp, "input", mp_input, 0); mp_primitive(mp, "endinput", mp_input, 1);
```

775. ⟨ Cases of *print_cmd_mod* for symbolic printing of primitives 239 ⟩ +≡

```
case mp_input:
  if (m ≡ 0) mp_print(mp, "input");
  else mp_print(mp, "endinput");
  break;
```

776. ⟨ Initiate or terminate input from a file 776 ⟩ ≡

```
  if (cur_mod() > 0) mp→force_eof ← true;
  else mp_start_input(mp)
```

This code is used in section 772.

777. We'll discuss the complicated parts of loop operations later. For now it suffices to know that there's a global variable called *loop_ptr* that will be Λ if no loop is in progress.

⟨ Repeat a loop 777 ⟩ ≡

```
  {
    while (token_state ∧ (nloc ≡ Λ)) mp_end_token_list(mp);    ▷ conserve stack space ◁
    if (mp→loop_ptr ≡ Λ) {
      const char *hlp[] ← {"I'm␣confused;␣after␣exiting␣from␣a␣loop,␣I␣still␣seem",
          "to␣want␣to␣repeat␣it.␣I'll␣try␣to␣forget␣the␣problem.", Λ};
      mp_error(mp, "Lost␣loop", hlp, true);
    }
    else {
      mp_resume_iteration(mp);    ▷ this procedure is in Part "Iterations" below ◁
    }
  }
```

This code is used in section 772.

778. ⟨ Exit a loop if the proper time has come 778 ⟩ ≡

```
{
  mp_get_boolean(mp);
  if (number_greater(internal_value(mp_tracing_commands), unity_t))
    mp_show_cmd_mod(mp, mp_nullary, cur_exp_value_boolean());
  if (cur_exp_value_boolean() ≡ mp_true_code) {
    if (mp→loop_ptr ≡ Λ) {
      const char *hlp[] ← {"Why␣say␣‘exitif’␣when␣there’s␣nothing␣to␣exit␣from?", Λ};
      if (cur_cmd() ≡ mp_semicolon) mp_error(mp, "No␣loop␣is␣in␣progress", hlp, true);
      else mp_back_error(mp, "No␣loop␣is␣in␣progress", hlp, true);
    }
    else ⟨ Exit prematurely from an iteration 779 ⟩
  }
  else if (cur_cmd() ≠ mp_semicolon) {
    const char *hlp[] ← {"After␣‘exitif␣<boolean␣exp>’␣I␣expect␣to␣see␣a␣semicolon.",
        "I␣shall␣pretend␣that␣one␣was␣there.", Λ};
    mp_back_error(mp, "Missing␣‘;’␣has␣been␣inserted", hlp, true);
  }
}
```

This code is used in section 772.

779. Here we use the fact that *forever_text* is the only *token_type* that is less than *loop_text*.

⟨ Exit prematurely from an iteration 779 ⟩ ≡

```
{
  mp_node p ← Λ;
  do {
    if (file_state) {
      mp_end_file_reading(mp);
    }
    else {
      if (token_type ≤ loop_text) p ← nstart;
      mp_end_token_list(mp);
    }
  } while (p ≡ Λ);
  if (p ≠ mp→loop_ptr→info) mp_fatal_error(mp, "***␣(loop␣confusion)");
  mp_stop_iteration(mp);    ▷ this procedure is in Part “Iterations” below ◁
}
```

This code is used in section 778.

780. ⟨ Expand the token after the next token 780 ⟩ ≡

```
{
  mp_node p;
  get_t_next(mp); p ← mp_cur_tok(mp); get_t_next(mp);
  if (cur_cmd() < mp_min_command) mp_expand(mp);
  else mp_back_input(mp);
  back_list(p);
}
```

This code is used in section 772.

781. ⟨ Put a string into the input buffer 781 ⟩ ≡

```
{
  mp_get_x_next(mp); mp_scan_primary(mp);
  if (mp→cur_exp.type ≠ mp_string_type) {
    mp_value new_expr;
    const char *hlp[] ← {"I'm going to flush this expression, since",
        "scantokens should be followed by a known string.", Λ};
    memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n); mp_disp_err(mp, Λ);
    mp_back_error(mp, "Not a string", hlp, true); mp_get_x_next(mp);
    mp_flush_cur_exp(mp, new_expr);
  }
  else {
    mp_back_input(mp);
    if (cur_exp_str()→len > 0) ⟨ Pretend we're reading a new one-line file 786 ⟩;
  }
}
```

This code is used in section 772.

782. ⟨ Run a script 782 ⟩ ≡

```
if (s ≠ Λ) {
  int k;
  mp_value new_expr;
  size_t size ← strlen(s);
  memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
  mp_begin_file_reading(mp); name ← is_scantok; mp→last ← mp→first; k ← mp→first + size;
  if (k ≥ mp→max_buf_stack) {
    while (k ≥ mp→buf_size) {
      mp_reallocate_buffer(mp, (mp→buf_size + (mp→buf_size/4)));
    }
    mp→max_buf_stack ← k + 1;
  }
  limit ← (halfword) k; (void) memcpy((mp→buffer + mp→first), s, size);
  mp→buffer[limit] ← xord('%'); mp→first ← (size_t)(limit + 1); loc ← start;
  mp_flush_cur_exp(mp, new_expr);
}
```

This code is used in sections 783, 784, and 785.

783. ⟨ Put a script result string into the input buffer 783 ⟩ ≡

```
{
  if (mp→extensions ≡ 0) {
    return;
  }
  mp_get_x_next(mp); mp_scan_primary(mp);
  if (mp→cur_exp.type ≠ mp_string_type) {
    mp_value new_expr;
    const char *hlp[] ← {"I'm␣going␣to␣flush␣this␣expression,␣since",
        "runscript␣should␣be␣followed␣by␣a␣known␣string.", Λ};
    memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n); mp_disp_err(mp, Λ);
    mp_back_error(mp, "Not␣a␣string", hlp, true); mp_get_x_next(mp);
    mp_flush_cur_exp(mp, new_expr);
  }
  else {
    mp_back_input(mp);
    if (cur_exp_str()→len > 0) {
      char *s ← mp→run_script(mp, (const char *) cur_exp_str()→str, cur_exp_str()→len);
      ⟨ Run a script 782 ⟩
      free(s);
    }
  }
}
```

This code is used in section 772.

784. The *texscriptmode* parameter controls how spaces and newlines get honored in **btex** or **verbatimtex** ... **etex**. The default value is 1. Possible values are: 0: no newlines, 1: newlines in **verbatimtex**, 2: newlines in **verbatimtex** and **etex**, 3: no leading and trailing strip in **verbatimtex**, 4: no leading and trailing strip in **verbatimtex** and **btex**. That way the Lua handler can do what it likes. An **etex** has to be followed by a space or ; or be at the end of a line and preceded by a space or at the beginning of a line.

⟨ Pass **btex** ... **etex** to script 784 ⟩ ≡

```
{
  char *txt ← Λ;
  char *ptr ← Λ;
  int slin ← line;
  int size ← 0;
  int done ← 0;
  int mode ← round_unscaled(internal_value(mp_texscriptmode));   ▷ default: 1 ◁
  int verb ← cur_mod() ≡ verbatim_code;
  int first;   ▷ we had a (mandate) trailing space ◁
  if (loc ≤ limit ∧ mp→char_class[mp→buffer[loc]] ≡ space_class) {
    incr(loc);
  }
  else {   ▷ maybe issue an error message and quit ◁
  }   ▷ we loop over lines ◁
  first ← loc;
  while (1) {   ▷ we don't need to check when we have less than 4 characters left ◁
    if (loc < limit − 4) {
      if (mp→buffer[loc] ≡ 'e') {
        incr(loc);
        if (mp→buffer[loc] ≡ 't') {
          incr(loc);
          if (mp→buffer[loc] ≡ 'e') {
            incr(loc);
            if (mp→buffer[loc] ≡ 'x') {   ▷ let's see if we have the right boundary ◁
              if (first ≡ (loc − 3)) {   ▷ when we're at the start of a line no leading space is required ◁
                done ← 1;
              }
              else if (mp→char_class[mp→buffer[loc − 4]] ≡ space_class) {
                  ▷ when we're beyond the start of a line a leading space is required ◁
                done ← 2;
              }
              if (done) {
                if ((loc + 1) ≤ limit) {
                  quarterword c ← mp→char_class[mp→buffer[loc + 1]];
                  if (c ≠ letter_class) {
                    incr(loc);   ▷ we're past the 'x' ◁
                    break;
                  }
                  else {   ▷ this is no valid etex ◁
                    done ← 0;
                  }
                }
                else {   ▷ when we're at the end of a line we're ok ◁
                  incr(loc);   ▷ we're past the 'x' ◁
                  break;
```

```
                }
              }
            }
          }
        }
      }
    }    ▷ no etex seen (yet) ◁
    if (loc ≥ limit) {
      if (size) {
        txt ← realloc(txt, size + limit − first + 1);
      }
      else {
        txt ← malloc(limit − first + 1);
      }
      (void) memcpy(txt + size, mp→buffer + first, limit − first);  size += limit − first + 1;
      if (mode ≤ 0) {
        txt[size − 1] ← '␣';
      }
      else if (verb) {    ▷ modes ≥ 1 permit a newline in verbatimtex ◁
        txt[size − 1] ← '\n';
      }
      else if (mode ≥ 2) {    ▷ modes ≥ 2 permit a newline in btex ◁
        txt[size − 1] ← '\n';
      }
      else {
        txt[size − 1] ← '␣';
      }
      if (move_to_next_line(mp)) {    ▷ we abort the scanning ◁
        goto FATAL_ERROR;
      }
      first ← loc;
    }
    else {
      incr(loc);
    }
  }
  if (done) {    ▷ we're past the 'x' ◁
    int l ← loc − 5;    ◇ 4
    int n ← l − first + 1;    ▷ we're before the etex ◁
    if (done ≡ 2) {    ▷ we had etex ◁
      l −= 1;  n −= 1;    ▷ we're before the etex ◁
    }
    if (size) {
      txt ← realloc(txt, size + n + 1);
    }
    else {
      txt ← malloc(n + 1);
    }
    (void) memcpy(txt + size, mp→buffer + first, n);    ▷ 0 ◁
    size += n;
    if (verb ∧ mode ≥ 3) {    ▷ don't strip verbatimtex ◁
      txt[size] ← '\0';  ptr ← txt;
```

```
      }
      else if (mode ≥ 4) {    ▷ don't strip btex ◁
        txt[size] ← '\0'; ptr ← txt;
      }
      else {    ▷ strip trailing whitespace, we have a '\0' so we are off by one ◁    ▷ while ( (size > 1) ∧
            ( mp→char_class[(ASCII_code) txt[size − 2]] ≡ space_class || txt[size − 2] ≡ '\n' ) ) ◁
        while ((size > 1) ∧ (mp→char_class[(ASCII_code) txt[size − 1]] ≡ space_class ∨ txt[size − 1] ≡ '\n'))
          {
          decr(size);
        }    ▷ prune the string ◁
        txt[size] ← '\0';    ▷ strip leading whitespace ◁
        ptr ← txt;
        while ((size > 1) ∧ (mp→char_class[(ASCII_code) ptr[0]] ≡ space_class ∨ ptr[0] ≡ '\n')) {
          incr(ptr); decr(size);
        }
      }    ▷ action ◁
      {
        char *s ← mp→make_text(mp, ptr, size, verb);
        ⟨ Run a script 782 ⟩
        free(s);
      }
      free(txt);    ▷ really needed ◁
      mp_get_next(mp); return;
    }    ▷ we don't recover because in practice the graphic will be broken anyway and we're not really
           interacting in mplib .. just fix the input ◁
  FATAL_ERROR:
    {    ▷ line numbers are not always meaningful so we can get a 0 reported ◁
      char msg[256];
      const char *hlp[] ← {"An␣'etex'␣is␣missing␣at␣this␣input␣level,␣nothing␣gets␣done.", Λ};
      if (slin > 0) {
        mp_snprintf(msg, 256, "No␣matching␣'etex'␣for␣'%stex'.", verb ? "verbatim" : "b");
      }
      else {
        mp_snprintf(msg, 256, "No␣matching␣'etex'␣for␣'%stex'␣in␣line␣%d.",
              verb ? "verbatim" : "b", slin);
      }
      mp_error(mp, msg, hlp, false); free(txt);
    }
  }
```

This code is used in section 742.

785. ⟨ Put a maketext result string into the input buffer 785 ⟩ ≡

```
{
  if (mp→extensions ≡ 0) {
    return;
  }
  mp_get_x_next(mp); mp_scan_primary(mp);
  if (mp→cur_exp.type ≠ mp_string_type) {
    mp_value new_expr;
    const char *hlp[] ← {"I'm going to flush this expression, since",
        "maketext should be followed by a known string.", Λ};
    memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n); mp_disp_err(mp, Λ);
    mp_back_error(mp, "Not a string", hlp, true); mp_get_x_next(mp);
    mp_flush_cur_exp(mp, new_expr);
  }
  else {
    mp_back_input(mp);
    if (cur_exp_str()→len > 0) {
      char *s ← mp→make_text(mp, (const char *) cur_exp_str()→str, cur_exp_str()→len, 0);
      ⟨ Run a script 782 ⟩
      free(s);
    }
  }
}
```

This code is used in section 772.

786. ⟨ Pretend we're reading a new one-line file 786 ⟩ ≡

```
{
  mp_value new_expr;
  memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
  mp_begin_file_reading(mp); name ← is_scantok; k ← mp→first + (size_t) cur_exp_str()→len;
  if (k ≥ mp→max_buf_stack) {
    while (k ≥ mp→buf_size) {
      mp_reallocate_buffer(mp, (mp→buf_size + (mp→buf_size/4)));
    }
    mp→max_buf_stack ← k + 1;
  }
  j ← 0; limit ← (halfword) k;
  while (mp→first < (size_t) limit) {
    mp→buffer[mp→first] ← *(cur_exp_str()→str + j); j++; incr(mp→first);
  }
  mp→buffer[limit] ← xord('%'); mp→first ← (size_t)(limit + 1); loc ← start;
  mp_flush_cur_exp(mp, new_expr);
}
```

This code is used in section 781.

787. Here finally is *get_x_next*.

The expression scanning routines to be considered later communicate via the global quantities *cur_type* and *cur_exp*; we must be very careful to save and restore these quantities while macros are being expanded.

⟨ Declarations 10 ⟩ +≡

```
static void mp_get_x_next(MP mp);
```

788. **void** *mp_get_x_next*(**MP** *mp*)

```
{
  mp_node save_exp;    ▷ a capsule to save cur_type and cur_exp ◁
  get_t_next(mp);
  if (cur_cmd() < mp_min_command) {
    save_exp ← mp_stash_cur_exp(mp);
    do {
      if (cur_cmd() ≡ mp_defined_macro) mp_macro_call(mp, cur_mod_node(), Λ, cur_sym());
      else mp_expand(mp);
      get_t_next(mp);
    } while (cur_cmd() < mp_min_command);
    mp_unstash_cur_exp(mp, save_exp);    ▷ that restores cur_type and cur_exp ◁
  }
}
```

789. Now let's consider the *macro_call* procedure, which is used to start up all user-defined macros. Since the arguments to a macro might be expressions, *macro_call* is recursive.

The first parameter to *macro_call* points to the reference count of the token list that defines the macro. The second parameter contains any arguments that have already been parsed (see below). The third parameter points to the symbolic token that names the macro. If the third parameter is Λ, the macro was defined by **vardef**, so its name can be reconstructed from the prefix and "at" arguments found within the second parameter.

What is this second parameter? It's simply a linked list of symbolic items, whose *info* fields point to the arguments. In other words, if *arg_list* ← Λ, no arguments have been scanned yet; otherwise *mp_info*(*arg_list*) points to the first scanned argument, and *mp_link*(*arg_list*) points to the list of further arguments (if any).

Arguments of type **expr** are so-called capsules, which we will discuss later when we concentrate on expressions; they can be recognized easily because their *link* field is **void**. Arguments of type **suffix** and **text** are token lists without reference counts.

790. After argument scanning is complete, the arguments are moved to the *param_stack*. (They can't be put on that stack any sooner, because the stack is growing and shrinking in unpredictable ways as more arguments are being acquired.) Then the macro body is fed to the scanner; i.e., the replacement text of the macro is placed at the top of the METAPOST's input stack, so that *get_t_next* will proceed to read it next.

⟨ Declarations 10 ⟩ +≡

```
static void mp_macro_call(MP mp, mp_node def_ref, mp_node arg_list, mp_sym macro_name);
```

791. **void** *mp_macro_call*(**MP** *mp*, **mp_node** *def_ref*, **mp_node** *arg_list*, **mp_sym** *macro_name*)

```
{  ▷ invokes a user-defined control sequence ◁
  mp_node r;  ▷ current node in the macro's token list ◁
  mp_node p, q;  ▷ for list manipulation ◁
  integer n;  ▷ the number of arguments ◁
  mp_node tail ← 0;  ▷ tail of the argument list ◁
  mp_sym l_delim ← Λ, r_delim ← Λ;  ▷ a delimiter pair ◁
  r ← mp_link(def_ref); add_mac_ref(def_ref);
  if (arg_list ≡ Λ) {
    n ← 0;
  }
  else ⟨Determine the number n of arguments already supplied, and set tail to the tail of arg_list 797⟩
  if (number_positive(internal_value(mp_tracing_macros)))
    ⟨Show the text of the macro being expanded, and the existing arguments 792⟩
  ⟨Scan the remaining arguments, if any; set r to the first token of the replacement text 798⟩;
  ⟨Feed the arguments and replacement text to the scanner 810⟩;
}
```

792. ⟨Show the text of the macro being expanded, and the existing arguments 792⟩ ≡

```
{
  mp_begin_diagnostic(mp); mp_print_ln(mp); mp_print_macro_name(mp, arg_list, macro_name);
  if (n ≡ 3) mp_print(mp, "@#");  ▷ indicate a suffixed macro ◁
  mp_show_macro(mp, def_ref, Λ, 100000);
  if (arg_list ≠ Λ) {
    n ← 0; p ← arg_list;
    do {
      q ← (mp_node) mp_sym_sym(p); mp_print_arg(mp, q, n, 0, 0); incr(n); p ← mp_link(p);
    } while (p ≠ Λ);
  }
  mp_end_diagnostic(mp, false);
}
```

This code is used in section 791.

793. ⟨Declarations 10⟩ +≡

```
static void mp_print_macro_name(MP mp, mp_node a, mp_sym n);
```

794. **void** *mp_print_macro_name*(**MP** *mp*, **mp_node** *a*, **mp_sym** *n*)

```
{
  mp_node p, q;    ▷ they traverse the first part of a ◁
  if (n ≠ Λ) {
    mp_print_text(n);
  }
  else {
    p ← (mp_node) mp_sym_sym(a);
    if (p ≡ Λ) {
      mp_print_text(mp_sym_sym((mp_node) mp_sym_sym(mp_link(a))));
    }
    else {
      q ← p;
      while (mp_link(q) ≠ Λ) q ← mp_link(q);
      mp_link(q) ← (mp_node) mp_sym_sym(mp_link(a)); mp_show_token_list(mp, p, Λ, 1000, 0);
      mp_link(q) ← Λ;
    }
  }
}
```

795. ⟨ Declarations 10 ⟩ +≡

```
static void mp_print_arg(MP mp, mp_node q, integer n, halfword b, quarterword bb);
```

796. **void** *mp_print_arg*(**MP** *mp*, **mp_node** *q*, **integer** *n*, **halfword** *b*, **quarterword** *bb*)

```
{
  if (q ∧ mp_link(q) ≡ MP_VOID) {
    mp_print_nl(mp, "(EXPR");
  }
  else {
    if ((bb < mp_text_sym) ∧ (b ≠ mp_text_macro)) mp_print_nl(mp, "(SUFFIX");
    else mp_print_nl(mp, "(TEXT");
  }
  mp_print_int(mp, n); mp_print(mp, ")<-");
  if (q ∧ mp_link(q) ≡ MP_VOID) mp_print_exp(mp, q, 1);
  else mp_show_token_list(mp, q, Λ, 1000, 0);
}
```

797. ⟨ Determine the number *n* of arguments already supplied, and set *tail* to the tail of *arg_list* 797 ⟩ ≡

```
{
  n ← 1; tail ← arg_list;
  while (mp_link(tail) ≠ Λ) {
    incr(n); tail ← mp_link(tail);
  }
}
```

This code is used in section 791.

798. ⟨ Scan the remaining arguments, if any; set r to the first token of the replacement text 798 ⟩ ≡

```
set_cur_cmd(mp_comma + 1);   ▷ anything <> comma will do ◁
while (mp_name_type(r) ≡ mp_expr_sym ∨ mp_name_type(r) ≡ mp_suffix_sym ∨ mp_name_type(r) ≡
      mp_text_sym) {
   ⟨ Scan the delimited argument represented by mp_sym_info(r) 799 ⟩;
   r ← mp_link(r);
}
if (cur_cmd() ≡ mp_comma) {
   char msg[256];
   const char *hlp[] ← {"I'm␣going␣to␣assume␣that␣the␣comma␣I␣just␣read␣was␣a",
      "right␣delimiter,␣and␣then␣I'll␣begin␣expanding␣the␣macro.",
      "You␣might␣want␣to␣delete␣some␣tokens␣before␣continuing.", Λ};
   mp_string rname;
   int old_setting ← mp→selector;

   mp→selector ← new_string;  mp_print_macro_name(mp, arg_list, macro_name);
   rname ← mp_make_string(mp);  mp→selector ← old_setting;
   mp_snprintf(msg, 256, "Too␣many␣arguments␣to␣%s;␣Missing␣`%s'␣has␣been␣inserted",
      mp_str(mp, rname), mp_str(mp, text(r_delim)));  delete_str_ref(rname);
   mp_error(mp, msg, hlp, true);
}
if (mp_sym_info(r) ≠ mp_general_macro) ⟨ Scan undelimited argument(s) 807 ⟩
r ← mp_link(r)
```

This code is used in section 791.

799. At this point, the reader will find it advisable to review the explanation of token list format that was presented earlier, paying special attention to the conventions that apply only at the beginning of a macro's token list.

On the other hand, the reader will have to take the expression-parsing aspects of the following program on faith; we will explain *cur_type* and *cur_exp* later. (Several things in this program depend on each other, and it's necessary to jump into the circle somewhere.)

⟨ Scan the delimited argument represented by *mp_sym_info*(*r*) 799 ⟩ ≡

```
if (cur_cmd() ≠ mp_comma) {
  mp_get_x_next(mp);
  if (cur_cmd() ≠ mp_left_delimiter) {
    char msg[256];
    const char *hlp[] ← {"That macro has more parameters than you thought.",
        "I'll continue by pretending that each missing argument",
        "is either zero or null.", Λ};
    mp_string sname;
    int old_setting ← mp→selector;
    mp→selector ← new_string; mp_print_macro_name(mp, arg_list, macro_name);
    sname ← mp_make_string(mp); mp→selector ← old_setting;
    mp_snprintf(msg, 256, "Missing argument to %s", mp_str(mp, sname)); delete_str_ref(sname);
    if (mp_name_type(r) ≡ mp_suffix_sym ∨ mp_name_type(r) ≡ mp_text_sym) {
      set_cur_exp_value_number(zero_t);     ▷ TODO: this was Λ ◁
      mp→cur_exp.type ← mp_token_list;
    }
    else {
      set_cur_exp_value_number(zero_t); mp→cur_exp.type ← mp_known;
    }
    mp_back_error(mp, msg, hlp, true); set_cur_cmd((mp_variable_type) mp_right_delimiter);
    goto FOUND;
  }
  l_delim ← cur_sym(); r_delim ← equiv_sym(cur_sym());
}
⟨ Scan the argument represented by mp_sym_info(r) 802 ⟩;
if (cur_cmd() ≠ mp_comma) ⟨ Check that the proper right delimiter was present 800 ⟩
FOUND: ⟨ Append the current expression to arg_list 801 ⟩
```

This code is used in section 798.

800. ⟨ Check that the proper right delimiter was present 800 ⟩ ≡

```
if ((cur_cmd() ≠ mp_right_delimiter) ∨ (equiv_sym(cur_sym()) ≠ l_delim)) {
  if (mp_name_type(mp_link(r)) ≡ mp_expr_sym ∨ mp_name_type(mp_link(r)) ≡
        mp_suffix_sym ∨ mp_name_type(mp_link(r)) ≡ mp_text_sym) {
    const char *hlp[] ← {"I've finished reading a macro argument and am about to",
        "read another; the arguments weren't delimited correctly.",
        "You might want to delete some tokens before continuing.", Λ};
    mp_back_error(mp, "Missing ',' has been inserted", hlp, true);
    set_cur_cmd((mp_variable_type) mp_comma);
  }
  else {
    char msg[256];
    const char *hlp[] ← {"I've gotten to the end of the macro parameter list.",
        "You might want to delete some tokens before continuing.", Λ};
    mp_snprintf(msg, 256, "Missing '%s' has been inserted", mp_str(mp, text(r_delim)));
    mp_back_error(mp, msg, hlp, true);
  }
}
```

This code is used in section 799.

801. A **suffix** or **text** parameter will have been scanned as a token list pointed to by *cur_exp*, in which case we will have *cur_type* ← *token_list*.

⟨ Append the current expression to *arg_list* 801 ⟩ ≡

```
{
  p ← mp_get_symbolic_node(mp);
  if (mp→cur_exp.type ≡ mp_token_list) set_mp_sym_sym(p, mp→cur_exp.data.node);
  else set_mp_sym_sym(p, mp_stash_cur_exp(mp));
  if (number_positive(internal_value(mp_tracing_macros))) {
    mp_begin_diagnostic(mp);
    mp_print_arg(mp, (mp_node) mp_sym_sym(p), n, mp_sym_info(r), mp_name_type(r));
    mp_end_diagnostic(mp, false);
  }
  if (arg_list ≡ Λ) {
    arg_list ← p;
  }
  else {
    mp_link(tail) ← p;
  }
  tail ← p; incr(n);
}
```

This code is used in sections 799 and 807.

802. ⟨ Scan the argument represented by *mp_sym_info*(*r*) 802 ⟩ ≡

```
if (mp_name_type(r) ≡ mp_text_sym) {
  mp_scan_text_arg(mp, l_delim, r_delim);
}
else {
  mp_get_x_next(mp);
  if (mp_name_type(r) ≡ mp_suffix_sym) mp_scan_suffix(mp);
  else mp_scan_expression(mp);
}
```

This code is used in section 799.

803. The parameters to *scan_text_arg* are either a pair of delimiters or zero; the latter case is for undelimited text arguments, which end with the first semicolon or **endgroup** or **end** that is not contained in a group.

⟨ Declarations 10 ⟩ +≡

```
static void mp_scan_text_arg(MP mp, mp_sym l_delim, mp_sym r_delim);
```

804.

```
void mp_scan_text_arg(MP mp, mp_sym l_delim, mp_sym r_delim)
{
  integer balance;    ▷ excess of l_delim over r_delim ◁
  mp_node p;    ▷ list tail ◁
  mp→warning_info ← l_delim; mp→scanner_status ← absorbing; p ← mp→hold_head; balance ← 1;
  mp_link(mp→hold_head) ← Λ;
  while (1) {
    get_t_next(mp);
    if (l_delim ≡ Λ) ⟨ Adjust the balance for an undelimited argument; break if done 806 ⟩
    else ⟨ Adjust the balance for a delimited argument; break if done 805 ⟩
    mp_link(p) ← mp_cur_tok(mp); p ← mp_link(p);
  }
  set_cur_exp_node(mp_link(mp→hold_head)); mp→cur_exp.type ← mp_token_list;
  mp→scanner_status ← normal;
}
```

805. ⟨ Adjust the balance for a delimited argument; **break** if done 805 ⟩ ≡

```
{
  if (cur_cmd() ≡ mp_right_delimiter) {
    if (equiv_sym(cur_sym()) ≡ l_delim) {
      decr(balance);
      if (balance ≡ 0) break;
    }
  }
  else if (cur_cmd() ≡ mp_left_delimiter) {
    if (equiv_sym(cur_sym()) ≡ r_delim) incr(balance);
  }
}
```

This code is used in section 804.

806. ⟨ Adjust the balance for an undelimited argument; **break** if done 806 ⟩ ≡

```
{
  if (mp_end_of_statement) {    ▷ cur_cmd ← semicolon, end_group, or stop ◁
    if (balance ≡ 1) {
      break;
    }
    else {
      if (cur_cmd() ≡ mp_end_group) decr(balance);
    }
  }
  else if (cur_cmd() ≡ mp_begin_group) {
    incr(balance);
  }
}
```

This code is used in section 804.

807. ⟨ Scan undelimited argument(s) 807 ⟩ ≡

```
{
  if (mp_sym_info(r) < mp_text_macro) {
    mp_get_x_next(mp);
    if (mp_sym_info(r) ≠ mp_suffix_macro) {
      if ((cur_cmd() ≡ mp_equals) ∨ (cur_cmd() ≡ mp_assignment)) mp_get_x_next(mp);
    }
  }
  switch (mp_sym_info(r)) {
  case mp_primary_macro: mp_scan_primary(mp); break;
  case mp_secondary_macro: mp_scan_secondary(mp); break;
  case mp_tertiary_macro: mp_scan_tertiary(mp); break;
  case mp_expr_macro: mp_scan_expression(mp); break;
  case mp_of_macro: ⟨ Scan an expression followed by ‘of ⟨primary⟩’ 808 ⟩;
    break;
  case mp_suffix_macro: ⟨ Scan a suffix with optional delimiters 809 ⟩;
    break;
  case mp_text_macro: mp_scan_text_arg(mp, Λ, Λ); break;
  }    ▷ there are no other cases ◁
  mp_back_input(mp); ⟨ Append the current expression to arg_list 801 ⟩;
}
```

This code is used in section 798.

808. ⟨ Scan an expression followed by '**of** ⟨primary⟩' 808 ⟩ ≡

```
{
  mp_scan_expression(mp); p ← mp_get_symbolic_node(mp); set_mp_sym_sym(p, mp_stash_cur_exp(mp));
  if (number_positive(internal_value(mp_tracing_macros))) {
    mp_begin_diagnostic(mp); mp_print_arg(mp, (mp_node) mp_sym_sym(p), n, 0, 0);
    mp_end_diagnostic(mp, false);
  }
  if (arg_list ≡ Λ) arg_list ← p;
  else mp_link(tail) ← p;
  tail ← p; incr(n);
  if (cur_cmd() ≠ mp_of_token) {
    char msg[256];
    mp_string sname;
    const char *hlp[] ← {"I've␣got␣the␣first␣argument;␣will␣look␣now␣for␣the␣other.", Λ};
    int old_setting ← mp→selector;

    mp→selector ← new_string; mp_print_macro_name(mp, arg_list, macro_name);
    sname ← mp_make_string(mp); mp→selector ← old_setting;
    mp_snprintf(msg, 256, "Missing␣'of'␣has␣been␣inserted␣for␣%s", mp_str(mp, sname));
    delete_str_ref(sname); mp_back_error(mp, msg, hlp, true);
  }
  mp_get_x_next(mp); mp_scan_primary(mp);
}
```

This code is used in section 807.

809. ⟨ Scan a suffix with optional delimiters 809 ⟩ ≡

```
{
  if (cur_cmd() ≠ mp_left_delimiter) {
    l_delim ← Λ;
  }
  else {
    l_delim ← cur_sym(); r_delim ← equiv_sym(cur_sym()); mp_get_x_next(mp);
  }
  mp_scan_suffix(mp);
  if (l_delim ≠ Λ) {
    if ((cur_cmd() ≠ mp_right_delimiter) ∨ (equiv_sym(cur_sym()) ≠ l_delim)) {
      char msg[256];
      const char *hlp[] ← {"I've␣gotten␣to␣the␣end␣of␣the␣macro␣parameter␣list.",
          "You␣might␣want␣to␣delete␣some␣tokens␣before␣continuing.", Λ};

      mp_snprintf(msg, 256, "Missing␣'%s'␣has␣been␣inserted", mp_str(mp, text(r_delim)));
      mp_back_error(mp, msg, hlp, true);
    }
    mp_get_x_next(mp);
  }
}
```

This code is used in section 807.

810. Before we put a new token list on the input stack, it is wise to clean off all token lists that have recently been depleted. Then a user macro that ends with a call to itself will not require unbounded stack space.

⟨ Feed the arguments and replacement text to the scanner 810 ⟩ ≡

```
while (token_state ∧ (nloc ≡ Λ)) mp_end_token_list(mp);   ▷ conserve stack space ◁
if (mp→param_ptr + n > mp→max_param_stack) {
  mp→max_param_stack ← mp→param_ptr + n;  mp_check_param_size(mp, mp→max_param_stack);
}
mp_begin_token_list(mp, def_ref, (quarterword) macro);
if (macro_name) name ← text(macro_name);
else name ← Λ;
nloc ← r;
if (n > 0) {
  p ← arg_list;
  do {
    mp→param_stack[mp→param_ptr] ← (mp_node) mp_sym_sym(p);  incr(mp→param_ptr);
    p ← mp_link(p);
  } while (p ≠ Λ);
  mp_flush_node_list(mp, arg_list);
}
```

This code is used in section 791.

811. It's sometimes necessary to put a single argument onto *param_stack*. The *stack_argument* subroutine does this.

```
static void mp_stack_argument(MP mp, mp_node p)
{
  if (mp→param_ptr ≡ mp→max_param_stack) {
    incr(mp→max_param_stack);  mp_check_param_size(mp, mp→max_param_stack);
  }
  mp→param_stack[mp→param_ptr] ← p;  incr(mp→param_ptr);
}
```

812. Conditional processing. Let's consider now the way **if** commands are handled.

Conditions can be inside conditions, and this nesting has a stack that is independent of other stacks. Four global variables represent the top of the condition stack: *cond_ptr* points to pushed-down entries, if any; *cur_if* tells whether we are processing **if** or **elseif**; *if_limit* specifies the largest code of a *fi_or_else* command that is syntactically legal; and *if_line* is the line number at which the current conditional began.

If no conditions are currently in progress, the condition stack has the special state *cond_ptr* $\leftarrow \Lambda$, *if_limit* $\leftarrow$ *normal*, *cur_if* $\leftarrow 0$, *if_line* $\leftarrow 0$. Otherwise *cond_ptr* points to a non-symbolic node; the *type*, *name_type*, and *link* fields of the first word contain *if_limit*, *cur_if*, and *cond_ptr* at the next level, and the second word contains the corresponding *if_line*.

```
#define if_line_field(A) ((mp_if_node)(A))→if_line_field_
#define if_code 1   ▷ code for if being evaluated ◁
#define fi_code 2   ▷ code for fi ◁
#define else_code 3   ▷ code for else ◁
#define else_if_code 4   ▷ code for elseif ◁
```

⟨ MPlib internal header stuff 8 ⟩ +≡

```
typedef struct mp_if_node_data {
  NODE_BODY;
  int if_line_field_;
} mp_if_node_data;
typedef struct mp_if_node_data *mp_if_node;
```

813.

```
#define if_node_size sizeof(struct mp_if_node_data)
        ▷ number of words in stack entry for conditionals ◁

static mp_node mp_get_if_node(MP mp)
{
  mp_if_node p ← (mp_if_node) malloc_node(if_node_size);
  mp_type(p) ← mp_if_node_type; return (mp_node) p;
}
```

814. ⟨ Global variables 18 ⟩ +≡

```
mp_node cond_ptr;   ▷ top of the condition stack ◁
integer if_limit;   ▷ upper bound on fi_or_else codes ◁
quarterword cur_if;   ▷ type of conditional being worked on ◁
integer if_line;   ▷ line where that conditional began ◁
```

815. ⟨ Set initial values of key variables 42 ⟩ +≡

```
mp→cond_ptr ← Λ; mp→if_limit ← normal; mp→cur_if ← 0; mp→if_line ← 0;
```

816. ⟨ Put each of METAPOST's primitives into the hash table 204 ⟩ +≡

```
mp_primitive(mp, "if", mp_if_test, if_code); mp_primitive(mp, "fi", mp_fi_or_else, fi_code);
mp→frozen_fi ← mp_frozen_primitive(mp, "fi", mp_fi_or_else, fi_code);
mp_primitive(mp, "else", mp_fi_or_else, else_code);
mp_primitive(mp, "elseif", mp_fi_or_else, else_if_code);
```

817. ⟨ Cases of *print_cmd_mod* for symbolic printing of primitives 239 ⟩ +≡

```
case mp_if_test: case mp_fi_or_else:
  switch (m) {
  case if_code: mp_print(mp, "if"); break;
  case fi_code: mp_print(mp, "fi"); break;
  case else_code: mp_print(mp, "else"); break;
  default: mp_print(mp, "elseif"); break;
  }
  break;
```

818. Here is a procedure that ignores text until coming to an **elseif**, **else**, or **fi** at level zero of **if** ... **fi** nesting. After it has acted, *cur_mod* will indicate the token that was found.

METAPOST's smallest two command codes are *if_test* and *fi_or_else*; this makes the skipping process a bit simpler.

```
void mp_pass_text(MP mp)
{
  integer l ← 0;
  mp→scanner_status ← skipping; mp→warning_line ← mp_true_line(mp);
  while (1) {
    get_t_next(mp);
    if (cur_cmd() ≤ mp_fi_or_else) {
      if (cur_cmd() < mp_fi_or_else) {
        incr(l);
      }
      else {
        if (l ≡ 0) break;
        if (cur_mod() ≡ fi_code) decr(l);
      }
    }
    else ⟨ Decrease the string reference count, if the current token is a string 819 ⟩
  }
  mp→scanner_status ← normal;
}
```

819. ⟨ Decrease the string reference count, if the current token is a string 819 ⟩ ≡

```
  if (cur_cmd() ≡ mp_string_token) {
    delete_str_ref(cur_mod_str());
  }
```

This code is used in sections 133, 818, and 1052.

820. When we begin to process a new **if**, we set *if_limit*: ← *if_code*; then if **elseif** or **else** or **fi** occurs before the current **if** condition has been evaluated, a colon will be inserted. A construction like '`if fi`' would otherwise get METAPOST confused.

⟨ Push the condition stack 820 ⟩ ≡

```
  {
    p ← mp_get_if_node(mp); mp_link(p) ← mp→cond_ptr; mp_type(p) ← (quarterword) mp→if_limit;
    mp_name_type(p) ← mp→cur_if; if_line_field(p) ← mp→if_line; mp→cond_ptr ← p;
    mp→if_limit ← if_code; mp→if_line ← mp_true_line(mp); mp→cur_if ← if_code;
  }
```

This code is used in section 824.

821. ⟨ Pop the condition stack 821 ⟩ ≡

```
{
  mp_node p ← mp→cond_ptr;
  mp→if_line ← if_line_field(p); mp→cur_if ← mp_name_type(p); mp→if_limit ← mp_type(p);
  mp→cond_ptr ← mp_link(p); mp_free_node(mp, p, if_node_size);
}
```

This code is used in sections 824, 825, and 827.

822. Here's a procedure that changes the *if_limit* code corresponding to a given value of *cond_ptr*.

```
static void mp_change_if_limit(MP mp, quarterword l, mp_node p)
{
  mp_node q;
  if (p ≡ mp→cond_ptr) {
    mp→if_limit ← l;    ▷ that's the easy case ◁
  }
  else {
    q ← mp→cond_ptr;
    while (1) {
      if (q ≡ Λ) mp_confusion(mp, "if");    ▷ clang: dereference of null pointer ◁
      assert(q);
      if (mp_link(q) ≡ p) {
        mp_type(q) ← l; return;
      }
      q ← mp_link(q);
    }
  }
}
```

823. The user is supposed to put colons into the proper parts of conditional statements. Therefore, METAPOST has to check for their presence.

```
static void mp_check_colon(MP mp)
{
  if (cur_cmd() ≠ mp_colon) {
    const char *hlp[] ← {"There␣should've␣been␣a␣colon␣after␣the␣condition.",
        "I␣shall␣pretend␣that␣one␣was␣there.", Λ};
    mp_back_error(mp, "Missing␣':'␣has␣been␣inserted", hlp, true);
  }
}
```

824. A condition is started when the *get_x_next* procedure encounters an *if_test* command; in that case *get_x_next* calls *conditional*, which is a recursive procedure.

```
void mp_conditional(MP mp)
{
  mp_node save_cond_ptr;   ▷ cond_ptr corresponding to this conditional ◁
  int new_if_limit;   ▷ future value of if_limit ◁
  mp_node p;   ▷ temporary register ◁
  ⟨Push the condition stack 820⟩;
  save_cond_ptr ← mp→cond_ptr;
RESWITCH: mp_get_boolean(mp); new_if_limit ← else_if_code;
  if (number_greater(internal_value(mp_tracing_commands), unity_t)) {
    ⟨Display the boolean value of cur_exp 826⟩;
  }
FOUND: mp_check_colon(mp);
  if (cur_exp_value_boolean() ≡ mp_true_code) {
    mp_change_if_limit(mp, (quarterword) new_if_limit, save_cond_ptr); return;
      ▷ wait for elseif, else, or fi ◁
  }
  ⟨Skip to elseif or else or fi, then goto done 825⟩;
DONE: mp→cur_if ← (quarterword) cur_mod(); mp→if_line ← mp_true_line(mp);
  if (cur_mod() ≡ fi_code) {⟨Pop the condition stack 821⟩}
  else if (cur_mod() ≡ else_if_code) {
    goto RESWITCH;
  }
  else {
    set_cur_exp_value_boolean(mp_true_code); new_if_limit ← fi_code; mp_get_x_next(mp); goto FOUND;
  }
}
```

825. In a construction like '**if if true**: 0 = 1: *foo* **else**: *bar* **fi**', the first **else** that we come to after learning that the **if** is false is not the **else** we're looking for. Hence the following curious logic is needed.

```
⟨Skip to elseif or else or fi, then goto done 825⟩ ≡
  while (1) {
    mp_pass_text(mp);
    if (mp→cond_ptr ≡ save_cond_ptr) goto DONE;
    else if (cur_mod() ≡ fi_code) ⟨Pop the condition stack 821⟩;
  }
```

This code is used in section 824.

826. ⟨Display the boolean value of *cur_exp* 826⟩ ≡

```
  {
    mp_begin_diagnostic(mp);
    if (cur_exp_value_boolean() ≡ mp_true_code) mp_print(mp, "{true}");
    else mp_print(mp, "{false}");
    mp_end_diagnostic(mp, false);
  }
```

This code is used in section 824.

827. The processing of conditionals is complete except for the following code, which is actually part of *get_x_next*. It comes into play when **elseif**, **else**, or **fi** is scanned.

⟨ Terminate the current conditional and skip to **fi** 827 ⟩ ≡

```
if (cur_mod() > mp→if_limit) {
  if (mp→if_limit ≡ if_code) {    ▷ condition not yet evaluated ◁
    const char *hlp[] ← {"Something␣was␣missing␣here", Λ};
    mp_back_input(mp); set_cur_sym(mp→frozen_colon);
    mp_ins_error(mp, "Missing␣`:'␣has␣been␣inserted", hlp, true);
  }
  else {
    const char *hlp[] ← {"I'm␣ignoring␣this;␣it␣doesn't␣match␣any␣if.", Λ};
    if (cur_mod() ≡ fi_code) {
      mp_error(mp, "Extra␣fi", hlp, true);
    }
    else if (cur_mod() ≡ else_code) {
      mp_error(mp, "Extra␣else", hlp, true);
    }
    else {
      mp_error(mp, "Extra␣elseif", hlp, true);
    }
  }
}
else {
  while (cur_mod() ≠ fi_code) mp_pass_text(mp);    ▷ skip to fi ◁
  ⟨ Pop the condition stack 821 ⟩;
}
```

This code is used in section 772.

828. Iterations. To bring our treatment of *get_x_next* to a close, we need to consider what METAPOST does when it sees **for**, **forsuffixes**, and **forever**.

There's a global variable *loop_ptr* that keeps track of the **for** loops that are currently active. If *loop_ptr* $\leftarrow \Lambda$, no loops are in progress; otherwise *loop_ptr.info* points to the iterative text of the current (innermost) loop, and *loop_ptr.link* points to the data for any other loops that enclose the current one.

A loop-control node also has two other fields, called *type* and *list*, whose contents depend on the type of loop:

loop_ptr.type $\leftarrow \Lambda$ means that the link of *loop_ptr.list* points to a list of symbolic nodes whose *info* fields point to the remaining argument values of a suffix list and expression list. In this case, an extra field *loop_ptr.start_list* is needed to make sure that *resume_operation* skips ahead.

loop_ptr.type $\leftarrow$ `MP_VOID` means that the current loop is '**forever**'.

loop_ptr.type $\leftarrow$ `PROGRESSION_FLAG` means that *loop_ptr.value*, *loop_ptr.step_size*, and *loop_ptr.final_value* contain the data for an arithmetic progression.

loop_ptr.type $\leftarrow p >$ `PROGRESSION_FLAG` means that p points to an edge header and *loop_ptr.list* points into the graphical object list for that edge header.

#**define** `PROGRESSION_FLAG` (**mp_node**)(2) ▷ $\Lambda + 2$ ◁
▷ *loop_type* value when *loop_list* points to a progression node ◁

⟨ Types in the outer block 37 ⟩ +≡
typedef struct mp_loop_data {
  mp_sym *var*; ▷ the var of the loop ◁
  mp_node *info*; ▷ iterative text of this loop ◁
  mp_node *type*; ▷ the special type of this loop, or a pointer into mem ◁
  mp_node *list*; ▷ the remaining list elements ◁
  mp_node *list_start*; ▷ head of the list of elements ◁
  mp_number *old_value*; ▷ previous value of current arithmetic value ◁
  mp_number *value*; ▷ current arithmetic value ◁
  mp_number *step_size*; ▷ arithmetic step size ◁
  mp_number *final_value*; ▷ end arithmetic value ◁
  struct mp_loop_data ∗*link*; ▷ the enclosing loop, if any ◁
} **mp_loop_data**;

829. ⟨ Global variables 18 ⟩ +≡
mp_loop_data ∗*loop_ptr*; ▷ top of the loop-control-node stack ◁

830. ⟨ Set initial values of key variables 42 ⟩ +≡
mp→loop_ptr $\leftarrow \Lambda$;

831. If the expressions that define an arithmetic progression in a **for** loop don't have known numeric values, the *bad_for* subroutine screams at the user.

```
static void mp_bad_for(MP mp, const char *s)
{
  char msg[256];
  mp_value new_expr;
  const char *hlp[] ← {"When␣you␣say␣'for␣x=a␣step␣b␣until␣c',",
      "the␣initial␣value␣'a'␣and␣the␣step␣size␣'b'",
      "and␣the␣final␣value␣'c'␣must␣have␣known␣numeric␣values.",
      "I'm␣zeroing␣this␣one.␣Proceed,␣with␣fingers␣crossed.", Λ};
  memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n); mp_disp_err(mp, Λ);
    ▷ show the bad expression above the message ◁
  mp_snprintf(msg, 256, "Improper␣%s␣has␣been␣replaced␣by␣0", s);
  mp_back_error(mp, msg, hlp, true); mp_get_x_next(mp); mp_flush_cur_exp(mp, new_expr);
}
```

832. Here's what METAPOST does when **for**, **forsuffixes**, or **forever** has just been scanned. (This code requires slight familiarity with expression-parsing routines that we have not yet discussed; but it seems to belong in the present part of the program, even though the original author didn't write it until later. The reader may wish to come back to it.)

```
void mp_begin_iteration(MP mp)
{
  halfword m;    ▷ start_for (for) or start_forsuffixes (forsuffixes) ◁
  mp_sym n;    ▷ hash address of the current symbol ◁
  mp_loop_data *s;    ▷ the new loop-control node ◁
  mp_subst_list_item *p ← Λ;    ▷ substitution list for scan_toks ◁
  mp_node q;    ▷ link manipulation register ◁

  m ← cur_mod(); n ← cur_sym(); s ← xmalloc(1, sizeof(mp_loop_data));
  s→type ← s→list ← s→info ← s→list_start ← Λ; s→link ← Λ; s→var ← Λ; new_number(s→value);
  new_number(s→old_value); new_number(s→step_size); new_number(s→final_value);
  if (m ≡ start_forever) {
    s→type ← MP_VOID; p ← Λ; mp_get_x_next(mp);
  }
  else {
    mp_get_symbol(mp); p ← xmalloc(1, sizeof(mp_subst_list_item)); p→link ← Λ;
    p→info ← cur_sym(); s→var ← cur_sym(); p→info_mod ← cur_sym_mod(); p→value_data ← 0;
    if (m ≡ start_for) {
      p→value_mod ← mp_expr_sym;
    }
    else {    ▷ start_forsuffixes ◁
      p→value_mod ← mp_suffix_sym;
    }
    mp_get_x_next(mp);
    if (p→value_mod ≡ mp_expr_sym ∧ cur_cmd() ≡ mp_within_token) ⟨Set up a picture iteration 844⟩
    else {
      ⟨Check for the assignment in a loop header 833⟩;
      ⟨Scan the values to be used in the loop 842⟩;
    }
  }
  ⟨Check for the presence of a colon 834⟩;
  ⟨Scan the loop text and put it on the loop control stack 835⟩;
  mp_resume_iteration(mp);
}
```

833. ⟨Check for the assignment in a loop header 833⟩ ≡

```
if ((cur_cmd() ≠ mp_equals) ∧ (cur_cmd() ≠ mp_assignment)) {
  const char *hlp[] ← {"The next thing in this loop should have been '=' or ':='.",
      "But don't worry; I'll pretend that an equals sign",
      "was present, and I'll look for the values next.", Λ};
  mp_back_error(mp, "Missing '=' has been inserted", hlp, true);
}
```

This code is used in section 832.

834. ⟨ Check for the presence of a colon 834 ⟩ ≡

if $(cur\_cmd() \neq mp\_colon)$ {
  const char $*hlp[] \leftarrow$ {"The␣next␣thing␣in␣this␣loop␣should␣have␣been␣a␣':'.",
    "So␣I'll␣pretend␣that␣a␣colon␣was␣present;",
    "everything␣from␣here␣to␣'endfor'␣will␣be␣iterated.", Λ};
  mp_back_error(*mp*, "Missing␣':'␣has␣been␣inserted", *hlp*, *true*);
}

This code is used in section 832.

835. We append a special *mp→frozen_repeat_loop* token in place of the '**endfor**' at the end of the loop. This will come through METAPOST's scanner at the proper time to cause the loop to be repeated.

(If the user tries some shenanigan like '**for** ... **let endfor**', he will be foiled by the *get_symbol* routine, which keeps frozen tokens unchanged. Furthermore the *mp→frozen_repeat_loop* is an **outer** token, so it won't be lost accidentally.)

⟨ Scan the loop text and put it on the loop control stack 835 ⟩ ≡

$q \leftarrow$ *mp_get_symbolic_node*(*mp*); *set_mp_sym_sym*(*q*, *mp→frozen_repeat_loop*);
mp→scanner_status ← *loop_defining*; *mp→warning_info* ← *n*;
s→info ← *mp_scan_toks*(*mp*, *mp_iteration*, *p*, *q*, 0); *mp→scanner_status* ← *normal*; *s→link* ← *mp→loop_ptr*;
mp→loop_ptr ← *s*

This code is used in section 832.

836. ⟨ Initialize table entries 186 ⟩ +≡

mp→frozen_repeat_loop ← *mp_frozen_primitive*(*mp*, "␣ENDFOR", *mp_repeat_loop* + *mp_outer_tag*, 0);

837. The loop text is inserted into METAPOST's scanning apparatus by the *resume_iteration* routine.

```
void mp_resume_iteration(MP mp)
{
  mp_node p, q;   ▷ link registers ◁
  p ← mp→loop_ptr→type;
  if (p ≡ PROGRESSION_FLAG) {
    set_cur_exp_value_number(mp→loop_ptr→value);
    if (⟨The arithmetic progression has ended 838⟩) {
      mp_stop_iteration(mp); return;
    }
    mp→cur_exp.type ← mp_known; q ← mp_stash_cur_exp(mp);   ▷ make q an expr argument ◁
    number_clone(mp→loop_ptr→old_value, cur_exp_value_number());
    set_number_from_addition(mp→loop_ptr→value, cur_exp_value_number(), mp→loop_ptr→step_size);
      ▷ set value(p) for the next iteration ◁   ▷ detect numeric overflow ◁
    if (number_positive(mp→loop_ptr→step_size)∧number_less(mp→loop_ptr→value, cur_exp_value_number()))
      {
      if (number_positive(mp→loop_ptr→final_value)) {
        number_clone(mp→loop_ptr→value, mp→loop_ptr→final_value);
        number_add_scaled(mp→loop_ptr→final_value, −1);
      }
      else {
        number_clone(mp→loop_ptr→value, mp→loop_ptr→final_value);
        number_add_scaled(mp→loop_ptr→value, 1);
      }
    }
    else if (number_negative(mp→loop_ptr→step_size) ∧ number_greater(mp→loop_ptr→value,
          cur_exp_value_number())) {
      if (number_negative(mp→loop_ptr→final_value)) {
        number_clone(mp→loop_ptr→value, mp→loop_ptr→final_value);
        number_add_scaled(mp→loop_ptr→final_value, 1);
      }
      else {
        number_clone(mp→loop_ptr→value, mp→loop_ptr→final_value);
        number_add_scaled(mp→loop_ptr→value, −1);
      }
    }
  }
  else if (p ≡ Λ) {
    p ← mp→loop_ptr→list;
    if (p ≠ Λ ∧ p ≡ mp→loop_ptr→list_start) {
      q ← p; p ← mp_link(p); mp_free_symbolic_node(mp, q); mp→loop_ptr→list ← p;
    }
    if (p ≡ Λ) {
      mp_stop_iteration(mp); return;
    }
    mp→loop_ptr→list ← mp_link(p); q ← (mp_node) mp_sym_sym(p);
    if (q) number_clone(mp→loop_ptr→old_value, q→data.n);
    mp_free_symbolic_node(mp, p);
  }
  else if (p ≡ MP_VOID) {
    mp_begin_token_list(mp, mp→loop_ptr→info, (quarterword) forever_text); return;
  }
```

```
    else ⟨Make q a capsule containing the next picture component from loop_list(loop_ptr) or goto
            not_found 840⟩
    mp_begin_token_list(mp, mp→loop_ptr→info, (quarterword) loop_text);  mp_stack_argument(mp, q);
    if (number_greater(internal_value(mp_tracing_commands), unity_t)) {
      ⟨Trace the start of a loop 839⟩;
    }
    return;
  NOT_FOUND: mp_stop_iteration(mp);
  }
```

838. ⟨The arithmetic progression has ended 838⟩ ≡

```
  (number_positive(mp→loop_ptr→step_size) ∧ number_greater(cur_exp_value_number( ),
      mp→loop_ptr→final_value)) ∨ (number_negative(mp→loop_ptr→step_size) ∧
      number_less(cur_exp_value_number( ), mp→loop_ptr→final_value))
```

This code is used in section 837.

839. ⟨Trace the start of a loop 839⟩ ≡

```
  {
    mp_begin_diagnostic(mp);  mp_print_nl(mp, "{loop␣value=");
    if ((q ≠ Λ) ∧ (mp_link(q) ≡ MP_VOID)) mp_print_exp(mp, q, 1);
    else mp_show_token_list(mp, q, Λ, 50, 0);
    mp_print_char(mp, xord('}'));  mp_end_diagnostic(mp, false);
  }
```

This code is used in section 837.

840. ⟨Make q a capsule containing the next picture component from *loop_list*(*loop_ptr*) or **goto** *not_found* 840⟩ ≡

```
  {
    q ← mp→loop_ptr→list;
    if (q ≡ Λ) goto NOT_FOUND;
    if (¬is_start_or_stop(q)) q ← mp_link(q);
    else if (¬is_stop(q)) q ← mp_skip_1component(mp, q);
    else goto NOT_FOUND;
    set_cur_exp_node((mp_node) mp_copy_objects(mp, mp→loop_ptr→list, q));
    mp_init_bbox(mp, (mp_edge_header_node) cur_exp_node( ));  mp→cur_exp.type ← mp_picture_type;
    mp→loop_ptr→list ← q;  q ← mp_stash_cur_exp(mp);
  }
```

This code is used in section 837.

841. A level of loop control disappears when *resume_iteration* has decided not to resume, or when an **exitif** construction has removed the loop text from the input stack.

```
void mp_stop_iteration(MP mp)
{
   mp_node p, q;   ▷ the usual ◁
   mp_loop_data *tmp;   ▷ for free() ◁
   p ← mp→loop_ptr→type;
   if (p ≡ PROGRESSION_FLAG) {
      mp_free_symbolic_node(mp, mp→loop_ptr→list);
   }
   else if (p ≡ Λ) {
      q ← mp→loop_ptr→list;
      while (q ≠ Λ) {
         p ← (mp_node) mp_sym_sym(q);
         if (p ≠ Λ) {
            if (mp_link(p) ≡ MP_VOID) {   ▷ it's an expr parameter ◁
               mp_recycle_value(mp, p); mp_free_value_node(mp, p);
            }
            else {
               mp_flush_token_list(mp, p);   ▷ it's a suffix or text parameter ◁
            }
         }
         p ← q; q ← mp_link(q); mp_free_symbolic_node(mp, p);
      }
   }
   else if (p > PROGRESSION_FLAG) {
      delete_edge_ref(p);
   }
   tmp ← mp→loop_ptr; mp→loop_ptr ← tmp→link; mp_flush_token_list(mp, tmp→info);
   free_number(tmp→value); free_number(tmp→step_size); free_number(tmp→final_value); xfree(tmp);
}
```

842. Now that we know all about loop control, we can finish up the missing portion of *begin_iteration* and we'll be done.

The following code is performed after the '=' has been scanned in a **for** construction (if $m \leftarrow start\_for$) or a **forsuffixes** construction (if $m \leftarrow start\_forsuffixes$).

⟨ Scan the values to be used in the loop 842 ⟩ ≡

```
s→type ← Λ; s→list ← mp_get_symbolic_node(mp); s→list_start ← s→list; q ← s→list;
do {
  mp_get_x_next(mp);
  if (m ≠ start_for) {
    mp_scan_suffix(mp);
  }
  else {
    if (cur_cmd() ≥ mp_colon)
      if (cur_cmd() ≤ mp_comma) goto CONTINUE;
    mp_scan_expression(mp);
    if (cur_cmd() ≡ mp_step_token)
      if (q ≡ s→list) {
        ⟨ Prepare for step-until construction and break 843 ⟩;
      }
    set_cur_exp_node(mp_stash_cur_exp(mp));
  }
  mp_link(q) ← mp_get_symbolic_node(mp); q ← mp_link(q);
  set_mp_sym_sym(q, mp→cur_exp.data.node);
  if (m ≡ start_for) mp_name_type(q) ← mp_expr_sym;
  else if (m ≡ start_forsuffixes) mp_name_type(q) ← mp_suffix_sym;
  mp→cur_exp.type ← mp_vacuous;
CONTINUE: ;
} while (cur_cmd() ≡ mp_comma)
```

This code is used in section 832.

843. ⟨ Prepare for step-until construction and **break** 843 ⟩ ≡

```
{
  if (mp→cur_exp.type ≠ mp_known) mp_bad_for(mp, "initial␣value");
  number_clone(s→value, cur_exp_value_number()); number_clone(s→old_value, cur_exp_value_number());
  mp_get_x_next(mp); mp_scan_expression(mp);
  if (mp→cur_exp.type ≠ mp_known) mp_bad_for(mp, "step␣size");
  number_clone(s→step_size, cur_exp_value_number());
  if (cur_cmd() ≠ mp_until_token) {
    const char *hlp[] ← {"I␣assume␣you␣meant␣to␣say␣‘until’␣after␣‘step’.",
        "So␣I’ll␣look␣for␣the␣final␣value␣and␣colon␣next.", Λ};
    mp_back_error(mp, "Missing␣‘until’␣has␣been␣inserted", hlp, true);
  }
  mp_get_x_next(mp); mp_scan_expression(mp);
  if (mp→cur_exp.type ≠ mp_known) mp_bad_for(mp, "final␣value");
  number_clone(s→final_value, cur_exp_value_number()); s→type ← PROGRESSION_FLAG; break;
}
```

This code is used in section 842.

844. The last case is when we have just seen "**within**", and we need to parse a picture expression and prepare to iterate over it.

⟨ Set up a picture iteration 844 ⟩ ≡

```
{
  mp_get_x_next(mp); mp_scan_expression(mp);
  ⟨ Make sure the current expression is a known picture 845 ⟩;
  s→type ← mp→cur_exp.data.node; mp→cur_exp.type ← mp_vacuous;
  q ← mp_link(edge_list(mp→cur_exp.data.node));
  if (q ≠ Λ)
    if (is_start_or_stop(q))
      if (mp_skip_1component(mp, q) ≡ Λ) q ← mp_link(q);
  s→list ← q;
}
```

This code is used in section 832.

845. ⟨ Make sure the current expression is a known picture 845 ⟩ ≡

```
if (mp→cur_exp.type ≠ mp_picture_type) {
  mp_value new_expr;
  const char *hlp[] ← {"When you say `for x in p', p must be a known picture.", Λ};
  memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
  new_expr.data.node ← (mp_node) mp_get_edge_header_node(mp); mp_disp_err(mp, Λ);
  mp_back_error(mp, "Improper iteration spec has been replaced by nullpicture", hlp, true);
  mp_get_x_next(mp); mp_flush_cur_exp(mp, new_expr);
  mp_init_edges(mp, (mp_edge_header_node) mp→cur_exp.data.node);
  mp→cur_exp.type ← mp_picture_type;
}
```

This code is used in section 844.

846. File names. It's time now to fret about file names. Besides the fact that different operating systems treat files in different ways, we must cope with the fact that completely different naming conventions are used by different groups of people. The following programs show what is required for one particular operating system; similar routines for other systems are not difficult to devise.

METAPOST assumes that a file name has three parts: the name proper; its "extension"; and a "file area" where it is found in an external file system. The extension of an input file is assumed to be '`.mp`' unless otherwise specified; it is '`.log`' on the transcript file that records each run of METAPOST; it is '`.tfm`' on the font metric files that describe characters in any fonts created by METAPOST; it is '`.ps`' or '.*nnn*' for some number *nnn* on the PostScript output files. The file area can be arbitrary on input files, but files are usually output to the user's current area. If an input file cannot be found on the specified area, METAPOST will look for it on a special system area; this special area is intended for commonly used input files.

Simple uses of METAPOST refer only to file names that have no explicit extension or area. For example, a person usually says '`input cmr10`' instead of '`input cmr10.new`'. Simple file names are best, because they make the METAPOST source files portable; whenever a file name consists entirely of letters and digits, it should be treated in the same way by all implementations of METAPOST. However, users need the ability to refer to other files in their environment, especially when responding to error messages concerning unopenable files; therefore we want to let them use the syntax that appears in their favorite operating system.

847. METAPOST uses the same conventions that have proved to be satisfactory for TEX and METAFONT. In order to isolate the system-dependent aspects of file names, the system-independent parts of METAPOST are expressed in terms of three system-dependent procedures called *begin_name*, *more_name*, and *end_name*. In essence, if the user-specified characters of the file name are $c_1 \ldots c_n$, the system-independent driver program does the operations

$$begin\_name;\ more\_name(c_1);\ \ldots\ ;\ more\_name(c_n);\ end\_name.$$

These three procedures communicate with each other via global variables. Afterwards the file name will appear in the string pool as three strings called *cur_name*, *cur_area*, and *cur_ext*; the latter two are NULL (i.e., `""`), unless they were explicitly specified by the user.

Actually the situation is slightly more complicated, because METAPOST needs to know when the file name ends. The *more_name* routine is a function (with side effects) that returns *true* on the calls *more_name*(c_1), ..., *more_name*(c_{n-1}). The final call *more_name*(c_n) returns *false*; or, it returns *true* and c_n is the last character on the current input line. In other words, *more_name* is supposed to return *true* unless it is sure that the file name has been completely scanned; and *end_name* is supposed to be able to finish the assembly of *cur_name*, *cur_area*, and *cur_ext* regardless of whether *more_name*(c_n) returned *true* or *false*.

⟨ Global variables 18 ⟩ +≡
char **cur_name*; ▷ name of file just scanned ◁
char **cur_area*; ▷ file area just scanned, or "" ◁
char **cur_ext*; ▷ file extension just scanned, or "" ◁

848. It is easier to maintain reference counts if we assign initial values.

⟨ Set initial values of key variables 42 ⟩ +≡
mp→*cur_name* ← *xstrdup*(`""`); *mp*→*cur_area* ← *xstrdup*(`""`); *mp*→*cur_ext* ← *xstrdup*(`""`);

849. ⟨ Dealloc variables 31 ⟩ +≡
xfree(*mp*→*cur_area*); *xfree*(*mp*→*cur_name*); *xfree*(*mp*→*cur_ext*);

850. The file names we shall deal with for illustrative purposes have the following structure: If the name contains '>' or ':', the file area consists of all characters up to and including the final such character; otherwise the file area is null. If the remaining file name contains '.', the file extension consists of all such characters from the first remaining '.' to the end, otherwise the file extension is null.

We can scan such file names easily by using two global variables that keep track of the occurrences of area and extension delimiters.

⟨Global variables 18⟩ +≡
```
integer area_delimiter;    ▷ most recent '>' or ':' relative to str_start[str_ptr] ◁
integer ext_delimiter;     ▷ the relevant '.', if any ◁
boolean quoted_filename;   ▷ whether the filename is wrapped in '"' markers ◁
```

851. Here now is the first of the system-dependent routines for file name scanning.

⟨Declarations 10⟩ +≡
```
static void mp_begin_name(MP mp);
static boolean mp_more_name(MP mp, ASCII_code c);
static void mp_end_name(MP mp);
```

852.
```
void mp_begin_name(MP mp)
{
  xfree(mp→cur_name); xfree(mp→cur_area); xfree(mp→cur_ext); mp→area_delimiter ← −1;
  mp→ext_delimiter ← −1; mp→quoted_filename ← false;
}
```

853. And here's the second.

```
#ifndef IS_DIR_SEP
#define IS_DIR_SEP(c) (c ≡ '/' ∨ c ≡ '\\')
#endif
  boolean mp_more_name(MP mp, ASCII_code c)
  {
    if (c ≡ '"') {
      mp→quoted_filename ← ¬mp→quoted_filename;
    }
    else if ((c ≡ '␣' ∨ c ≡ '\t') ∧ (mp→quoted_filename ≡ false)) {
      return false;
    }
    else {
      if (IS_DIR_SEP(c)) {
        mp→area_delimiter ← (integer) mp→cur_length; mp→ext_delimiter ← −1;
      }
      else if (c ≡ '.') {
        mp→ext_delimiter ← (integer) mp→cur_length;
      }
      append_char(c);    ▷ contribute c to the current string ◁
    }
    return true;
  }
```

854. The third.

```
#define copy_pool_segment(A, B, C)
        {
          A ← xmalloc(C + 1, sizeof(char)); (void) memcpy(A, (char *)(mp→cur_string + B), C);
          A[C] ← 0;
        }
  void mp_end_name(MP mp)
  {
    size_t s ← 0;    ▷ length of area, name, and extension ◁
    size_t len;    ▷ "my/w.mp" ◁
    if (mp→area_delimiter < 0) {
      mp→cur_area ← xstrdup("");
    }
    else {
      len ← (size_t) mp→area_delimiter − s + 1; copy_pool_segment(mp→cur_area, s, len); s += len;
    }
    if (mp→ext_delimiter < 0) {
      mp→cur_ext ← xstrdup(""); len ← (unsigned)(mp→cur_length − s);
    }
    else {
      copy_pool_segment(mp→cur_ext, mp→ext_delimiter, (mp→cur_length − (size_t) mp→ext_delimiter));
      len ← (size_t) mp→ext_delimiter − s;
    }
    copy_pool_segment(mp→cur_name, s, len); mp_reset_cur_string(mp);
  }
```

855. Conversely, here is a routine that takes three strings and prints a file name that might have produced them. (The routine is system dependent, because some operating systems put the file area last instead of first.)

⟨ Basic printing procedures 91 ⟩ +≡

```
  static void mp_print_file_name(MP mp, char *n, char *a, char *e)
  {
    boolean must_quote ← false;
    if (((a ≠ Λ) ∧ (strchr(a, '␣') ≠ Λ)) ∨ ((n ≠ Λ) ∧ (strchr(n, '␣') ≠ Λ)) ∨ ((e ≠ Λ) ∧ (strchr(e, '␣') ≠ Λ)))
      must_quote ← true;
    if (must_quote) mp_print_char(mp, (ASCII_code) '"');
    mp_print(mp, a); mp_print(mp, n); mp_print(mp, e);
    if (must_quote) mp_print_char(mp, (ASCII_code) '"');
  }
```

856. Another system-dependent routine is needed to convert three internal METAPOST strings to the *name_of_file* value that is used to open files. The present code allows both lowercase and uppercase letters in the file name.

```
#define append_to_name(A)
        {
          mp→name_of_file[k++] ← (char) xchr(xord((ASCII_code)(A)));
        }

void mp_pack_file_name(MP mp, const char *n, const char *a, const char *e)
{
  integer k;    ▷ number of positions filled in name_of_file ◁
  const char *j;    ▷ a character index ◁
  size_t slen;
  k ← 0; assert(n ≠ Λ); xfree(mp→name_of_file); slen ← strlen(n) + 1;
  if (a ≠ Λ) slen += strlen(a);
  if (e ≠ Λ) slen += strlen(e);
  mp→name_of_file ← xmalloc(slen, 1);
  if (a ≠ Λ) {
    for (j ← a; *j ≠ '\0'; j++) {
      append_to_name(*j);
    }
  }
  for (j ← n; *j ≠ '\0'; j++) {
    append_to_name(*j);
  }
  if (e ≠ Λ) {
    for (j ← e; *j ≠ '\0'; j++) {
      append_to_name(*j);
    }
  }
  mp→name_of_file[k] ← 0;
}
```

857. ⟨ Internal library declarations 14 ⟩ +≡

```
void mp_pack_file_name(MP mp, const char *n, const char *a, const char *e);
```

858. ⟨ Option variables 30 ⟩ +≡

```
char *mem_name;    ▷ for commandline ◁
```

859. Stripping a *.mem* extension here is for backward compatibility.

⟨ Find and load preload file, if required 859 ⟩ ≡

```
if (¬opt→ini_version) {
  mp→mem_name ← xstrdup(opt→mem_name);
  if (mp→mem_name) {
    size_t l ← strlen(mp→mem_name);
    if (l > 4) {
      char *test ← strstr(mp→mem_name, ".mem");
      if (test ≡ mp→mem_name + l − 4) {
        *test ← 0;
      }
    }
  }
  if (mp→mem_name ≠ Λ) {
    if (¬mp_open_mem_file(mp)) {
      mp→history ← mp_fatal_error_stop; mp_jump_out(mp);
    }
  }
}
```

This code is used in section 20.

860. ⟨ Dealloc variables 31 ⟩ +≡

```
xfree(mp→mem_name);
```

861. This part of the program becomes active when a "virgin" METAPOST is trying to get going, just after the preliminary initialization. The buffer contains the first line of input in *buffer*[*loc* .. (*last* − 1)], where *loc* < *last* and *buffer*[*loc*] <> "".

⟨ Declarations 10 ⟩ +≡

```
static boolean mp_open_mem_name(MP mp);
static boolean mp_open_mem_file(MP mp);
```

862. **boolean** *mp_open_mem_name*(**MP** *mp*)

```
{
  if (mp→mem_name ≠ Λ) {
    size_t l ← strlen(mp→mem_name);
    char *s ← xstrdup(mp→mem_name);
    if (l > 4) {
      char *test ← strstr(s, ".mp");
      if (test ≡ Λ ∨ test ≠ s + l − 4) {
        s ← xrealloc(s, l + 5, 1); strcat(s, ".mp");
      }
    }
    else {
      s ← xrealloc(s, l + 5, 1); strcat(s, ".mp");
    }
    s ← (mp→find_file)(mp, s, "r", mp_filetype_program); xfree(mp→name_of_file);
    if (s ≡ Λ) return false;
    mp→name_of_file ← xstrdup(s); mp→mem_file ← (mp→open_file)(mp, s, "r", mp_filetype_program);
    free(s);
    if (mp→mem_file) return true;
  }
  return false;
}
boolean mp_open_mem_file(MP mp)
{
  if (mp→mem_file ≠ Λ) return true;
  if (mp_open_mem_name(mp)) return true;
  if (mp_xstrcmp(mp→mem_name, "plain")) {
    wake_up_terminal(); wterm("Sorry,␣I␣can\'t␣find␣the␣'"); wterm(mp→mem_name);
    wterm("'␣preload␣file;␣will␣try␣'plain'."); wterm_cr; update_terminal();
      ▷ now pull out all the stops: try for the system plain file ◁
    xfree(mp→mem_name); mp→mem_name ← xstrdup("plain");
    if (mp_open_mem_name(mp)) return true;
  }
  wake_up_terminal(); wterm_ln("I␣can't␣find␣the␣'plain'␣preload␣file!\n"); return false;
}
```

863. Operating systems often make it possible to determine the exact name (and possible version number) of a file that has been opened. The following routine, which simply makes a METAPOST string from the value of *name_of_file*, should ideally be changed to deduce the full name of file f, which is the file most recently opened, if it is possible to do this.

```
static mp_string mp_make_name_string(MP mp)
{
  int k;    ▷ index into name_of_file ◁
  int name_length ← (int) strlen(mp→name_of_file);
  str_room(name_length);
  for (k ← 0; k < name_length; k++) {
    append_char(xord((ASCII_code) mp→name_of_file[k]));
  }
  return mp_make_string(mp);
}
```

864. Now let's consider the "driver" routines by which METAPOST deals with file names in a system-independent manner. First comes a procedure that looks for a file name in the input by taking the information from the input buffer. (We can't use *get_next*, because the conversion to tokens would destroy necessary information.)

This procedure doesn't allow semicolons or percent signs to be part of file names, because of other conventions of METAPOST. *The METAFONTbook* doesn't use semicolons or percents immediately after file names, but some users no doubt will find it natural to do so; therefore system-dependent changes to allow such characters in file names should probably be made with reluctance, and only when an entire file name that includes special characters is "quoted" somehow.

```
static void mp_scan_file_name(MP mp)
{
  mp_begin_name(mp);
  while (mp→buffer[loc] ≡ '␣') incr(loc);
  while (1) {
    if ((mp→buffer[loc] ≡ ';') ∨ (mp→buffer[loc] ≡ '%')) break;
    if (¬mp_more_name(mp, mp→buffer[loc])) break;
    incr(loc);
  }
  mp_end_name(mp);
}
```

865. Here is another version that takes its input from a string.

⟨ Declare subroutines for parsing file names 865 ⟩ ≡
```
void mp_str_scan_file(MP mp, mp_string s);
```
See also section 867.

This code is used in section 14.

866.
```
void mp_str_scan_file(MP mp, mp_string s)
{
  size_t p, q;    ▷ current position and stopping point ◁
  mp_begin_name(mp); p ← 0; q ← s→len;
  while (p < q) {
    if (¬mp_more_name(mp, *(s→str + p))) break;
    incr(p);
  }
  mp_end_name(mp);
}
```

867. And one that reads from a **char** ∗.

⟨ Declare subroutines for parsing file names 865 ⟩ +≡
```
extern void mp_ptr_scan_file(MP mp, char *s);
```

868. **void** *mp_ptr_scan_file*(**MP** *mp*, **char** $*s$)

```
{
  char *p, *q;    ▷ current position and stopping point ◁
  mp_begin_name(mp); p ← s; q ← p + strlen(s);
  while (p < q) {
    if (¬mp_more_name(mp, (ASCII_code)(*p))) break;
    p++;
  }
  mp_end_name(mp);
}
```

869. The option variable *job_name* contains the file name that was first **input** by the user. This name is used to initialize the *job_name* global as well as the *mp_job_name* internal, and is extended by '`.log`' and '`ps`' and '`.mem`' and '`.tfm`' in order to make the names of METAPOST's output files.

⟨ Global variables 18 ⟩ +≡

```
boolean log_opened;    ▷ has the transcript file been opened? ◁
char *log_name;    ▷ full name of the log file ◁
```

870. ⟨ Option variables 30 ⟩ +≡

```
char *job_name;    ▷ principal file name ◁
```

871. Initially *job_name* $\leftarrow \Lambda$; it becomes nonzero as soon as the true name is known. We have *job_name* $\leftarrow \Lambda$ if and only if the '`log`' file has not been opened, except of course for a short time just after *job_name* has become nonzero.

⟨ Allocate or initialize variables 32 ⟩ +≡

```
mp→job_name ← mp_xstrdup(mp, opt→job_name);
  ▷ if (mp→job_name ≠ Λ) { char *s ← mp→job_name + strlen(mp→job_name); while (s > mp→job_name)
    { if (*s ≡ '.') { *s ← '\0'; } s−−; } }◁
if (opt→noninteractive) {
  if (mp→job_name ≡ Λ) mp→job_name ← mp_xstrdup(mp, mp→mem_name);
}
mp→log_opened ← false;
```

872. Cannot do this earlier because at the ⟨ Allocate or initialize variables 32 ⟩ block, the string pool is not yet initialized.

⟨ Fix up *mp→internal*[*mp_job_name*] 872 ⟩ ≡

```
if (mp→job_name ≠ Λ) {
  if (internal_string(mp_job_name) ≠ 0) delete_str_ref(internal_string(mp_job_name));
  set_internal_string(mp_job_name, mp_rts(mp, mp→job_name));
}
```

This code is used in sections 20, 879, 884, 1068, and 1246.

873. ⟨ Dealloc variables 31 ⟩ +≡

```
xfree(mp→job_name);
```

874. Here is a routine that manufactures the output file names, assuming that *job_name* <> 0. It ignores and changes the current settings of *cur_area* and *cur_ext*.

```
#define pack_cur_name  mp_pack_file_name(mp, mp→cur_name, mp→cur_area, mp→cur_ext)
```

⟨ Internal library declarations 14 ⟩ +≡

```
void mp_pack_job_name(MP mp, const char *s);
```

875. **void** *mp_pack_job_name*(**MP** *mp*, **const char** *$*s$*)

```
{    ▷ s ← ".log", ".mem", ".ps", or .nnn ◁
  xfree(mp→cur_name); mp→cur_name ← xstrdup(mp→job_name); xfree(mp→cur_area);
  mp→cur_area ← xstrdup(""); xfree(mp→cur_ext); mp→cur_ext ← xstrdup(s); pack_cur_name;
}
```

876. If some trouble arises when METAPOST tries to open a file, the following routine calls upon the user to supply another file name. Parameter s is used in the error message to identify the type of file; parameter e is the default extension if none is given. Upon exit from the routine, variables *cur_name*, *cur_area*, *cur_ext*, and *name_of_file* are ready for another attempt at file opening.

⟨Internal library declarations 14⟩ +≡

```
void mp_prompt_file_name(MP mp, const char *s, const char *e);
```

877. **void** *mp_prompt_file_name*(**MP** *mp*, **const char** *$*s$*, **const char** *$*e$*)

```
{
  size_t k;    ▷ index into buffer ◁
  char *saved_cur_name;
  if (mp→interaction ≡ mp_scroll_mode) wake_up_terminal();
  if (strcmp(s, "input␣file␣name") ≡ 0) {
    mp_print_err(mp, "I␣can\'t␣open␣file␣`");
  }
  else {
    mp_print_err(mp, "I␣can\'t␣write␣on␣file␣`");
  }
  if (strcmp(s, "file␣name␣for␣output") ≡ 0) {
    mp_print(mp, mp→name_of_file);
  }
  else {
    mp_print_file_name(mp, mp→cur_name, mp→cur_area, mp→cur_ext);
  }
  mp_print(mp, "'.");
  if (strcmp(e, "") ≡ 0) mp_show_context(mp);
  mp_print_nl(mp, "Please␣type␣another␣"); mp_print(mp, s);
  if (mp→noninteractive ∨ mp→interaction < mp_scroll_mode)
    mp_fatal_error(mp, "***␣(job␣aborted,␣file␣error␣in␣nonstop␣mode)");
  saved_cur_name ← xstrdup(mp→cur_name); clear_terminal(); prompt_input(":␣");
  ⟨Scan file name in the buffer 878⟩;
  if (strcmp(mp→cur_ext, "") ≡ 0) mp→cur_ext ← xstrdup(e);
  if (strlen(mp→cur_name) ≡ 0) {
    mp→cur_name ← saved_cur_name;
  }
  else {
    xfree(saved_cur_name);
  }
  pack_cur_name;
}
```

878. ⟨Scan file name in the buffer 878⟩ ≡

```
{
  mp_begin_name(mp); k ← mp→first;
  while ((mp→buffer[k] ≡ '␣') ∧ (k < mp→last)) incr(k);
  while (1) {
    if (k ≡ mp→last) break;
    if (¬mp_more_name(mp, mp→buffer[k])) break;
    incr(k);
  }
  mp_end_name(mp);
}
```

This code is used in section 877.

879. The *open_log_file* routine is used to open the transcript file and to help it catch up to what has previously been printed on the terminal.

```
void mp_open_log_file(MP mp)
{
  unsigned old_setting;   ▷ previous selector setting ◁
  int k;   ▷ index into months and buffer ◁
  int l;   ▷ end of first input line ◁
  integer m;   ▷ the current month ◁
  const char *months ← "JANFEBMARAPRMAYJUNJULAUGSEPOCTNOVDEC";
    ▷ abbreviations of month names ◁
  if (mp→log_opened) return;
  old_setting ← mp→selector;
  if (mp→job_name ≡ Λ) {
    mp→job_name ← xstrdup("mpout"); ⟨Fix up mp→internal[mp_job_name] 872⟩;
  }
  mp_pack_job_name(mp, ".log");
  while (¬mp_open_out(mp, &mp→log_file, mp_filetype_log)) ⟨Try to get a different log file name 881⟩
  mp→log_name ← xstrdup(mp→name_of_file); mp→selector ← log_only; mp→log_opened ← true;
  ⟨Print the banner line, including the date and time 882⟩;
  mp→input_stack[mp→input_ptr] ← mp→cur_input;   ▷ make sure bottom level is in memory ◁
  if (¬mp→noninteractive) {
    mp_print_nl(mp, "**"); l ← mp→input_stack[0].limit_field − 1;   ▷ last position of first line ◁
    for (k ← 0; k ≤ l; k++) mp_print_char(mp, mp→buffer[k]);
    mp_print_ln(mp);   ▷ now the transcript file contains the first line of input ◁
  }
  mp→selector ← old_setting + 2;   ▷ log_only or term_and_log ◁
}
```

880. ⟨Dealloc variables 31⟩ +≡

```
xfree(mp→log_name);
```

881. Sometimes *open_log_file* is called at awkward moments when METAPOST is unable to print error messages or even to *show_context*. The *prompt_file_name* routine can result in a *fatal_error*, but the **error** routine will not be invoked because *log_opened* will be false.

The normal idea of *mp_batch_mode* is that nothing at all should be written on the terminal. However, in the unusual case that no log file could be opened, we make an exception and allow an explanatory message to be seen.

Incidentally, the program always refers to the log file as a '`transcript file`', because some systems cannot use the extension '`.log`' for this file.

⟨ Try to get a different log file name 881 ⟩ ≡

```
{
  mp→selector ← term_only; mp_prompt_file_name(mp, "transcript␣file␣name", ".log");
}
```

This code is used in section 879.

882. ⟨ Print the banner line, including the date and time 882 ⟩ ≡

```
{
  wlog(mp→banner); mp_print(mp, "␣␣"); mp_print_int(mp, round_unscaled(internal_value(mp_day)));
  mp_print_char(mp, xord('␣')); m ← round_unscaled(internal_value(mp_month));
  for (k ← 3 * m − 3; k < 3 * m; k++) {
    wlog_chr((unsigned char) months[k]);
  }
  mp_print_char(mp, xord('␣')); mp_print_int(mp, round_unscaled(internal_value(mp_year)));
  mp_print_char(mp, xord('␣')); mp_print_dd(mp, round_unscaled(internal_value(mp_hour)));
  mp_print_char(mp, xord(':')); mp_print_dd(mp, round_unscaled(internal_value(mp_minute)));
}
```

This code is used in section 879.

883. The *try_extension* function tries to open an input file determined by *cur_name*, *cur_area*, and the argument *ext*. It returns *false* if it can't find the file in *cur_area* or the appropriate system area.

```
static boolean mp_try_extension(MP mp, const char *ext)
{
  mp_pack_file_name(mp, mp→cur_name, mp→cur_area, ext); in_name ← xstrdup(mp→cur_name);
  in_area ← xstrdup(mp→cur_area); in_ext ← xstrdup(ext);
  if (mp_open_in(mp, &cur_file, mp_filetype_program)) {
    return true;
  }
  else {
    mp_pack_file_name(mp, mp→cur_name, Λ, ext);
    return mp_open_in(mp, &cur_file, mp_filetype_program);
  }
}
```

884. Let's turn now to the procedure that is used to initiate file reading when an '`input`' command is being processed.

```
void mp_start_input(MP mp)
{   ▷ METAPOST will input something ◁
  char *fname ← Λ;
  ⟨Put the desired file name in (cur_name, cur_ext, cur_area) 887⟩;
  while (1) {
    mp_begin_file_reading(mp);   ▷ set up cur_file and new level of input ◁
    if (strlen(mp→cur_ext) ≡ 0) {
      if (mp_try_extension(mp, ".mp")) break;
      else if (mp_try_extension(mp, "")) break;
      else if (mp_try_extension(mp, ".mf")) break;
    }
    else if (mp_try_extension(mp, mp→cur_ext)) {
      break;
    }
    mp_end_file_reading(mp);   ▷ remove the level that didn't work ◁
    mp_prompt_file_name(mp, "input␣file␣name", "");
  }
  name ← mp_make_name_string(mp); fname ← xstrdup(mp→name_of_file);
  if (mp→job_name ≡ Λ) {
    mp→job_name ← xstrdup(mp→cur_name); ⟨Fix up mp→internal[mp_job_name] 872⟩;
  }
  if (¬mp→log_opened) {
    mp_open_log_file(mp);
  }   ▷ open_log_file doesn't show_context, so limit and loc needn't be set to meaningful values yet ◁
  if (((int) mp→term_offset + (int) strlen(fname)) > (mp→max_print_line − 2)) mp_print_ln(mp);
  else if ((mp→term_offset > 0) ∨ (mp→file_offset > 0)) mp_print_char(mp, xord('␣'));
  mp_print_char(mp, xord('(')); incr(mp→open_parens); mp_print(mp, fname); xfree(fname);
  update_terminal(); ⟨Flush name and replace it with cur_name if it won't be needed 885⟩;
  ⟨Read the first line of the new file 886⟩;
}
```

885. This code should be omitted if *make_name_string* returns something other than just a copy of its argument and the full file name is needed for opening `MPX` files or implementing the switch-to-editor option.

```
⟨Flush name and replace it with cur_name if it won't be needed 885⟩ ≡
  mp_flush_string(mp, name); name ← mp_rts(mp, mp→cur_name); xfree(mp→cur_name)
```

This code is used in section 884.

886. If the file is empty, it is considered to contain a single blank line, so there is no need to test the return value.

```
⟨Read the first line of the new file 886⟩ ≡
  {
    line ← 1; (void) mp_input_ln(mp, cur_file); mp_firm_up_the_line(mp); mp→buffer[limit] ← xord('%');
    mp→first ← (size_t)(limit + 1); loc ← start;
  }
```

This code is used in sections 884 and 888.

887. ⟨ Put the desired file name in (*cur_name*, *cur_ext*, *cur_area*) 887 ⟩ ≡

```
while (token_state ∧ (nloc ≡ Λ)) mp_end_token_list(mp);
if (token_state) {
  const char *hlp[] ← {"Sorry...I've␣converted␣what␣follows␣to␣tokens,",
      "possibly␣garbaging␣the␣name␣you␣gave.",
      "Please␣delete␣the␣tokens␣and␣insert␣the␣name␣again.", Λ};
  mp_error(mp, "File␣names␣can't␣appear␣within␣macros", hlp, true);
}
if (file_state) {
  mp_scan_file_name(mp);
}
else {
  xfree(mp→cur_name); mp→cur_name ← xstrdup(""); xfree(mp→cur_ext); mp→cur_ext ← xstrdup("");
  xfree(mp→cur_area); mp→cur_area ← xstrdup("");
}
```

This code is used in section 884.

888. The following simple routine starts reading the MPX file associated with the current input file.

```
void mp_start_mpx_input(MP mp)
{
  char *origname ← Λ;    ▷ a copy of nameoffile ◁
  mp_pack_file_name(mp, in_name, in_area, in_ext); origname ← xstrdup(mp→name_of_file);
  mp_pack_file_name(mp, in_name, in_area, ".mpx");
  if (¬(mp→run_make_mpx)(mp, origname, mp→name_of_file)) goto NOT_FOUND;
  mp_begin_file_reading(mp);
  if (¬mp_open_in(mp, &cur_file, mp_filetype_program)) {
    mp_end_file_reading(mp); goto NOT_FOUND;
  }
  name ← mp_make_name_string(mp); mp→mpx_name[iindex] ← name; add_str_ref(name);
  ⟨ Read the first line of the new file 886 ⟩;
  xfree(origname); return;
NOT_FOUND: ⟨ Explain that the MPX file can't be read and succumb 895 ⟩;
  xfree(origname);
}
```

889. This should ideally be changed to do whatever is necessary to create the MPX file given by *name_of_file* if it does not exist or if it is out of date. This requires invoking MPtoTeX on the *origname* and passing the results through TEX and DVItoMP. (It is possible to use a completely different typesetting program if suitable postprocessor is available to perform the function of DVItoMP.)

890. ⟨ Exported types 19 ⟩ +≡

```
typedef int (*mp_makempx_cmd)(MP mp, char *origname, char *mtxname);
```

891. ⟨ Option variables 30 ⟩ +≡

```
mp_makempx_cmd run_make_mpx;
```

892. ⟨ Allocate or initialize variables 32 ⟩ +≡

```
set_callback_option(run_make_mpx);
```

893. ⟨ Declarations 10 ⟩ +≡

```
static int mp_run_make_mpx(MP mp, char *origname, char *mtxname);
```

894. The default does nothing.

```
int mp_run_make_mpx(MP mp, char *origname, char *mtxname)
{
  (void) mp; (void) origname; (void) mtxname; return false;
}
```

895. ⟨ Explain that the MPX file can't be read and *succumb* 895 ⟩ ≡

```
{
  const char *hlp[] ← {"The␣two␣files␣given␣above␣are␣one␣of␣your␣source␣files",
      "and␣an␣auxiliary␣file␣I␣need␣to␣read␣to␣find␣out␣what␣your",
      "btex..etex␣blocks␣mean.␣If␣you␣don't␣know␣why␣I␣had␣trouble,",
      "try␣running␣it␣manually␣through␣MPtoTeX,␣TeX,␣and␣DVItoMP", Λ};
  if (mp→interaction ≡ mp_error_stop_mode) wake_up_terminal();
  mp_print_nl(mp, ">>␣"); mp_print(mp, origname); mp_print_nl(mp, ">>␣");
  mp_print(mp, mp→name_of_file); xfree(origname);
  if (mp→interaction ≡ mp_error_stop_mode) mp→interaction ← mp_scroll_mode;
      ▷ no more interaction ◁
  if (mp→log_opened) mp_error(mp, "!␣Unable␣to␣read␣mpx␣file", hlp, true);
  mp→history ← mp_fatal_error_stop; mp_jump_out(mp);   ▷ irrecoverable error ◁
}
```

This code is used in section 888.

896. The last file-opening commands are for files accessed via the **readfrom** operator and the **write** command. Such files are stored in separate arrays.

⟨ Types in the outer block 37 ⟩ +≡

```
typedef unsigned int readf_index;   ▷ 0..max_read_files ◁
typedef unsigned int write_index;   ▷ 0..max_write_files ◁
```

897. ⟨ Global variables 18 ⟩ +≡

```
readf_index max_read_files;   ▷ maximum number of simultaneously open readfrom files ◁
void **rd_file;   ▷ readfrom files ◁
char **rd_fname;   ▷ corresponding file name or 0 if file not open ◁
readf_index read_files;   ▷ number of valid entries in the above arrays ◁
write_index max_write_files;   ▷ maximum number of simultaneously open write ◁
void **wr_file;   ▷ write files ◁
char **wr_fname;   ▷ corresponding file name or 0 if file not open ◁
write_index write_files;   ▷ number of valid entries in the above arrays ◁
```

898. ⟨ Allocate or initialize variables 32 ⟩ +≡

```
mp→max_read_files ← 8; mp→rd_file ← xmalloc((mp→max_read_files + 1), sizeof(void *));
mp→rd_fname ← xmalloc((mp→max_read_files + 1), sizeof(char *));
memset(mp→rd_fname, 0, sizeof(char *) * (mp→max_read_files + 1)); mp→max_write_files ← 8;
mp→wr_file ← xmalloc((mp→max_write_files + 1), sizeof(void *));
mp→wr_fname ← xmalloc((mp→max_write_files + 1), sizeof(char *));
memset(mp→wr_fname, 0, sizeof(char *) * (mp→max_write_files + 1));
```

899. This routine starts reading the file named by string s without setting *loc*, *limit*, or *name*. It returns *false* if the file is empty or cannot be opened. Otherwise it updates *rd_file*[n] and *rd_fname*[n].

```
static boolean mp_start_read_input(MP mp, char *s, readf_index n)
{
  mp_ptr_scan_file(mp, s); pack_cur_name; mp_begin_file_reading(mp);
  if (¬mp_open_in(mp, &mp→rd_file[n], (int)(mp_filetype_text + n))) goto NOT_FOUND;
  if (¬mp_input_ln(mp, mp→rd_file[n])) {
    (mp→close_file)(mp, mp→rd_file[n]); goto NOT_FOUND;
  }
  mp→rd_fname[n] ← xstrdup(s); return true;
NOT_FOUND: mp_end_file_reading(mp); return false;
}
```

900. Open *wr_file*[n] using file name s and update *wr_fname*[n].

⟨ Declarations 10 ⟩ +≡

```
static void mp_open_write_file(MP mp, char *s, readf_index n);
```

901.

```
void mp_open_write_file(MP mp, char *s, readf_index n)
{
  mp_ptr_scan_file(mp, s); pack_cur_name;
  while (¬mp_open_out(mp, &mp→wr_file[n], (int)(mp_filetype_text + n)))
    mp_prompt_file_name(mp, "file␣name␣for␣write␣output", "");
  mp→wr_fname[n] ← xstrdup(s);
}
```

902. Introduction to the parsing routines. We come now to the central nervous system that sparks many of METAPOST's activities. By evaluating expressions, from their primary constituents to ever larger subexpressions, METAPOST builds the structures that ultimately define complete pictures or fonts of type.

Four mutually recursive subroutines are involved in this process: We call them

$$scan\_primary,\ scan\_secondary,\ scan\_tertiary,\ \text{and}\ scan\_expression.$$

Each of them is parameterless and begins with the first token to be scanned already represented in *cur_cmd*, *cur_mod*, and *cur_sym*. After execution, the value of the primary or secondary or tertiary or expression that was found will appear in the global variables *cur_type* and *cur_exp*. The token following the expression will be represented in *cur_cmd*, *cur_mod*, and *cur_sym*.

Technically speaking, the parsing algorithms are "LL(1)," more or less; backup mechanisms have been added in order to provide reasonable error recovery.

```
#define cur_exp_value_boolean()  number_to_int(mp→cur_exp.data.n)
#define cur_exp_value_number()  mp→cur_exp.data.n
#define cur_exp_node()  mp→cur_exp.data.node
#define cur_exp_str()  mp→cur_exp.data.str
#define cur_exp_knot()  mp→cur_exp.data.p
#define set_cur_exp_value_scaled(A)
        do {
          if (cur_exp_str()) {
            delete_str_ref(cur_exp_str());
          }
          set_number_from_scaled(mp→cur_exp.data.n, (A));  cur_exp_node() ← Λ;  cur_exp_str() ← Λ;
          cur_exp_knot() ← Λ;
        } while (0)
#define set_cur_exp_value_boolean(A)
        do {
          if (cur_exp_str()) {
            delete_str_ref(cur_exp_str());
          }
          set_number_from_int(mp→cur_exp.data.n, (A));  cur_exp_node() ← Λ;  cur_exp_str() ← Λ;
          cur_exp_knot() ← Λ;
        } while (0)
#define set_cur_exp_value_number(A)
        do {
          if (cur_exp_str()) {
            delete_str_ref(cur_exp_str());
          }
          number_clone(mp→cur_exp.data.n, (A));  cur_exp_node() ← Λ;  cur_exp_str() ← Λ;
          cur_exp_knot() ← Λ;
        } while (0)
#define set_cur_exp_node(A)
        do {
          if (cur_exp_str()) {
            delete_str_ref(cur_exp_str());
          }
          cur_exp_node() ← A;  cur_exp_str() ← Λ;  cur_exp_knot() ← Λ;
          set_number_to_zero(mp→cur_exp.data.n);
        } while (0)
#define set_cur_exp_str(A)
        do {
```

```
    if (cur_exp_str()) {
      delete_str_ref(cur_exp_str());
    }
    cur_exp_str() ← A; add_str_ref(cur_exp_str()); cur_exp_node() ← Λ; cur_exp_knot() ← Λ;
    set_number_to_zero(mp→cur_exp.data.n);
  } while (0)
#define set_cur_exp_knot(A)
  do {
    if (cur_exp_str()) {
      delete_str_ref(cur_exp_str());
    }
    cur_exp_knot() ← A; cur_exp_node() ← Λ; cur_exp_str() ← Λ;
    set_number_to_zero(mp→cur_exp.data.n);
  } while (0)
```

903. ⟨ Global variables 18 ⟩ +≡

```
mp_value cur_exp;    ▷ the value of the expression just found ◁
```

904. ⟨ Set initial values of key variables 42 ⟩ +≡

```
memset(&mp→cur_exp.data, 0, sizeof(mp_value)); new_number(mp→cur_exp.data.n);
```

905. ⟨ Free table entries 187 ⟩ +≡

```
free_number(mp→cur_exp.data.n);
```

906. Many different kinds of expressions are possible, so it is wise to have precise descriptions of what *cur_type* and *cur_exp* mean in all cases:

cur_type ← *mp_vacuous* means that this expression didn't turn out to have a value at all, because it arose from a **begingroup** ... **endgroup** construction in which there was no expression before the **endgroup**. In this case *cur_exp* has some irrelevant value.

cur_type ← *mp_boolean_type* means that *cur_exp* is either *true_code* or *false_code*.

cur_type ← *mp_unknown_boolean* means that *cur_exp* points to a capsule node that is in a ring of equivalent booleans whose value has not yet been defined.

cur_type ← *mp_string_type* means that *cur_exp* is a string number (i.e., an integer in the range $0 \le cur\_exp < str\_ptr$). That string's reference count includes this particular reference.

cur_type ← *mp_unknown_string* means that *cur_exp* points to a capsule node that is in a ring of equivalent strings whose value has not yet been defined.

cur_type ← *mp_pen_type* means that *cur_exp* points to a node in a pen. Nobody else points to any of the nodes in this pen. The pen may be polygonal or elliptical.

cur_type ← *mp_unknown_pen* means that *cur_exp* points to a capsule node that is in a ring of equivalent pens whose value has not yet been defined.

cur_type ← *mp_path_type* means that *cur_exp* points to a the first node of a path; nobody else points to this particular path. The control points of the path will have been chosen.

cur_type ← *mp_unknown_path* means that *cur_exp* points to a capsule node that is in a ring of equivalent paths whose value has not yet been defined.

cur_type ← *mp_picture_type* means that *cur_exp* points to an edge header node. There may be other pointers to this particular set of edges. The header node contains a reference count that includes this particular reference.

cur_type ← *mp_unknown_picture* means that *cur_exp* points to a capsule node that is in a ring of equivalent pictures whose value has not yet been defined.

cur_type ← *mp_transform_type* means that *cur_exp* points to a *mp_transform_type* capsule node. The *value* part of this capsule points to a transform node that contains six numeric values, each of which is *independent*, *dependent*, *mp_proto_dependent*, or *known*.

cur_type ← *mp_color_type* means that *cur_exp* points to a *color_type* capsule node. The *value* part of this capsule points to a color node that contains three numeric values, each of which is *independent*, *dependent*, *mp_proto_dependent*, or *known*.

cur_type ← *mp_cmykcolor_type* means that *cur_exp* points to a *mp_cmykcolor_type* capsule node. The *value* part of this capsule points to a color node that contains four numeric values, each of which is *independent*, *dependent*, *mp_proto_dependent*, or *known*.

cur_type ← *mp_pair_type* means that *cur_exp* points to a capsule node whose type is *mp_pair_type*. The *value* part of this capsule points to a pair node that contains two numeric values, each of which is *independent*, *dependent*, *mp_proto_dependent*, or *known*.

cur_type ← *mp_known* means that *cur_exp* is a *scaled* value.

cur_type ← *mp_dependent* means that *cur_exp* points to a capsule node whose type is *dependent*. The *dep_list* field in this capsule points to the associated dependency list.

cur_type ← *mp_proto_dependent* means that *cur_exp* points to a *mp_proto_dependent* capsule node. The *dep_list* field in this capsule points to the associated dependency list.

cur_type ← *independent* means that *cur_exp* points to a capsule node whose type is *independent*. This somewhat unusual case can arise, for example, in the expression '$x +$ **begingroup string** $x; 0$ **endgroup**'.

cur_type ← *mp_token_list* means that *cur_exp* points to a linked list of tokens.

The possible settings of *cur_type* have been listed here in increasing numerical order. Notice that *cur_type* will never be *mp_numeric_type* or *suffixed_macro* or *mp_unsuffixed_macro*, although variables of those types are allowed. Conversely, METAPOST has no variables of type *mp_vacuous* or *token_list*.

907. Capsules are non-symbolic nodes that have a similar meaning to *cur_type* and *cur_exp*. Such nodes have *name_type* ← *capsule*, and their *type* field is one of the possibilities for *cur_type* listed above. Also *link* ≤ **void** in capsules that aren't part of a token list.

The *value* field of a capsule is, in most cases, the value that corresponds to its *type*, as *cur_exp* corresponds to *cur_type*. However, when *cur_exp* would point to a capsule, no extra layer of indirection is present; the *value* field is what would have been called *value*(*cur_exp*) if it had not been encapsulated. Furthermore, if the type is *dependent* or *mp_proto_dependent*, the *value* field of a capsule is replaced by *dep_list* and *prev_dep* fields, since dependency lists in capsules are always part of the general *dep_list* structure.

The *get_x_next* routine is careful not to change the values of *cur_type* and *cur_exp* when it gets an expanded token. However, *get_x_next* might call a macro, which might parse an expression, which might execute lots of commands in a group; hence it's possible that *cur_type* might change from, say, *mp_unknown_boolean* to *mp_boolean_type*, or from *dependent* to *known* or *independent*, during the time *get_x_next* is called. The programs below are careful to stash sensitive intermediate results in capsules, so that METAPOST's generality doesn't cause trouble.

Here's a procedure that illustrates these conventions. It takes the contents of (*cur_type*, *cur_exp*) and stashes them away in a capsule. It is not used when *cur_type* ← *mp_token_list*. After the operation, *cur_type* ← *mp_vacuous*; hence there is no need to copy path lists or to update reference counts, etc.

The special link `MP_VOID` is put on the capsule returned by *stash_cur_exp*, because this procedure is used to store macro parameters that must be easily distinguishable from token lists.

⟨ Declare the stashing/unstashing routines 907 ⟩ ≡

```
static mp_node mp_stash_cur_exp(MP mp)
{
  mp_node p;    ▷ the capsule that will be returned ◁
  mp_variable_type exp_type ← mp→cur_exp.type;
  switch (exp_type) {
  case unknown_types: case mp_transform_type: case mp_color_type: case mp_pair_type:
    case mp_dependent: case mp_proto_dependent: case mp_independent: case mp_cmykcolor_type:
    p ← cur_exp_node( ); break;    ▷ case mp_path_type: case mp_pen_type: case mp_string_type: ◁
  default: p ← mp_get_value_node(mp); mp_name_type(p) ← mp_capsule;
    mp_type(p) ← mp→cur_exp.type; set_value_number(p, cur_exp_value_number( ));
      ▷ this also resets the rest to 0/NULL ◁
    if (cur_exp_str( )) {
      set_value_str(p, cur_exp_str( ));
    }
    else if (cur_exp_knot( )) {
      set_value_knot(p, cur_exp_knot( ));
    }
    else if (cur_exp_node( )) {
      set_value_node(p, cur_exp_node( ));
    }
    break;
  }
  mp→cur_exp.type ← mp_vacuous; mp_link(p) ← MP_VOID; return p;
}
```

See also section 908.

This code is used in section 910.

908. The inverse of *stash_cur_exp* is the following procedure, which deletes an unnecessary capsule and puts its contents into *cur_type* and *cur_exp*.

The program steps of METAPOST can be divided into two categories: those in which *cur_type* and *cur_exp* are "alive" and those in which they are "dead," in the sense that *cur_type* and *cur_exp* contain relevant information or not. It's important not to ignore them when they're alive, and it's important not to pay attention to them when they're dead.

There's also an intermediate category: If *cur_type* ← *mp_vacuous*, then *cur_exp* is irrelevant, hence we can proceed without caring if *cur_type* and *cur_exp* are alive or dead. In such cases we say that *cur_type* and *cur_exp* are *dormant*. It is permissible to call *get_x_next* only when they are alive or dormant.

The *stash* procedure above assumes that *cur_type* and *cur_exp* are alive or dormant. The *unstash* procedure assumes that they are dead or dormant; it resuscitates them.

⟨ Declare the stashing/unstashing routines 907 ⟩ +≡

```
static void mp_unstash_cur_exp(MP mp, mp_node p);
```

909.

```
void mp_unstash_cur_exp(MP mp, mp_node p)
{
  mp→cur_exp.type ← mp_type(p);
  switch (mp→cur_exp.type) {
  case unknown_types: case mp_transform_type: case mp_color_type: case mp_pair_type:
    case mp_dependent: case mp_proto_dependent: case mp_independent: case mp_cmykcolor_type:
    set_cur_exp_node(p); break;
  case mp_token_list:    ▷ this is how symbols are stashed ◁
    set_cur_exp_node(value_node(p)); mp_free_value_node(mp, p); break;
  case mp_path_type: case mp_pen_type: set_cur_exp_knot(value_knot(p)); mp_free_value_node(mp, p);
    break;
  case mp_string_type: set_cur_exp_str(value_str(p)); mp_free_value_node(mp, p); break;
  case mp_picture_type: set_cur_exp_node(value_node(p)); mp_free_value_node(mp, p); break;
  case mp_boolean_type: case mp_known: set_cur_exp_value_number(value_number(p));
    mp_free_value_node(mp, p); break;
  default: set_cur_exp_value_number(value_number(p));
    if (value_knot(p)) {
      set_cur_exp_knot(value_knot(p));
    }
    else if (value_node(p)) {
      set_cur_exp_node(value_node(p));
    }
    else if (value_str(p)) {
      set_cur_exp_str(value_str(p));
    }
    mp_free_value_node(mp, p); break;
  }
}
```

910. The following procedure prints the values of expressions in an abbreviated format. If its first parameter p is NULL, the value of (*cur_type*, *cur_exp*) is displayed; otherwise p should be a capsule containing the desired value. The second parameter controls the amount of output. If it is 0, dependency lists will be abbreviated to '`linearform`' unless they consist of a single term. If it is greater than 1, complicated structures (pens, pictures, and paths) will be displayed in full.

⟨ Declarations 10 ⟩ +≡
  ⟨ Declare the procedure called *print_dp* 919 ⟩;
  ⟨ Declare the stashing/unstashing routines 907 ⟩;
  static void *mp_print_exp*(**MP** *mp*, **mp_node** *p*, **quarterword** *verbosity*);

911. **void** *mp_print_exp*(**MP** *mp*, **mp_node** *p*, **quarterword** *verbosity*)

```
{
  boolean restore_cur_exp;   ▷ should cur_exp be restored? ◁
  mp_variable_type t;   ▷ the type of the expression ◁
  mp_number vv;   ▷ the value of the expression ◁
  mp_node v ← Λ;
  new_number(vv);
  if (p ≠ Λ) {
    restore_cur_exp ← false;
  }
  else {
    p ← mp_stash_cur_exp(mp); restore_cur_exp ← true;
  }
  t ← mp_type(p);
  if (t < mp_dependent) {   ▷ no dep list, could be a capsule ◁
    if (t ≠ mp_vacuous ∧ t ≠ mp_known ∧ value_node(p) ≠ Λ) v ← value_node(p);
    else number_clone(vv, value_number(p));
  }
  else if (t < mp_independent) {
    v ← (mp_node) dep_list((mp_value_node) p);
  }
  ⟨ Print an abbreviated value of v or vv with format depending on t 912 ⟩;
  if (restore_cur_exp) mp_unstash_cur_exp(mp, p);
  free_number(vv);
}
```

912. ⟨Print an abbreviated value of v or vv with format depending on t 912⟩ ≡

```
switch (t) {
case mp_vacuous: mp_print(mp, "vacuous"); break;
case mp_boolean_type:
  if (number_to_boolean(vv) ≡ mp_true_code) mp_print(mp, "true");
  else mp_print(mp, "false");
  break;
case unknown_types: case mp_numeric_type:
  ⟨Display a variable that's been declared but not defined 920⟩;
  break;
case mp_string_type: mp_print_char(mp, xord('"')); mp_print_str(mp, value_str(p));
  mp_print_char(mp, xord('"')); break;
case mp_pen_type: case mp_path_type: case mp_picture_type: ⟨Display a complex type 918⟩;
  break;
case mp_transform_type:
  if (number_zero(vv) ∧ v ≡ Λ) mp_print_type(mp, t);
  else ⟨Display a transform node 915⟩;
  break;
case mp_color_type:
  if (number_zero(vv) ∧ v ≡ Λ) mp_print_type(mp, t);
  else ⟨Display a color node 916⟩;
  break;
case mp_pair_type:
  if (number_zero(vv) ∧ v ≡ Λ) mp_print_type(mp, t);
  else ⟨Display a pair node 914⟩;
  break;
case mp_cmykcolor_type:
  if (number_zero(vv) ∧ v ≡ Λ) mp_print_type(mp, t);
  else ⟨Display a cmykcolor node 917⟩;
  break;
case mp_known: print_number(vv); break;
case mp_dependent: case mp_proto_dependent: mp_print_dp(mp, t, (mp_value_node) v, verbosity);
  break;
case mp_independent: mp_print_variable_name(mp, p); break;
default: mp_confusion(mp, "exp"); break;
}
```

This code is used in section 911.

913. ⟨Display big node item v 913⟩ ≡

```
{
  if (mp_type(v) ≡ mp_known) print_number(value_number(v));
  else if (mp_type(v) ≡ mp_independent) mp_print_variable_name(mp, v);
  else mp_print_dp(mp, mp_type(v), (mp_value_node) dep_list((mp_value_node) v), verbosity);
}
```

This code is used in sections 914, 915, 916, and 917.

914. In these cases, v starts as the big node.

⟨ Display a pair node 914 ⟩ ≡
  {
    mp_node *vvv* ← *v*;
    mp_print_char(*mp*, *xord*('(')); ▷ clang: dereference of null pointer ◁
    assert(*vvv*); *v* ← *x_part*(*vvv*); ⟨ Display big node item *v* 913 ⟩;
    mp_print_char(*mp*, *xord*(',')); *v* ← *y_part*(*vvv*); ⟨ Display big node item *v* 913 ⟩;
    mp_print_char(*mp*, *xord*(')'));
  }

This code is used in section 912.

915. ⟨ Display a transform node 915 ⟩ ≡
  {
    mp_node *vvv* ← *v*;
    mp_print_char(*mp*, *xord*('(')); ▷ clang: dereference of null pointer ◁
    assert(*vvv*); *v* ← *tx_part*(*vvv*); ⟨ Display big node item *v* 913 ⟩;
    mp_print_char(*mp*, *xord*(',')); *v* ← *ty_part*(*vvv*); ⟨ Display big node item *v* 913 ⟩;
    mp_print_char(*mp*, *xord*(',')); *v* ← *xx_part*(*vvv*); ⟨ Display big node item *v* 913 ⟩;
    mp_print_char(*mp*, *xord*(',')); *v* ← *xy_part*(*vvv*); ⟨ Display big node item *v* 913 ⟩;
    mp_print_char(*mp*, *xord*(',')); *v* ← *yx_part*(*vvv*); ⟨ Display big node item *v* 913 ⟩;
    mp_print_char(*mp*, *xord*(',')); *v* ← *yy_part*(*vvv*); ⟨ Display big node item *v* 913 ⟩;
    mp_print_char(*mp*, *xord*(')'));
  }

This code is used in section 912.

916. ⟨ Display a color node 916 ⟩ ≡
  {
    mp_node *vvv* ← *v*;
    mp_print_char(*mp*, *xord*('(')); ▷ clang: dereference of null pointer ◁
    assert(*vvv*); *v* ← *red_part*(*vvv*); ⟨ Display big node item *v* 913 ⟩;
    mp_print_char(*mp*, *xord*(',')); *v* ← *green_part*(*vvv*); ⟨ Display big node item *v* 913 ⟩;
    mp_print_char(*mp*, *xord*(',')); *v* ← *blue_part*(*vvv*); ⟨ Display big node item *v* 913 ⟩;
    mp_print_char(*mp*, *xord*(')'));
  }

This code is used in section 912.

917. ⟨ Display a cmykcolor node 917 ⟩ ≡
  {
    mp_node *vvv* ← *v*;
    mp_print_char(*mp*, *xord*('(')); ▷ clang: dereference of null pointer ◁
    assert(*vvv*); *v* ← *cyan_part*(*vvv*); ⟨ Display big node item *v* 913 ⟩;
    mp_print_char(*mp*, *xord*(',')); *v* ← *magenta_part*(*vvv*); ⟨ Display big node item *v* 913 ⟩;
    mp_print_char(*mp*, *xord*(',')); *v* ← *yellow_part*(*vvv*); ⟨ Display big node item *v* 913 ⟩;
    mp_print_char(*mp*, *xord*(',')); *v* ← *black_part*(*vvv*); ⟨ Display big node item *v* 913 ⟩;
    mp_print_char(*mp*, *xord*(')'));
  }

This code is used in section 912.

918. Values of type **picture**, **path**, and **pen** are displayed verbosely in the log file only, unless the user has given a positive value to *tracingonline*.

⟨ Display a complex type 918 ⟩ ≡

```
if (verbosity ≤ 1) {
  mp_print_type(mp, t);
}
else {
  if (mp→selector ≡ term_and_log)
    if (number_nonpositive(internal_value(mp_tracing_online))) {
      mp→selector ← term_only; mp_print_type(mp, t);
      mp_print(mp, "␣(see␣the␣transcript␣file)"); mp→selector ← term_and_log;
    }
  switch (t) {
  case mp_pen_type: mp_print_pen(mp, value_knot(p), "", false); break;
  case mp_path_type: mp_print_path(mp, value_knot(p), "", false); break;
  case mp_picture_type: mp_print_edges(mp, v, "", false); break;
  default: break;
  }
}
```

This code is used in section 912.

919. ⟨ Declare the procedure called *print_dp* 919 ⟩ ≡

```
static void mp_print_dp(MP mp, quarterword t, mp_value_node p, quarterword verbosity)
{
  mp_value_node q;    ▷ the node following p ◁
  q ← (mp_value_node) mp_link(p);
  if ((dep_info(q) ≡ Λ) ∨ (verbosity > 0)) mp_print_dependency(mp, p, t);
  else mp_print(mp, "linearform");
}
```

This code is used in section 910.

920. The displayed name of a variable in a ring will not be a capsule unless the ring consists entirely of capsules.

⟨ Display a variable that's been declared but not defined 920 ⟩ ≡

```
{
  mp_print_type(mp, t);
  if (v ≠ Λ) {
    mp_print_char(mp, xord('␣'));
    while ((mp_name_type(v) ≡ mp_capsule) ∧ (v ≠ p)) v ← value_node(v);
    mp_print_variable_name(mp, v);
  }
}
```

This code is used in section 912.

921. When errors are detected during parsing, it is often helpful to display an expression just above the error message, using *disp_err* just before *mp_error*.

⟨ Declarations 10 ⟩ +≡

```
static void mp_disp_err(MP mp, mp_node p);
```

922. **void** *mp_disp_err*(**MP** *mp*, **mp_node** *p*)

```
{
  if (mp→interaction ≡ mp_error_stop_mode) wake_up_terminal();
  mp_print_nl(mp, ">>␣"); mp_print_exp(mp, p, 1);    ▷ "medium verbose" printing of the expression ◁
}
```

923. If *cur_type* and *cur_exp* contain relevant information that should be recycled, we will use the following procedure, which changes *cur_type* to *known* and stores a given value in *cur_exp*. We can think of *cur_type* and *cur_exp* as either alive or dormant after this has been done, because *cur_exp* will not contain a pointer value.

```
void mp_flush_cur_exp(MP mp, mp_value v)
{
  if (is_number(mp→cur_exp.data.n)) {
    free_number(mp→cur_exp.data.n);
  }
  switch (mp→cur_exp.type) {
  case unknown_types: case mp_transform_type: case mp_color_type: case mp_pair_type:
    case mp_dependent: case mp_proto_dependent: case mp_independent: case mp_cmykcolor_type:
    mp_recycle_value(mp, cur_exp_node()); mp_free_value_node(mp, cur_exp_node()); break;
  case mp_string_type: delete_str_ref(cur_exp_str()); break;
  case mp_pen_type: case mp_path_type: mp_toss_knot_list(mp, cur_exp_knot()); break;
  case mp_picture_type: delete_edge_ref(cur_exp_node()); break;
  default: break;
  }
  mp→cur_exp ← v; mp→cur_exp.type ← mp_known;
}
```

924. There's a much more general procedure that is capable of releasing the storage associated with any non-symbolic value packet.

⟨ Declarations 10 ⟩ +≡

```
  static void mp_recycle_value(MP mp, mp_node p);
```

925. **static void** *mp_recycle_value*(**MP** *mp*, **mp_node** *p*)

```
{
  mp_variable_type t;   ▷ a type code ◁
  FUNCTION_TRACE2("mp_recycle_value(%p)\n", p);
  if (p ≡ Λ ∨ p ≡ MP_VOID) return;
  t ← mp_type(p);
  switch (t) {
  case mp_vacuous: case mp_boolean_type: case mp_known: case mp_numeric_type: break;
  case unknown_types: mp_ring_delete(mp, p); break;
  case mp_string_type: delete_str_ref(value_str(p)); break;
  case mp_path_type: case mp_pen_type: mp_toss_knot_list(mp, value_knot(p)); break;
  case mp_picture_type: delete_edge_ref(value_node(p)); break;
  case mp_cmykcolor_type:
    if (value_node(p) ≠ Λ) {
      mp_recycle_value(mp, cyan_part(value_node(p)));
      mp_recycle_value(mp, magenta_part(value_node(p)));
      mp_recycle_value(mp, yellow_part(value_node(p)));
      mp_recycle_value(mp, black_part(value_node(p)));
      mp_free_value_node(mp, cyan_part(value_node(p)));
      mp_free_value_node(mp, magenta_part(value_node(p)));
      mp_free_value_node(mp, black_part(value_node(p)));
      mp_free_value_node(mp, yellow_part(value_node(p)));
      mp_free_node(mp, value_node(p), cmykcolor_node_size);
    }
    break;
  case mp_pair_type:
    if (value_node(p) ≠ Λ) {
      mp_recycle_value(mp, x_part(value_node(p))); mp_recycle_value(mp, y_part(value_node(p)));
      mp_free_value_node(mp, x_part(value_node(p))); mp_free_value_node(mp, y_part(value_node(p)));
      mp_free_pair_node(mp, value_node(p));
    }
    break;
  case mp_color_type:
    if (value_node(p) ≠ Λ) {
      mp_recycle_value(mp, red_part(value_node(p))); mp_recycle_value(mp, green_part(value_node(p)));
      mp_recycle_value(mp, blue_part(value_node(p))); mp_free_value_node(mp, red_part(value_node(p)));
      mp_free_value_node(mp, green_part(value_node(p)));
      mp_free_value_node(mp, blue_part(value_node(p)));
      mp_free_node(mp, value_node(p), color_node_size);
    }
    break;
  case mp_transform_type:
    if (value_node(p) ≠ Λ) {
      mp_recycle_value(mp, tx_part(value_node(p))); mp_recycle_value(mp, ty_part(value_node(p)));
      mp_recycle_value(mp, xx_part(value_node(p))); mp_recycle_value(mp, xy_part(value_node(p)));
      mp_recycle_value(mp, yx_part(value_node(p))); mp_recycle_value(mp, yy_part(value_node(p)));
      mp_free_value_node(mp, tx_part(value_node(p))); mp_free_value_node(mp, ty_part(value_node(p)));
      mp_free_value_node(mp, xx_part(value_node(p))); mp_free_value_node(mp, xy_part(value_node(p)));
      mp_free_value_node(mp, yx_part(value_node(p))); mp_free_value_node(mp, yy_part(value_node(p)));
      mp_free_node(mp, value_node(p), transform_node_size);
    }
    break;
```

case *mp_dependent*: **case** *mp_proto_dependent*: ▷ Recycle a dependency list ◁
{
mp_value_node $qq \leftarrow$ (**mp_value_node**) *dep_list*((**mp_value_node**) p);
while (*dep_info*(qq) $\neq \Lambda$) $qq \leftarrow$ (**mp_value_node**) *mp_link*(qq);
set_mp_link(*prev_dep*((**mp_value_node**) p), *mp_link*(qq));
set_prev_dep(*mp_link*(qq), *prev_dep*((**mp_value_node**) p)); *set_mp_link*(qq, Λ);
mp_flush_node_list(*mp*, (**mp_node**) *dep_list*((**mp_value_node**) p));
}
break;
case *mp_independent*: ⟨Recycle an independent variable 926⟩;
break;
case *mp_token_list*: **case** *mp_structured*: *mp_confusion*(*mp*, `"recycle"`); **break**;
case *mp_unsuffixed_macro*: **case** *mp_suffixed_macro*: *mp_delete_mac_ref*(*mp*, *value_node*(p)); **break**;
default: ▷ there are no other valid cases, but please the compiler ◁
break;
}
mp_type(p) $\leftarrow$ *mp_undefined*;
}

926. When an independent variable disappears, it simply fades away, unless something depends on it. In the latter case, a dependent variable whose coefficient of dependence is maximal will take its place. The relevant algorithm is due to Ignacio A. Zabala, who implemented it as part of his Ph.n-¿data. thesis (Stanford University, December 1982).

For example, suppose that variable x is being recycled, and that the only variables depending on x are $y = 2x + a$ and $z = x + b$. In this case we want to make y independent and $z = .5y - .5a + b$; no other variables will depend on y. If *tracingequations* > 0 in this situation, we will print '`### -2x=-y+a`'.

There's a slight complication, however: An independent variable x can occur both in dependency lists and in proto-dependency lists. This makes it necessary to be careful when deciding which coefficient is maximal.

Furthermore, this complication is not so slight when a proto-dependent variable is chosen to become independent. For example, suppose that $y = 2x + 100a$ is proto-dependent while $z = x + b$ is dependent; then we must change $z = .5y - 50a + b$ to a proto-dependency, because of the large coefficient '50'.

In order to deal with these complications without wasting too much time, we shall link together the occurrences of x among all the linear dependencies, maintaining separate lists for the dependent and proto-dependent cases.

⟨ Recycle an independent variable 926 ⟩ ≡

```
{
  mp_value_node q, r, s;
  mp_node pp;   ▷ link manipulation register ◁
  mp_number v;   ▷ a value ◁
  mp_number test;   ▷ a temporary value ◁
  new_number(test); new_number(v);
  if (t < mp_dependent) number_clone(v, value_number(p));
  set_number_to_zero(mp→max_c[mp_dependent]); set_number_to_zero(mp→max_c[mp_proto_dependent]);
  mp→max_link[mp_dependent] ← Λ; mp→max_link[mp_proto_dependent] ← Λ;
  q ← (mp_value_node) mp_link(mp→dep_head);
  while (q ≠ mp→dep_head) {
    s ← (mp_value_node) mp→temp_head; set_mp_link(s, dep_list(q));
    while (1) {
      r ← (mp_value_node) mp_link(s);
      if (dep_info(r) ≡ Λ) break;
      if (dep_info(r) ≠ p) {
        s ← r;
      }
      else {
        t ← mp_type(q);
        if (mp_link(s) ≡ dep_list(q)) {   ▷ reset the dep_list ◁
          set_dep_list(q, mp_link(r));
        }
        set_mp_link(s, mp_link(r)); set_dep_info(r, (mp_node) q); number_clone(test, dep_value(r));
        number_abs(test);
        if (number_greater(test, mp→max_c[t])) {   ▷ Record a new maximum coefficient of type t ◁
          if (number_positive(mp→max_c[t])) {
            set_mp_link(mp→max_ptr[t], (mp_node) mp→max_link[t]);
            mp→max_link[t] ← mp→max_ptr[t];
          }
          number_clone(mp→max_c[t], test); mp→max_ptr[t] ← r;
        }
        else {
          set_mp_link(r, (mp_node) mp→max_link[t]); mp→max_link[t] ← r;
        }
      }
```

```
    }
    q ← (mp_value_node) mp_link(r);
  }
  if (number_positive(mp→max_c[mp_dependent]) ∨ number_positive(mp→max_c[mp_proto_dependent])) {
      ▷ Choose a dependent variable to take the place of the disappearing independent variable, and change
        all remaining dependencies accordingly ◁
    mp_number test, ret;    ▷ temporary use ◁
    new_number(ret); new_number(test); number_clone(test, mp→max_c[mp_dependent]);
    number_divide_int(test, 4096);
    if (number_greaterequal(test, mp→max_c[mp_proto_dependent])) t ← mp_dependent;
    else t ← mp_proto_dependent;    ▷ Let s ← max_ptr[t]. At this point we have value(s) = ±max_c[t],
          and dep_info(s) points to the dependent variable pp of type t from whose dependency list we
          have removed node s. We must reinsert node s into the dependency list, with coefficient −1.0,
          and with pp as the new independent variable. Since pp will have a larger serial number than any
          other variable, we can put node s at the head of the list. ◁
        ▷ Determine the dependency list s to substitute for the independent variable p ◁
    s ← mp→max_ptr[t]; pp ← (mp_node) dep_info(s); number_clone(v, dep_value(s));
    if (t ≡ mp_dependent) {
      set_dep_value(s, fraction_one_t);
    }
    else {
      set_dep_value(s, unity_t);
    }
    number_negate(dep_value(s)); r ← (mp_value_node) dep_list((mp_value_node) pp);
    set_mp_link(s, (mp_node) r);
    while (dep_info(r) ≠ Λ) r ← (mp_value_node) mp_link(r);
    q ← (mp_value_node) mp_link(r); set_mp_link(r, Λ);
    set_prev_dep(q, prev_dep((mp_value_node) pp));
    set_mp_link(prev_dep((mp_value_node) pp), (mp_node) q); mp_new_indep(mp, pp);
    if (cur_exp_node() ≡ pp ∧ mp→cur_exp.type ≡ t) mp→cur_exp.type ← mp_independent;
    if (number_positive(internal_value(mp_tracing_equations))) {
        ▷ Show the transformed dependency ◁
      if (mp_interesting(mp, p)) {
        mp_begin_diagnostic(mp); mp_show_transformed_dependency(mp, v, t, p);
        mp_print_dependency(mp, s, t); mp_end_diagnostic(mp, false);
      }
    }
    t ← (quarterword)(mp_dependent + mp_proto_dependent − t);    ▷ complement t ◁
    if (number_positive(mp→max_c[t])) {    ▷ we need to pick up an unchosen dependency ◁
      set_mp_link(mp→max_ptr[t], (mp_node) mp→max_link[t]); mp→max_link[t] ← mp→max_ptr[t];
    }    ▷ Finally, there are dependent and proto-dependent variables whose dependency lists must be
          brought up to date. ◁
    if (t ≠ mp_dependent) {    ▷ Substitute new dependencies in place of p ◁
      for (t ← mp_dependent; t ≤ mp_proto_dependent; t ← t + 1) {
        r ← mp→max_link[t];
        while (r ≠ Λ) {
          q ← (mp_value_node) dep_info(r); number_clone(test, v); number_negate(test);
          make_fraction(ret, dep_value(r), test);
          set_dep_list(q, mp_p_plus_fq(mp, (mp_value_node) dep_list(q), ret, s, t, mp_dependent));
          if (dep_list(q) ≡ (mp_node) mp→dep_final) mp_make_known(mp, q, mp→dep_final);
          q ← r; r ← (mp_value_node) mp_link(r); mp_free_dep_node(mp, q);
        }
```

```
      }
    }
    else {    ▷ Substitute new proto-dependencies in place of p ◁
      for (t ← mp_dependent; t ≤ mp_proto_dependent; t ← t + 1) {
        r ← mp→max_link[t];
        while (r ≠ Λ) {
          q ← (mp_value_node) dep_info(r);
          if (t ≡ mp_dependent) {    ▷ for safety's sake, we change q to mp_proto_dependent ◁
            if (cur_exp_node() ≡ (mp_node) q ∧ mp→cur_exp.type ≡ mp_dependent)
              mp→cur_exp.type ← mp_proto_dependent;
            set_dep_list(q, mp_p_over_v(mp, (mp_value_node) dep_list(q), unity_t, mp_dependent,
                mp_proto_dependent)); mp_type(q) ← mp_proto_dependent;
            fraction_to_round_scaled(dep_value(r));
          }
          number_clone(test, v); number_negate(test); make_scaled(ret, dep_value(r), test);
          set_dep_list(q, mp_p_plus_fq(mp, (mp_value_node) dep_list(q), ret, s, mp_proto_dependent,
              mp_proto_dependent));
          if (dep_list(q) ≡ (mp_node) mp→dep_final) mp_make_known(mp, q, mp→dep_final);
          q ← r; r ← (mp_value_node) mp_link(r); mp_free_dep_node(mp, q);
        }
      }
    }
    mp_flush_node_list(mp, (mp_node) s);
    if (mp→fix_needed) mp_fix_dependencies(mp);
    check_arith(); free_number(ret);
  }
  free_number(v); free_number(test);
}
```

This code is used in section 925.

927. ⟨ Declarations 10 ⟩ +≡

```
static void mp_show_transformed_dependency(MP mp, mp_number v, mp_variable_type t, mp_node
    p);
```

928. **static void** *mp_show_transformed_dependency*(**MP** *mp*, **mp_number** *v*, **mp_variable_type** *t*, **mp_node** *p*)

```
{
  mp_number vv;    ▷ for temp use ◁
  new_number(vv); mp_print_nl(mp, "###␣");
  if (number_positive(v)) mp_print_char(mp, xord('-'));
  if (t ≡ mp_dependent) {
    number_clone(vv, mp→max_c[mp_dependent]); fraction_to_round_scaled(vv);
  }
  else {
    number_clone(vv, mp→max_c[mp_proto_dependent]);
  }
  if (¬number_equal(vv, unity_t)) {
    print_number(vv);
  }
  mp_print_variable_name(mp, p);
  while (indep_scale(p) > 0) {
    mp_print(mp, "*4"); set_indep_scale(p, indep_scale(p) − 2);
  }
  if (t ≡ mp_dependent) mp_print_char(mp, xord('='));
  else mp_print(mp, "␣=␣");
  free_number(vv);
}
```

929. The code for independency removal makes use of three non-symbolic arrays.

⟨ Global variables 18 ⟩ +≡

```
  mp_number max_c[mp_proto_dependent + 1];    ▷ max coefficient magnitude ◁
  mp_value_node max_ptr[mp_proto_dependent + 1];    ▷ where p occurs with max_c ◁
  mp_value_node max_link[mp_proto_dependent + 1];    ▷ other occurrences of p ◁
```

930. ⟨ Initialize table entries 186 ⟩ +≡

```
{
  int i;
  for (i ← 0; i < mp_proto_dependent + 1; i++) {
    new_number(mp→max_c[i]);
  }
}
```

931. ⟨ Dealloc variables 31 ⟩ +≡

```
{
  int i;
  for (i ← 0; i < mp_proto_dependent + 1; i++) {
    free_number(mp→max_c[i]);
  }
}
```

932. A global variable *var_flag* is set to a special command code just before METAPOST calls *scan_expression*, if the expression should be treated as a variable when this command code immediately follows. For example, *var_flag* is set to *assignment* at the beginning of a statement, because we want to know the *location* of a variable at the left of '`:=`', not the *value* of that variable.

The *scan_expression* subroutine calls *scan_tertiary*, which calls *scan_secondary*, which calls *scan_primary*, which sets *var_flag*: $\leftarrow 0$. In this way each of the scanning routines "knows" when it has been called with a special *var_flag*, but *var_flag* is usually zero.

A variable preceding a command that equals *var_flag* is converted to a token list rather than a value. Furthermore, an '`=`' sign following an expression with *var_flag* $\leftarrow$ *assignment* is not considered to be a relation that produces boolean expressions.

⟨ Global variables 18 ⟩ +≡
int *var_flag*; ▷ command that wants a variable ◁

933. ⟨ Set initial values of key variables 42 ⟩ +≡
mp→*var_flag* $\leftarrow 0$;

934. Parsing primary expressions. The first parsing routine, *scan_primary*, is also the most complicated one, since it involves so many different cases. But each case—with one exception—is fairly simple by itself.

When *scan_primary* begins, the first token of the primary to be scanned should already appear in *cur_cmd*, *cur_mod*, and *cur_sym*. The values of *cur_type* and *cur_exp* should be either dead or dormant, as explained earlier. If *cur_cmd* is not between *min_primary_command* and *max_primary_command*, inclusive, a syntax error will be signaled.

Later we'll come to procedures that perform actual operations like addition, square root, and so on; our purpose now is to do the parsing. But we might as well mention those future procedures now, so that the suspense won't be too bad:

do_nullary(*c*) does primitive operations that have no operands (e.g., '**true**' or '**pencircle**');

do_unary(*c*) applies a primitive operation to the current expression;

do_binary(*p*, *c*) applies a primitive operation to the capsule *p* and the current expression.

```
⟨ Declare the basic parsing subroutines 934 ⟩ ≡
  static void check_for_mediation(MP mp);
  void mp_scan_primary(MP mp)
  {
    mp_command_code my_var_flag;    ▷ initial value of my_var_flag ◁
    my_var_flag ← mp→var_flag; mp→var_flag ← 0;
  RESTART: check_arith();    ▷ Supply diagnostic information, if requested ◁
    if (mp→interrupt ≠ 0) {
      if (mp→OK_to_interrupt) {
        mp_back_input(mp); check_interrupt; mp_get_x_next(mp);
      }
    }
    switch (cur_cmd()) {
    case mp_left_delimiter:
      {    ▷ Scan a delimited primary ◁
        mp_node p, q, r;    ▷ for list manipulation ◁
        mp_sym l_delim, r_delim;    ▷ hash addresses of a delimiter pair ◁
        l_delim ← cur_sym(); r_delim ← equiv_sym(cur_sym()); mp_get_x_next(mp);
        mp_scan_expression(mp);
        if ((cur_cmd() ≡ mp_comma) ∧ (mp→cur_exp.type ≥ mp_known)) {
            ▷ Scan the rest of a delimited set of numerics ◁    ▷ This code uses the fact that red_part and
            green_part are synonymous with x_part and y_part. ◁
          p ← mp_stash_cur_exp(mp); mp_get_x_next(mp); mp_scan_expression(mp);
            ▷ Make sure the second part of a pair or color has a numeric type ◁
          if (mp→cur_exp.type < mp_known) {
            const char *hlp[] ← {"I've␣started␣to␣scan␣a␣pair␣`(a,b)'␣or␣a␣color␣`(a,b,c)';",
                "but␣after␣finding␣a␣nice␣`a'␣I␣found␣a␣`b'␣that␣isn't",
                "of␣numeric␣type.␣So␣I've␣changed␣that␣part␣to␣zero.",
                "(The␣b␣that␣I␣didn't␣like␣appears␣above␣the␣error␣message.)", Λ};
            mp_value new_expr;
            memset(&new_expr, 0, sizeof(mp_value)); mp_disp_err(mp, Λ);
            new_number(new_expr.data.n); set_number_to_zero(new_expr.data.n);
            mp_back_error(mp, "Nonnumeric␣ypart␣has␣been␣replaced␣by␣0", hlp, true);
            mp_get_x_next(mp); mp_flush_cur_exp(mp, new_expr);
          }
          q ← mp_get_value_node(mp); mp_name_type(q) ← mp_capsule;
          if (cur_cmd() ≡ mp_comma) {
```

```
mp_init_color_node(mp, q); r ← value_node(q); mp_stash_in(mp, y_part(r));
mp_unstash_cur_exp(mp, p); mp_stash_in(mp, x_part(r));
  ▷ Scan the last of a triplet of numerics ◁
mp_get_x_next(mp); mp_scan_expression(mp);
if (mp→cur_exp.type < mp_known) {
  mp_value new_expr;
  const char *hlp[] ← {"I've␣just␣scanned␣a␣color␣`(a,b,c)'␣or␣\
      cmykcolor(a,b,c,d);␣but␣the␣`c'",
      "isn't␣of␣numeric␣type.␣So␣I've␣changed␣that␣part␣to␣zero.",
      "(The␣c␣that␣I␣didn't␣like␣appears␣above␣the␣error␣message.)", Λ};
  memset(&new_expr, 0, sizeof(mp_value)); mp_disp_err(mp, Λ);
  new_number(new_expr.data.n); set_number_to_zero(new_expr.data.n);
  mp_back_error(mp, "Nonnumeric␣third␣part␣has␣been␣replaced␣by␣0", hlp, true);
  mp_get_x_next(mp); mp_flush_cur_exp(mp, new_expr);
}
mp_stash_in(mp, blue_part(r));
if (cur_cmd() ≡ mp_comma) {
  mp_node t;    ▷ a token ◁
  mp_init_cmykcolor_node(mp, q); t ← value_node(q);
  mp_type(cyan_part(t)) ← mp_type(red_part(r));
  set_value_number(cyan_part(t), value_number(red_part(r)));
  mp_type(magenta_part(t)) ← mp_type(green_part(r));
  set_value_number(magenta_part(t), value_number(green_part(r)));
  mp_type(yellow_part(t)) ← mp_type(blue_part(r));
  set_value_number(yellow_part(t), value_number(blue_part(r)));    ▷ see mp_stash_in ◁
  if (((mp_type(cyan_part(t))) ≠ mp_independent) ∧ ((mp_type(cyan_part(t))) ≠ mp_known))
    {    ▷ Copy the dep list ◁
    set_dep_list(cyan_part(t), dep_list((mp_value_node) red_part(r)));
    set_prev_dep(cyan_part(t), prev_dep((mp_value_node) red_part(r)));
    set_mp_link(prev_dep(cyan_part(t)), (mp_node) cyan_part(t));
  }
  if (((mp_type(magenta_part(t))) ≠ mp_independent) ∧ ((mp_type(magenta_part(t))) ≠
        mp_known)) {    ▷ Copy the dep list ◁
    set_dep_list(magenta_part(t), dep_list((mp_value_node) green_part(r)));
    set_prev_dep(magenta_part(t), prev_dep((mp_value_node) green_part(r)));
    set_mp_link(prev_dep(magenta_part(t)), (mp_node) magenta_part(t));
  }
  if (((mp_type(yellow_part(t))) ≠ mp_independent)∧((mp_type(yellow_part(t))) ≠ mp_known))
    {    ▷ Copy the dep list ◁
    set_dep_list(yellow_part(t), dep_list((mp_value_node) blue_part(r)));
    set_prev_dep(yellow_part(t), prev_dep((mp_value_node) blue_part(r)));
    set_mp_link(prev_dep(yellow_part(t)), (mp_node) yellow_part(t));
  }
  mp_recycle_value(mp, r); r ← t;    ▷ Scan the last of a quartet of numerics ◁
  mp_get_x_next(mp); mp_scan_expression(mp);
  if (mp→cur_exp.type < mp_known) {
    const char *hlp[] ← {"I've␣just␣scanned␣a␣cmykcolor␣`(c,m,y,k\
        )';␣but␣the␣`k'␣isn't",
        "of␣numeric␣type.␣So␣I've␣changed␣that␣part␣to␣zero.",
        "(The␣k␣that␣I␣didn't␣like␣appears␣above␣the␣error␣message.)", Λ};
    mp_value new_expr;
```

```
          memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
          mp_disp_err(mp, Λ); set_number_to_zero(new_expr.data.n);
          mp_back_error(mp, "Nonnumeric␣blackpart␣has␣been␣replaced␣by␣0", hlp, true);
          mp_get_x_next(mp); mp_flush_cur_exp(mp, new_expr);
        }
        mp_stash_in(mp, black_part(r));
      }
    }
    else {
      mp_init_pair_node(mp, q); r ← value_node(q); mp_stash_in(mp, y_part(r));
      mp_unstash_cur_exp(mp, p); mp_stash_in(mp, x_part(r));
    }
    mp_check_delimiter(mp, l_delim, r_delim); mp→cur_exp.type ← mp_type(q); set_cur_exp_node(q);
  }
  else {
    mp_check_delimiter(mp, l_delim, r_delim);
  }
}
break;
case mp_begin_group:   ▷ Scan a grouped primary ◁
  ▷ The local variable group_line keeps track of the line where a begingroup command occurred; this
    will be useful in an error message if the group doesn't actually end. ◁
{
  integer group_line;   ▷ where a group began ◁
  group_line ← mp_true_line(mp);
  if (number_positive(internal_value(mp_tracing_commands))) show_cur_cmd_mod;
  mp_save_boundary(mp);
  do {
    mp_do_statement(mp);   ▷ ends with cur_cmd ≥ semicolon ◁
  } while (cur_cmd() ≡ mp_semicolon);
  if (cur_cmd() ≠ mp_end_group) {
    char msg[256];
    const char *hlp[] ← {"I␣saw␣a␣'begingroup'␣back␣there␣that␣hasn't␣been␣matched",
        "by␣'endgroup'.␣So␣I've␣inserted␣'endgroup'␣now.", Λ};
    mp_snprintf(msg, 256, "A␣group␣begun␣on␣line␣%d␣never␣ended", (int) group_line);
    mp_back_error(mp, msg, hlp, true); set_cur_cmd((mp_variable_type) mp_end_group);
  }
  mp_unsave(mp);   ▷ this might change cur_type, if independent variables are recycled ◁
  if (number_positive(internal_value(mp_tracing_commands))) show_cur_cmd_mod;
}
break;
case mp_string_token:   ▷ Scan a string constant ◁
  mp→cur_exp.type ← mp_string_type; set_cur_exp_str(cur_mod_str()); break;
case mp_numeric_token:
  {   ▷ Scan a primary that starts with a numeric token ◁   ▷ A numeric token might be a primary by
        itself, or it might be the numerator of a fraction composed solely of numeric tokens, or it might
        multiply the primary that follows (provided that the primary doesn't begin with a plus sign or a
        minus sign). The code here uses the facts that max_primary_command ← plus_or_minus and
        max_primary_command − 1 ← numeric_token. If a fraction is found that is less than unity, we
        try to retain higher precision when we use it in scalar multiplication. ◁
    mp_number num, denom;   ▷ for primaries that are fractions, like '1/2' ◁
```

```
    new_number(num); new_number(denom); set_cur_exp_value_number(cur_mod_number());
    mp→cur_exp.type ← mp_known; mp_get_x_next(mp);
    if (cur_cmd() ≠ mp_slash) {
      set_number_to_zero(num); set_number_to_zero(denom);
    }
    else {
      mp_get_x_next(mp);
      if (cur_cmd() ≠ mp_numeric_token) {
        mp_back_input(mp); set_cur_cmd((mp_variable_type) mp_slash); set_cur_mod(mp_over);
        set_cur_sym(mp→frozen_slash); free_number(num); free_number(denom); goto DONE;
      }
      number_clone(num, cur_exp_value_number()); number_clone(denom, cur_mod_number());
      if (number_zero(denom)) {    ▷ Protest division by zero ◁
        const char *hlp[] ← {"I'll␣pretend␣that␣you␣meant␣to␣divide␣by␣1.", Λ};
        mp_error(mp, "Division␣by␣zero", hlp, true);
      }
      else {
        mp_number ret;
        new_number(ret); make_scaled(ret, num, denom); set_cur_exp_value_number(ret);
        free_number(ret);
      }
      check_arith(); mp_get_x_next(mp);
    }
    if (cur_cmd() ≥ mp_min_primary_command) {
      if (cur_cmd() < mp_numeric_token) {    ▷ in particular, cur_cmd <> plus_or_minus ◁
        mp_node p;    ▷ for list manipulation ◁
        mp_number absnum, absdenom;
        new_number(absnum); new_number(absdenom); p ← mp_stash_cur_exp(mp);
        mp_scan_primary(mp); number_clone(absnum, num); number_abs(absnum);
        number_clone(absdenom, denom); number_abs(absdenom);
        if (number_greaterequal(absnum, absdenom) ∨ (mp→cur_exp.type < mp_color_type)) {
          mp_do_binary(mp, p, mp_times);
        }
        else {
          mp_frac_mult(mp, num, denom); mp_free_value_node(mp, p);
        }
        free_number(absnum); free_number(absdenom);
      }
    }
    free_number(num); free_number(denom); goto DONE;
  }
  break;
case mp_nullary:    ▷ Scan a nullary operation ◁
  mp_do_nullary(mp, (quarterword) cur_mod()); break;
case mp_unary: case mp_type_name: case mp_cycle: case mp_plus_or_minus:
  {    ▷ Scan a unary operation ◁
    quarterword c;    ▷ a primitive operation code ◁
    c ← (quarterword) cur_mod(); mp_get_x_next(mp); mp_scan_primary(mp);
    mp_do_unary(mp, c); goto DONE;
  }
  break;
```

```
case mp_primary_binary:
  {    ▷ Scan a binary operation with 'of' between its operands ◁
    mp_node p;    ▷ for list manipulation ◁
    quarterword c;    ▷ a primitive operation code ◁

    c ← (quarterword) cur_mod( ); mp_get_x_next(mp); mp_scan_expression(mp);
    if (cur_cmd( ) ≠ mp_of_token) {
      char msg[256];
      mp_string sname;
      const char *hlp[ ] ← {"I've␣got␣the␣first␣argument;␣will␣look␣now␣for␣the␣other.",
          Λ};
      int old_setting ← mp→selector;

      mp→selector ← new_string; mp_print_cmd_mod(mp, mp_primary_binary, c);
      mp→selector ← old_setting; sname ← mp_make_string(mp);
      mp_snprintf(msg, 256, "Missing␣'of'␣has␣been␣inserted␣for␣%s", mp_str(mp, sname));
      delete_str_ref(sname); mp_back_error(mp, msg, hlp, true);
    }
    p ← mp_stash_cur_exp(mp); mp_get_x_next(mp); mp_scan_primary(mp); mp_do_binary(mp, p, c);
    goto DONE;
  }
  break;
case mp_str_op:    ▷ Convert a suffix to a string ◁
  mp_get_x_next(mp); mp_scan_suffix(mp); mp→old_setting ← mp→selector;
  mp→selector ← new_string; mp_show_token_list(mp, cur_exp_node( ), Λ, 100000, 0);
  mp_flush_token_list(mp, cur_exp_node( )); set_cur_exp_str(mp_make_string(mp));
  mp→selector ← mp→old_setting; mp→cur_exp.type ← mp_string_type; goto DONE; break;
case mp_void_op:
  {    ▷ Convert a suffix to a boolean ◁
    mp_value new_expr;

    memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n); mp_get_x_next(mp);
    mp_scan_suffix(mp);
    if (cur_exp_node( ) ≡ Λ) {
      set_number_from_boolean(new_expr.data.n, mp_true_code);
    }
    else {
      set_number_from_boolean(new_expr.data.n, mp_false_code);
    }
    mp_flush_cur_exp(mp, new_expr); cur_exp_node( ) ← Λ;
      ▷ !! do not replace with set_cur_exp_node( ) !! ◁
    mp→cur_exp.type ← mp_boolean_type; goto DONE;
  }
  break;
case mp_internal_quantity:    ▷ Scan an internal numeric quantity ◁    ▷ If an internal quantity appears
      all by itself on the left of an assignment, we return a token list of length one, containing the address
      of the internal quantity, with name_type equal to mp_internal_sym. (This accords with the
      conventions of the save stack, as described earlier.) ◁
  {
    halfword qq ← cur_mod( );

    if (my_var_flag ≡ mp_assignment) {
      mp_get_x_next(mp);
      if (cur_cmd( ) ≡ mp_assignment) {
```

```
        set_cur_exp_node(mp_get_symbolic_node(mp)); set_mp_sym_info(cur_exp_node(), qq);
        mp_name_type(cur_exp_node()) ← mp_internal_sym; mp→cur_exp.type ← mp_token_list;
        goto DONE;
      }
      mp_back_input(mp);
    }
    if (internal_type(qq) ≡ mp_string_type) {
      set_cur_exp_str(internal_string(qq));
    }
    else {
      set_cur_exp_value_number(internal_value(qq));
    }
    mp→cur_exp.type ← internal_type(qq);
  }
  break;
case mp_capsule_token: mp_make_exp_copy(mp, cur_mod_node()); break;
case mp_tag_token: ⟨Scan a variable primary; goto restart if it turns out to be a macro 938⟩;
  break;
default: mp_bad_exp(mp, "A␣primary"); goto RESTART; break;
}
mp_get_x_next(mp);    ▷ the routines goto done if they don't want this ◁
DONE: check_for_mediation(mp);
}
```

See also sections 935, 945, 946, 948, 949, 950, and 955.

This code is used in section 1280.

935. Expressions of the form '`a[b,c]`' are converted into '`b+a*(c-b)`', without checking the types of `b` or `c`, provided that `a` is numeric.

⟨ Declare the basic parsing subroutines 934 ⟩ +≡

```
static void check_for_mediation(MP mp)
{
  mp_node p, q, r;    ▷ for list manipulation ◁
  if (cur_cmd() ≡ mp_left_bracket) {
    if (mp→cur_exp.type ≥ mp_known) {    ▷ Scan a mediation construction ◁
      p ← mp_stash_cur_exp(mp); mp_get_x_next(mp); mp_scan_expression(mp);
      if (cur_cmd() ≠ mp_comma) {    ▷ Put the left bracket and the expression back to be rescanned ◁
          ▷ The left bracket that we thought was introducing a subscript might have actually been the
           left bracket in a mediation construction like 'x[a,b]'. So we don't issue an error message at
           this point; but we do want to back up so as to avoid any embarrassment about our incorrect
           assumption. ◁
        mp_back_input(mp);    ▷ that was the token following the current expression ◁
        mp_back_expr(mp); set_cur_cmd((mp_variable_type) mp_left_bracket);
        set_cur_mod_number(zero_t); set_cur_sym(mp→frozen_left_bracket); mp_unstash_cur_exp(mp, p);
      }
      else {
        q ← mp_stash_cur_exp(mp); mp_get_x_next(mp); mp_scan_expression(mp);
        if (cur_cmd() ≠ mp_right_bracket) {
          const char *hlp[] ← {"I've␣scanned␣an␣expression␣of␣the␣form␣`a[b,c',",
              "so␣a␣right␣bracket␣should␣have␣come␣next.",
              "I␣shall␣pretend␣that␣one␣was␣there.", Λ};
          mp_back_error(mp, "Missing␣`]'␣has␣been␣inserted", hlp, true);
        }
        r ← mp_stash_cur_exp(mp); mp_make_exp_copy(mp, q); mp_do_binary(mp, r, mp_minus);
        mp_do_binary(mp, p, mp_times); mp_do_binary(mp, q, mp_plus); mp_get_x_next(mp);
      }
    }
  }
}
```

936. Errors at the beginning of expressions are flagged by *bad_exp*.

```
static void mp_bad_exp(MP mp, const char *s)
{
  char msg[256];
  int save_flag;
  const char *hlp[] ← {"I'm␣afraid␣I␣need␣some␣sort␣of␣value␣in␣order␣to␣continue,",
      "so␣I've␣tentatively␣inserted␣'0'.␣You␣may␣want␣to",
      "delete␣this␣zero␣and␣insert␣something␣else;",
      "see␣Chapter␣27␣of␣The␣METAFONTbook␣for␣an␣example.", Λ};
  {
    mp_string cm;
    int old_selector ← mp→selector;
    mp→selector ← new_string; mp_print_cmd_mod(mp, cur_cmd(), cur_mod());
    mp→selector ← old_selector; cm ← mp_make_string(mp);
    mp_snprintf(msg, 256, "%s␣expression␣can't␣begin␣with␣'%s'", s, mp_str(mp, cm));
    delete_str_ref(cm);
  }
  mp_back_input(mp); set_cur_sym(Λ); set_cur_cmd((mp_variable_type) mp_numeric_token);
  set_cur_mod_number(zero_t); mp_ins_error(mp, msg, hlp, true); save_flag ← mp→var_flag;
  mp→var_flag ← 0; mp_get_x_next(mp); mp→var_flag ← save_flag;
}
```

937. The *stash_in* subroutine puts the current (numeric) expression into a field within a "big node."

```
static void mp_stash_in(MP mp, mp_node p)
{
  mp_value_node q;   ▷ temporary register ◁
  mp_type(p) ← mp→cur_exp.type;
  if (mp→cur_exp.type ≡ mp_known) {
    set_value_number(p, cur_exp_value_number());
  }
  else {
    if (mp→cur_exp.type ≡ mp_independent) {   ▷ Stash an independent cur_exp into a big node ◁
        ▷ In rare cases the current expression can become independent. There may be many dependency
          lists pointing to such an independent capsule, so we can't simply move it into place within a big
          node. Instead, we copy it, then recycle it. ◁
      q ← mp_single_dependency(mp, cur_exp_node());
      if (q ≡ mp→dep_final) {
        mp_type(p) ← mp_known; set_value_number(p, zero_t); mp_free_dep_node(mp, q);
      }
      else {
        mp_new_dep(mp, p, mp_dependent, q);
      }
      mp_recycle_value(mp, cur_exp_node()); mp_free_value_node(mp, cur_exp_node());
    }
    else {
      set_dep_list((mp_value_node) p, dep_list((mp_value_node) cur_exp_node()));
      set_prev_dep((mp_value_node) p, prev_dep((mp_value_node) cur_exp_node()));
      set_mp_link(prev_dep((mp_value_node) p), p);
      mp_free_dep_node(mp, (mp_value_node) cur_exp_node());
    }
  }
  mp→cur_exp.type ← mp_vacuous;
}
```

938. The most difficult part of *scan_primary* has been saved for last, since it was necessary to build up some confidence first. We can now face the task of scanning a variable.

As we scan a variable, we build a token list containing the relevant names and subscript values, simultaneously following along in the "collective" structure to see if we are actually dealing with a macro instead of a value.

The local variables *pre_head* and *post_head* will point to the beginning of the prefix and suffix lists; *tail* will point to the end of the list that is currently growing.

Another local variable, *tt*, contains partial information about the declared type of the variable-so-far. If $tt \geq mp\_unsuffixed\_macro$, the relation $tt \leftarrow mp\_type(q)$ will always hold. If $tt \leftarrow undefined$, the routine doesn't bother to update its information about type. And if $undefined < tt < mp\_unsuffixed\_macro$, the precise value of *tt* isn't critical.

⟨ Scan a variable primary; **goto** *restart* if it turns out to be a macro 938 ⟩ ≡

```
{
  mp_node p, q;    ▷ for list manipulation ◁
  mp_node t;    ▷ a token ◁
  mp_node pre_head, post_head, tail;    ▷ prefix and suffix list variables ◁
  quarterword tt;    ▷ approximation to the type of the variable-so-far ◁
  mp_node macro_ref ← 0;    ▷ reference count for a suffixed macro ◁
  pre_head ← mp_get_symbolic_node(mp); tail ← pre_head; post_head ← Λ; tt ← mp_vacuous;
  while (1) {
    t ← mp_cur_tok(mp); mp_link(tail) ← t;
    if (tt ≠ mp_undefined) {
        ▷ Find the approximate type tt and corresponding q ◁    ▷ Every time we call get_x_next, there's a
          chance that the variable we've been looking at will disappear. Thus, we cannot safely keep q
          pointing into the variable structure; we need to start searching from the root each time. ◁
      mp_sym qq;
      p ← mp_link(pre_head); qq ← mp_sym_sym(p); tt ← mp_undefined;
      if (eq_type(qq) % mp_outer_tag ≡ mp_tag_token) {
        q ← equiv_node(qq);
        if (q ≡ Λ) goto DONE2;
        while (1) {
          p ← mp_link(p);
          if (p ≡ Λ) {
            tt ← mp_type(q); goto DONE2;
          }
          if (mp_type(q) ≠ mp_structured) goto DONE2;
          q ← mp_link(attr_head(q));    ▷ the collective_subscript attribute ◁
          if (mp_type(p) ≡ mp_symbol_node) {    ▷ it's not a subscript ◁
            do {
              q ← mp_link(q);
            } while (¬(hashloc(q) ≥ mp_sym_sym(p)));
            if (hashloc(q) > mp_sym_sym(p)) goto DONE2;
          }
        }
      }
    DONE2:
      if (tt ≥ mp_unsuffixed_macro) {
          ▷ Either begin an unsuffixed macro call or prepare for a suffixed one ◁
        mp_link(tail) ← Λ;
        if (tt > mp_unsuffixed_macro) {    ▷ tt ← mp_suffixed_macro ◁
```

$post\_head \leftarrow mp\_get\_symbolic\_node(mp)$; $tail \leftarrow post\_head$; $mp\_link(tail) \leftarrow t$;
$tt \leftarrow mp\_undefined$; $macro\_ref \leftarrow value\_node(q)$; $add\_mac\_ref(macro\_ref)$;
}
else { ▷ Set up unsuffixed macro call and **goto** *restart* ◁
▷ The only complication associated with macro calling is that the prefix and "at" parameters must be packaged in an appropriate list of lists. ◁
$p \leftarrow mp\_get\_symbolic\_node(mp)$; $set\_mp\_sym\_sym(pre\_head, mp\_link(pre\_head))$;
$mp\_link(pre\_head) \leftarrow p$; $set\_mp\_sym\_sym(p, t)$;
$mp\_macro\_call(mp, value\_node(q), pre\_head, \Lambda)$; $mp\_get\_x\_next(mp)$; **goto** RESTART;
}
}
}
$mp\_get\_x\_next(mp)$; $tail \leftarrow t$;
if $(cur\_cmd() \equiv mp\_left\_bracket)$ {
▷ Scan for a subscript; replace *cur_cmd* by *numeric_token* if found ◁
$mp\_get\_x\_next(mp)$; $mp\_scan\_expression(mp)$;
if $(cur\_cmd() \neq mp\_right\_bracket)$ {
▷ Put the left bracket and the expression back to be rescanned ◁ ▷ The left bracket that we thought was introducing a subscript might have actually been the left bracket in a mediation construction like '`x[a,b]`'. So we don't issue an error message at this point; but we do want to back up so as to avoid any embarrassment about our incorrect assumption. ◁
$mp\_back\_input(mp)$; ▷ that was the token following the current expression ◁
$mp\_back\_expr(mp)$; $set\_cur\_cmd((\mathbf{mp\_variable\_type})\, mp\_left\_bracket)$;
$set\_cur\_mod\_number(zero\_t)$; $set\_cur\_sym(mp\rightarrow frozen\_left\_bracket)$;
}
else {
if $(mp\rightarrow cur\_exp.type \neq mp\_known)$ $mp\_bad\_subscript(mp)$;
$set\_cur\_cmd((\mathbf{mp\_variable\_type})\, mp\_numeric\_token)$;
$set\_cur\_mod\_number(cur\_exp\_value\_number())$; $set\_cur\_sym(\Lambda)$;
}
}
if $(cur\_cmd() > mp\_max\_suffix\_token)$ **break**;
if $(cur\_cmd() < mp\_min\_suffix\_token)$ **break**;
} ▷ now *cur_cmd* is *internal_quantity*, *tag_token*, or *numeric_token* ◁ ▷ Handle unusual cases that masquerade as variables, and **goto** *restart* or **goto** *done* if appropriate; otherwise make a copy of the variable and **goto** *done* ◁ ▷ If the variable does exist, we also need to check for a few other special cases before deciding that a plain old ordinary variable has, indeed, been scanned. ◁
if $(post\_head \neq \Lambda)$ { ▷ Set up suffixed macro call and **goto** *restart* ◁
▷ If the "variable" that turned out to be a suffixed macro no longer exists, we don't care, because we have reserved a pointer (*macro_ref*) to its token list. ◁
$mp\_back\_input(mp)$; $p \leftarrow mp\_get\_symbolic\_node(mp)$; $q \leftarrow mp\_link(post\_head)$;
$set\_mp\_sym\_sym(pre\_head, mp\_link(pre\_head))$; $mp\_link(pre\_head) \leftarrow post\_head$;
$set\_mp\_sym\_sym(post\_head, q)$; $mp\_link(post\_head) \leftarrow p$; $set\_mp\_sym\_sym(p, mp\_link(q))$;
$mp\_link(q) \leftarrow \Lambda$; $mp\_macro\_call(mp, macro\_ref, pre\_head, \Lambda)$; $decr\_mac\_ref(macro\_ref)$;
$mp\_get\_x\_next(mp)$; **goto** RESTART;
}
$q \leftarrow mp\_link(pre\_head)$; $mp\_free\_symbolic\_node(mp, pre\_head)$;
if $(cur\_cmd() \equiv my\_var\_flag)$ {
$mp\rightarrow cur\_exp.type \leftarrow mp\_token\_list$; $set\_cur\_exp\_node(q)$; **goto** DONE;
}
$p \leftarrow mp\_find\_variable(mp, q)$;
if $(p \neq \Lambda)$ {

```
      mp_make_exp_copy(mp, p);
    }
    else {
      mp_value new_expr;
      const char *hlp[] ← {"While␣I␣was␣evaluating␣the␣suffix␣of␣this␣variable,",
          "something␣was␣redefined,␣and␣it's␣no␣longer␣a␣variable!",
          "In␣order␣to␣get␣back␣on␣my␣feet,␣I've␣inserted␣'0'␣instead.", Λ};
      char *msg ← mp_obliterated(mp, q);
      memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
      set_number_to_zero(new_expr.data.n); mp_back_error(mp, msg, hlp, true); free(msg);
      mp_get_x_next(mp); mp_flush_cur_exp(mp, new_expr);
    }
    mp_flush_node_list(mp, q); goto DONE;
  }
```

This code is used in section 934.

939. Here's a routine that puts the current expression back to be read again.

```
  static void mp_back_expr(MP mp)
  {
    mp_node p;    ▷ capsule token ◁
    p ← mp_stash_cur_exp(mp); mp_link(p) ← Λ; back_list(p);
  }
```

940. Unknown subscripts lead to the following error message.

```
  static void mp_bad_subscript(MP mp)
  {
    mp_value new_expr;
    const char *hlp[] ← {"A␣bracketed␣subscript␣must␣have␣a␣known␣numeric␣value;",
        "unfortunately,␣what␣I␣found␣was␣the␣value␣that␣appears␣just",
        "above␣this␣error␣message.␣So␣I'll␣try␣a␣zero␣subscript.", Λ};
    memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n); mp_disp_err(mp, Λ);
    mp_error(mp, "Improper␣subscript␣has␣been␣replaced␣by␣zero", hlp, true);
    mp_flush_cur_exp(mp, new_expr);
  }
```

941. How do things stand now? Well, we have scanned an entire variable name, including possible subscripts and/or attributes; *cur_cmd*, *cur_mod*, and *cur_sym* represent the token that follows. If *post_head* $\leftarrow \Lambda$, a token list for this variable name starts at *mp_link*(*pre_head*), with all subscripts evaluated. But if *post_head* <> Λ, the variable turned out to be a suffixed macro; *pre_head* is the head of the prefix list, while *post_head* is the head of a token list containing both '`@!`' and the suffix.

Our immediate problem is to see if this variable still exists. (Variable structures can change drastically whenever we call *get_x_next*; users aren't supposed to do this, but the fact that it is possible means that we must be cautious.)

The following procedure creates an error message for when a variable unexpectedly disappears.

```
static char *mp_obliterated(MP mp, mp_node q)
{
  char msg[256];
  mp_string sname;
  int old_setting ← mp→selector;

  mp→selector ← new_string; mp_show_token_list(mp, q, Λ, 1000, 0); sname ← mp_make_string(mp);
  mp→selector ← old_setting;
  mp_snprintf(msg, 256, "Variable␣%s␣has␣been␣obliterated", mp_str(mp, sname));
  delete_str_ref(sname); return xstrdup(msg);
}
```

942. Our remaining job is simply to make a copy of the value that has been found. Some cases are harder than others, but complexity arises solely because of the multiplicity of possible cases.

⟨ Declare the procedure called *make_exp_copy* 942 ⟩ ≡
⟨ Declare subroutines needed by *make_exp_copy* 943 ⟩;

```
static void mp_make_exp_copy(MP mp, mp_node p)
{
  mp_node t;    ▷ register(s) for list manipulation ◁
  mp_value_node q;
RESTART: mp→cur_exp.type ← mp_type(p);
  switch (mp→cur_exp.type) {
  case mp_vacuous: case mp_boolean_type: case mp_known:
    set_cur_exp_value_number(value_number(p)); break;
  case unknown_types: t ← mp_new_ring_entry(mp, p); set_cur_exp_node(t); break;
  case mp_string_type: set_cur_exp_str(value_str(p)); break;
  case mp_picture_type: set_cur_exp_node(value_node(p)); add_edge_ref(cur_exp_node()); break;
  case mp_pen_type: set_cur_exp_knot(copy_pen(value_knot(p))); break;
  case mp_path_type: set_cur_exp_knot(mp_copy_path(mp, value_knot(p))); break;
  case mp_transform_type: case mp_color_type: case mp_cmykcolor_type: case mp_pair_type:
      ▷ Copy the big node p ◁    ▷ The most tedious case arises when the user refers to a pair, color, or
        transform variable; we must copy several fields, each of which can be independent, dependent,
        mp_proto_dependent, or known. ◁
    if (value_node(p) ≡ Λ) {
      switch (mp_type(p)) {
      case mp_pair_type: mp_init_pair_node(mp, p); break;
      case mp_color_type: mp_init_color_node(mp, p); break;
      case mp_cmykcolor_type: mp_init_cmykcolor_node(mp, p); break;
      case mp_transform_type: mp_init_transform_node(mp, p); break;
      default:    ▷ there are no other valid cases, but please the compiler ◁
        break;
      }
    }
    t ← mp_get_value_node(mp); mp_name_type(t) ← mp_capsule;
    q ← (mp_value_node) value_node(p);
    switch (mp→cur_exp.type) {
    case mp_pair_type: mp_init_pair_node(mp, t); mp_install(mp, y_part(value_node(t)), y_part(q));
      mp_install(mp, x_part(value_node(t)), x_part(q)); break;
    case mp_color_type: mp_init_color_node(mp, t);
      mp_install(mp, blue_part(value_node(t)), blue_part(q));
      mp_install(mp, green_part(value_node(t)), green_part(q));
      mp_install(mp, red_part(value_node(t)), red_part(q)); break;
    case mp_cmykcolor_type: mp_init_cmykcolor_node(mp, t);
      mp_install(mp, black_part(value_node(t)), black_part(q));
      mp_install(mp, yellow_part(value_node(t)), yellow_part(q));
      mp_install(mp, magenta_part(value_node(t)), magenta_part(q));
      mp_install(mp, cyan_part(value_node(t)), cyan_part(q)); break;
    case mp_transform_type: mp_init_transform_node(mp, t);
      mp_install(mp, yy_part(value_node(t)), yy_part(q));
      mp_install(mp, yx_part(value_node(t)), yx_part(q));
      mp_install(mp, xy_part(value_node(t)), xy_part(q));
      mp_install(mp, xx_part(value_node(t)), xx_part(q));
```

```
        mp_install(mp, ty_part(value_node(t)), ty_part(q));
        mp_install(mp, tx_part(value_node(t)), tx_part(q));  break;
      default:      ▷ there are no other valid cases, but please the compiler ◁
        break;
      }
      set_cur_exp_node(t); break;
    case mp_dependent: case mp_proto_dependent:
      mp_encapsulate(mp, mp_copy_dep_list(mp, (mp_value_node) dep_list((mp_value_node) p)));
      break;
    case mp_numeric_type: mp_new_indep(mp, p);  goto RESTART; break;
    case mp_independent: q ← mp_single_dependency(mp, p);
      if (q ≡ mp→dep_final) {
        mp→cur_exp.type ← mp_known;  set_cur_exp_value_number(zero_t);  mp_free_dep_node(mp, q);
      }
      else {
        mp→cur_exp.type ← mp_dependent;  mp_encapsulate(mp, q);
      }
      break;
    default: mp_confusion(mp, "copy");  break;
    }
  }
```

This code is used in section 710.

943. The *encapsulate* subroutine assumes that *dep_final* is the tail of dependency list p.

```
⟨ Declare subroutines needed by make_exp_copy 943 ⟩ ≡
  static void mp_encapsulate(MP mp, mp_value_node p)
  {
    mp_node q ← mp_get_value_node(mp);
    FUNCTION_TRACE2("mp_encapsulate(%p)\n", p);  mp_name_type(q) ← mp_capsule;
    mp_new_dep(mp, q, mp→cur_exp.type, p);  set_cur_exp_node(q);
  }
```

See also section 944.

This code is used in section 942.

944. The *install* procedure copies a numeric field q into field r of a big node that will be part of a capsule.

⟨ Declare subroutines needed by *make_exp_copy* 943 ⟩ +≡

```
static void mp_install(MP mp, mp_node r, mp_node q)
{
  mp_value_node p;   ▷ temporary register ◁
  if (mp_type(q) ≡ mp_known) {
    mp_type(r) ← mp_known; set_value_number(r, value_number(q));
  }
  else if (mp_type(q) ≡ mp_independent) {
    p ← mp_single_dependency(mp, q);
    if (p ≡ mp→dep_final) {
      mp_type(r) ← mp_known; set_value_number(r, zero_t); mp_free_dep_node(mp, p);
    }
    else {
      mp_new_dep(mp, r, mp_dependent, p);
    }
  }
  else {
    mp_new_dep(mp, r, mp_type(q), mp_copy_dep_list(mp,
        (mp_value_node) dep_list((mp_value_node) q)));
  }
}
```

945. Here is a comparatively simple routine that is used to scan the **suffix** parameters of a macro.

```
⟨Declare the basic parsing subroutines 934⟩ +≡
  static void mp_scan_suffix(MP mp)
  {
    mp_node h, t;    ▷ head and tail of the list being built ◁
    mp_node p;    ▷ temporary register ◁
    h ← mp_get_symbolic_node(mp); t ← h;
    while (1) {
      if (cur_cmd() ≡ mp_left_bracket) {
          ▷ Scan a bracketed subscript and set cur_cmd: ← numeric_token ◁
        mp_get_x_next(mp); mp_scan_expression(mp);
        if (mp→cur_exp.type ≠ mp_known) mp_bad_subscript(mp);
        if (cur_cmd() ≠ mp_right_bracket) {
          const char *hlp[] ← {"I've␣seen␣a␣`['␣and␣a␣subscript␣value,␣in␣a␣suffix,",
              "so␣a␣right␣bracket␣should␣have␣come␣next.",
              "I␣shall␣pretend␣that␣one␣was␣there.", Λ};
          mp_back_error(mp, "Missing␣`]'␣has␣been␣inserted", hlp, true);
        }
        set_cur_cmd((mp_variable_type) mp_numeric_token);
        set_cur_mod_number(cur_exp_value_number());
      }
      if (cur_cmd() ≡ mp_numeric_token) {
        mp_number arg1;
        new_number(arg1); number_clone(arg1, cur_mod_number()); p ← mp_new_num_tok(mp, arg1);
        free_number(arg1);
      }
      else if ((cur_cmd() ≡ mp_tag_token) ∨ (cur_cmd() ≡ mp_internal_quantity)) {
        p ← mp_get_symbolic_node(mp); set_mp_sym_sym(p, cur_sym());
        mp_name_type(p) ← cur_sym_mod();
      }
      else {
        break;
      }
      mp_link(t) ← p; t ← p; mp_get_x_next(mp);
    }
    set_cur_exp_node(mp_link(h)); mp_free_symbolic_node(mp, h); mp→cur_exp.type ← mp_token_list;
  }
```

946. Parsing secondary and higher expressions.

After the intricacies of *scan_primary*, the *scan_secondary* routine is refreshingly simple. It's not trivial, but the operations are relatively straightforward; the main difficulty is, again, that expressions and data structures might change drastically every time we call *get_x_next*, so a cautious approach is mandatory. For example, a macro defined by **primarydef** might have disappeared by the time its second argument has been scanned; we solve this by increasing the reference count of its token list, so that the macro can be called even after it has been clobbered.

⟨Declare the basic parsing subroutines 934⟩ +≡

```
static void mp_scan_secondary(MP mp)
{
  mp_node p;   ▷ for list manipulation ◁
  halfword c, d;   ▷ operation codes or modifiers ◁
  mp_node cc ← Λ;
  mp_sym mac_name ← Λ;   ▷ token defined with primarydef ◁
RESTART:
  if ((cur_cmd() < mp_min_primary_command) ∨ (cur_cmd() > mp_max_primary_command))
    mp_bad_exp(mp, "A␣secondary");
  mp_scan_primary(mp);
CONTINUE:
  if (cur_cmd() ≤ mp_max_secondary_command ∧ cur_cmd() ≥ mp_min_secondary_command) {
    p ← mp_stash_cur_exp(mp); d ← cur_cmd(); c ← cur_mod();
    if (d ≡ mp_secondary_primary_macro) {
      cc ← cur_mod_node(); mac_name ← cur_sym(); add_mac_ref(cc);
    }
    mp_get_x_next(mp); mp_scan_primary(mp);
    if (d ≠ mp_secondary_primary_macro) {
      mp_do_binary(mp, p, c);
    }
    else {
      mp_back_input(mp); mp_binary_mac(mp, p, cc, mac_name); decr_mac_ref(cc);
      mp_get_x_next(mp); goto RESTART;
    }
    goto CONTINUE;
  }
}
```

947. The following procedure calls a macro that has two parameters, p and *cur_exp*.

```
static void mp_binary_mac(MP mp, mp_node p, mp_node c, mp_sym n)
{
  mp_node q, r;   ▷ nodes in the parameter list ◁
  q ← mp_get_symbolic_node(mp); r ← mp_get_symbolic_node(mp); mp_link(q) ← r;
  set_mp_sym_sym(q, p); set_mp_sym_sym(r, mp_stash_cur_exp(mp)); mp_macro_call(mp, c, q, n);
}
```

948. The next procedure, *scan_tertiary*, is pretty much the same deal.

⟨Declare the basic parsing subroutines 934⟩ +≡

```
static void mp_scan_tertiary(MP mp)
{
  mp_node p;    ▷ for list manipulation ◁
  halfword c, d;    ▷ operation codes or modifiers ◁
  mp_node cc ← Λ;
  mp_sym mac_name ← Λ;    ▷ token defined with secondarydef ◁
RESTART:
  if ((cur_cmd() < mp_min_primary_command) ∨ (cur_cmd() > mp_max_primary_command))
    mp_bad_exp(mp, "A␣tertiary");
  mp_scan_secondary(mp);
CONTINUE:
  if (cur_cmd() ≤ mp_max_tertiary_command) {
    if (cur_cmd() ≥ mp_min_tertiary_command) {
      p ← mp_stash_cur_exp(mp); c ← cur_mod(); d ← cur_cmd();
      if (d ≡ mp_tertiary_secondary_macro) {
        cc ← cur_mod_node(); mac_name ← cur_sym(); add_mac_ref(cc);
      }
      mp_get_x_next(mp); mp_scan_secondary(mp);
      if (d ≠ mp_tertiary_secondary_macro) {
        mp_do_binary(mp, p, c);
      }
      else {
        mp_back_input(mp); mp_binary_mac(mp, p, cc, mac_name); decr_mac_ref(cc);
        mp_get_x_next(mp); goto RESTART;
      }
      goto CONTINUE;
    }
  }
}
```

949. Finally we reach the deepest level in our quartet of parsing routines. This one is much like the others; but it has an extra complication from paths, which materialize here.

⟨ Declare the basic parsing subroutines 934 ⟩ +≡

```
static int mp_scan_path(MP mp);
static void mp_scan_expression(MP mp)
{
  int my_var_flag;    ▷ initial value of var_flag ◁
  my_var_flag ← mp→var_flag; check_expansion_depth();
RESTART:
  if ((cur_cmd() < mp_min_primary_command) ∨ (cur_cmd() > mp_max_primary_command))
    mp_bad_exp(mp, "An");
  mp_scan_tertiary(mp);
CONTINUE:
  if (cur_cmd() ≤ mp_max_expression_command) {
    if (cur_cmd() ≥ mp_min_expression_command) {
      if ((cur_cmd() ≠ mp_equals) ∨ (my_var_flag ≠ mp_assignment)) {
        mp_node p;    ▷ for list manipulation ◁
        mp_node cc ← Λ;
        halfword c;
        halfword d;    ▷ operation codes or modifiers ◁
        mp_sym mac_name;    ▷ token defined with tertiarydef ◁
        mac_name ← Λ; p ← mp_stash_cur_exp(mp); d ← cur_cmd(); c ← cur_mod();
        if (d ≡ mp_expression_tertiary_macro) {
          cc ← cur_mod_node(); mac_name ← cur_sym(); add_mac_ref(cc);
        }
        if ((d < mp_ampersand) ∨ ((d ≡ mp_ampersand) ∧ ((mp_type(p) ≡ mp_pair_type) ∨ (mp_type(p) ≡
              mp_path_type)))) {
            ▷ Scan a path construction operation; but return if p has the wrong type ◁
          mp_unstash_cur_exp(mp, p);
          if (¬mp_scan_path(mp)) {
            mp→expand_depth_count −−; return;
          }
        }
        else {
          mp_get_x_next(mp); mp_scan_tertiary(mp);
          if (d ≠ mp_expression_tertiary_macro) {
            mp_do_binary(mp, p, c);
          }
          else {
            mp_back_input(mp); mp_binary_mac(mp, p, cc, mac_name); decr_mac_ref(cc);
            mp_get_x_next(mp); goto RESTART;
          }
        }
        goto CONTINUE;
      }
    }
  }
  mp→expand_depth_count −−;
}
```

950. The reader should review the data structure conventions for paths before hoping to understand the next part of this code.

#define *min_tension* *three_quarter_unit_t*

⟨ Declare the basic parsing subroutines 934 ⟩ +≡

```
static void force_valid_tension_setting(MP mp)
{
  if ((mp→cur_exp.type ≠ mp_known) ∨ number_less(cur_exp_value_number(), min_tension)) {
    mp_value new_expr;
    const char *hlp[] ← {"The␣expression␣above␣should␣have␣been␣a␣number␣>=3/4.", Λ};
    memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n); mp_disp_err(mp, Λ);
    number_clone(new_expr.data.n, unity_t);
    mp_back_error(mp, "Improper␣tension␣has␣been␣set␣to␣1", hlp, true); mp_get_x_next(mp);
    mp_flush_cur_exp(mp, new_expr);
  }
}
static int mp_scan_path(MP mp)
{
  mp_knot path_p, path_q, r;
  mp_knot pp, qq;
  halfword d;    ▷ operation code or modifier ◁
  boolean cycle_hit;    ▷ did a path expression just end with 'cycle'? ◁
  mp_number x, y;    ▷ explicit coordinates or tension at a path join ◁
  int t;    ▷ knot type following a path join ◁
  t ← 0; cycle_hit ← false;    ▷ Convert the left operand, p, into a partial path ending at q; but return if
      p doesn't have a suitable type ◁
  if (mp→cur_exp.type ≡ mp_pair_type) path_p ← mp_pair_to_knot(mp);
  else if (mp→cur_exp.type ≡ mp_path_type) path_p ← cur_exp_knot();
  else return 0;
  path_q ← path_p;
  while (mp_next_knot(path_q) ≠ path_p) path_q ← mp_next_knot(path_q);
  if (mp_left_type(path_p) ≠ mp_endpoint) {    ▷ open up a cycle ◁
    r ← mp_copy_knot(mp, path_p); mp_next_knot(path_q) ← r; path_q ← r;
  }
  mp_left_type(path_p) ← mp_open; mp_right_type(path_q) ← mp_open; new_number(y); new_number(x);
CONTINUE_PATH:    ▷ Determine the path join parameters; but goto finish_path if there's only a direction
      specifier ◁    ▷ At this point cur_cmd is either ampersand, left_brace, or path_join. ◁
  if (cur_cmd() ≡ mp_left_brace) {
      ▷ Put the pre-join direction information into node q ◁    ▷ At this point mp_right_type(q) is usually
        open, but it may have been set to some other value by a previous operation. We must maintain the
        value of mp_right_type(q) in cases such as '..{curl2}z{0,0}..'. ◁
    t ← mp_scan_direction(mp);
    if (t ≠ mp_open) {
      mp_right_type(path_q) ← (unsigned short) t;
      number_clone(path_q→right_given, cur_exp_value_number());
      if (mp_left_type(path_q) ≡ mp_open) {
        mp_left_type(path_q) ← (unsigned short) t;
        number_clone(path_q→left_given, cur_exp_value_number());
      }    ▷ note that left_given(q) ← left_curl(q) ◁
    }
  }
  d ← cur_cmd();
```

```
if (d ≡ mp_path_join) {   ▷ Determine the tension and/or control points ◁
  mp_get_x_next(mp);
  if (cur_cmd() ≡ mp_tension) {   ▷ Set explicit tensions ◁
    mp_get_x_next(mp); set_number_from_scaled(y, cur_cmd());
    if (cur_cmd() ≡ mp_at_least) mp_get_x_next(mp);
    mp_scan_primary(mp); force_valid_tension_setting(mp);
    if (number_to_scaled(y) ≡ mp_at_least) {
      if (is_number(cur_exp_value_number())) number_negate(cur_exp_value_number());
    }
    number_clone(path_q→right_tension, cur_exp_value_number());
    if (cur_cmd() ≡ mp_and_command) {
      mp_get_x_next(mp); set_number_from_scaled(y, cur_cmd());
      if (cur_cmd() ≡ mp_at_least) mp_get_x_next(mp);
      mp_scan_primary(mp); force_valid_tension_setting(mp);
      if (number_to_scaled(y) ≡ mp_at_least) {
        if (is_number(cur_exp_value_number())) number_negate(cur_exp_value_number());
      }
    }
    number_clone(y, cur_exp_value_number());
  }
  else if (cur_cmd() ≡ mp_controls) {   ▷ Set explicit control points ◁
    mp_right_type(path_q) ← mp_explicit; t ← mp_explicit; mp_get_x_next(mp);
    mp_scan_primary(mp); mp_known_pair(mp); number_clone(path_q→right_x, mp→cur_x);
    number_clone(path_q→right_y, mp→cur_y);
    if (cur_cmd() ≠ mp_and_command) {
      number_clone(x, path_q→right_x); number_clone(y, path_q→right_y);
    }
    else {
      mp_get_x_next(mp); mp_scan_primary(mp); mp_known_pair(mp); number_clone(x, mp→cur_x);
      number_clone(y, mp→cur_y);
    }
  }
  else {
    set_number_to_unity(path_q→right_tension); set_number_to_unity(y); mp_back_input(mp);
      ▷ default tension ◁
    goto DONE;
  }
  if (cur_cmd() ≠ mp_path_join) {
    const char *hlp[] ← {"A␣path␣join␣command␣should␣end␣with␣two␣dots.", Λ};
    mp_back_error(mp, "Missing␣‘..’␣has␣been␣inserted", hlp, true);
  }
DONE: ;
}
else if (d ≠ mp_ampersand) {
  goto FINISH_PATH;
}
mp_get_x_next(mp);
if (cur_cmd() ≡ mp_left_brace) {   ▷ Put the post-join direction information into x and t ◁
    ▷ Since left_tension and mp_left_y share the same position in knot nodes, and since left_given is
      similarly equivalent to left_x, we use x and y to hold the given direction and tension information
      when there are no explicit control points. ◁
  t ← mp_scan_direction(mp);
```

```
    if (mp_right_type(path_q) ≠ mp_explicit) number_clone(x, cur_exp_value_number());
    else t ← mp_explicit;    ▷ the direction information is superfluous ◁
  }
  else if (mp_right_type(path_q) ≠ mp_explicit) {
    t ← mp_open; set_number_to_zero(x);
  }
  if (cur_cmd() ≡ mp_cycle) {
      ▷ Get ready to close a cycle ◁    ▷ If a person tries to define an entire path by saying '(x,y)&cycle',
        we silently change the specification to '(x,y)..cycle', since a cycle shouldn't have length zero. ◁
    cycle_hit ← true; mp_get_x_next(mp); pp ← path_p; qq ← path_p;
    if (d ≡ mp_ampersand) {
      if (path_p ≡ path_q) {
        d ← mp_path_join; set_number_to_unity(path_q→right_tension); set_number_to_unity(y);
      }
    }
  }
  else {
    mp_scan_tertiary(mp);    ▷ Convert the right operand, cur_exp, into a partial path from pp to qq ◁
    if (mp→cur_exp.type ≠ mp_path_type) pp ← mp_pair_to_knot(mp);
    else pp ← cur_exp_knot();
    qq ← pp;
    while (mp_next_knot(qq) ≠ pp) qq ← mp_next_knot(qq);
    if (mp_left_type(pp) ≠ mp_endpoint) {    ▷ open up a cycle ◁
      r ← mp_copy_knot(mp, pp); mp_next_knot(qq) ← r; qq ← r;
    }
    mp_left_type(pp) ← mp_open; mp_right_type(qq) ← mp_open;
  }    ▷ Join the partial paths and reset p and q to the head and tail of the result ◁
  if (d ≡ mp_ampersand) {
    if (¬(number_equal(path_q→x_coord, pp→x_coord)) ∨ ¬(number_equal(path_q→y_coord, pp→y_coord))) {
      const char *hlp[] ← {"When␣you␣join␣paths␣'p&q',␣the␣ending␣point␣of␣p",
          "must␣be␣exactly␣equal␣to␣the␣starting␣point␣of␣q.",
          "So␣I'm␣going␣to␣pretend␣that␣you␣said␣'p..q'␣instead.", Λ};
      mp_back_error(mp, "Paths␣don't␣touch;␣'&'␣will␣be␣changed␣to␣'..'", hlp, true);
      mp_get_x_next(mp); d ← mp_path_join; set_number_to_unity(path_q→right_tension);
      set_number_to_unity(y);
    }
  }    ▷ Plug an opening in mp_right_type(pp), if possible ◁
  if (mp_right_type(pp) ≡ mp_open) {
    if ((t ≡ mp_curl) ∨ (t ≡ mp_given)) {
      mp_right_type(pp) ← (unsigned short) t; number_clone(pp→right_given, x);
    }
  }
  if (d ≡ mp_ampersand) {    ▷ Splice independent paths together ◁
    if (mp_left_type(path_q) ≡ mp_open)
      if (mp_right_type(path_q) ≡ mp_open) {
        mp_left_type(path_q) ← mp_curl; set_number_to_unity(path_q→left_curl);
      }
    if (mp_right_type(pp) ≡ mp_open)
      if (t ≡ mp_open) {
        mp_right_type(pp) ← mp_curl; set_number_to_unity(pp→right_curl);
      }
```

```
      mp_right_type(path_q) ← mp_right_type(pp);  mp_next_knot(path_q) ← mp_next_knot(pp);
      number_clone(path_q→right_x, pp→right_x);  number_clone(path_q→right_y, pp→right_y);  mp_xfree(pp);
      if (qq ≡ pp) qq ← path_q;
    }
    else {    ▷ Plug an opening in mp_right_type(q), if possible ◁
      if (mp_right_type(path_q) ≡ mp_open) {
        if ((mp_left_type(path_q) ≡ mp_curl) ∨ (mp_left_type(path_q) ≡ mp_given)) {
          mp_right_type(path_q) ← mp_left_type(path_q);
          number_clone(path_q→right_given, path_q→left_given);
        }
      }
      mp_next_knot(path_q) ← pp;  number_clone(pp→left_y, y);
      if (t ≠ mp_open) {
        number_clone(pp→left_x, x);  mp_left_type(pp) ← (unsigned short) t;
      }
    }
    path_q ← qq;
    if (cur_cmd() ≥ mp_min_expression_command)
      if (cur_cmd() ≤ mp_ampersand)
        if (¬cycle_hit) goto CONTINUE_PATH;
  FINISH_PATH:    ▷ Choose control points for the path and put the result into cur_exp ◁
    if (cycle_hit) {
      if (d ≡ mp_ampersand) path_p ← path_q;
    }
    else {
      mp_left_type(path_p) ← mp_endpoint;
      if (mp_right_type(path_p) ≡ mp_open) {
        mp_right_type(path_p) ← mp_curl;  set_number_to_unity(path_p→right_curl);
      }
      mp_right_type(path_q) ← mp_endpoint;
      if (mp_left_type(path_q) ≡ mp_open) {
        mp_left_type(path_q) ← mp_curl;  set_number_to_unity(path_q→left_curl);
      }
      mp_next_knot(path_q) ← path_p;
    }
    mp_make_choices(mp, path_p);  mp→cur_exp.type ← mp_path_type;  set_cur_exp_knot(path_p);
    free_number(x); free_number(y); return 1;
  }
```

951. A pair of numeric values is changed into a knot node for a one-point path when METAPOST discovers that the pair is part of a path.

```
  static mp_knot mp_pair_to_knot(MP mp)
  {    ▷ convert a pair to a knot with two endpoints ◁
    mp_knot q;    ▷ the new node ◁
    q ← mp_new_knot(mp);  mp_left_type(q) ← mp_endpoint;  mp_right_type(q) ← mp_endpoint;
    mp_originator(q) ← mp_metapost_user;  mp_next_knot(q) ← q;  mp_known_pair(mp);
    number_clone(q→x_coord, mp→cur_x);  number_clone(q→y_coord, mp→cur_y);  return q;
  }
```

952. The *known_pair* subroutine sets *cur_x* and *cur_y* to the components of the current expression, assuming that the current expression is a pair of known numerics. Unknown components are zeroed, and the current expression is flushed.

⟨ Declarations 10 ⟩ +≡
static void *mp_known_pair*(**MP** *mp*);

953.
```
void mp_known_pair(MP mp)
{
  mp_value new_expr;
  mp_node p;    ▷ the pair node ◁
  memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
  if (mp→cur_exp.type ≠ mp_pair_type) {
    const char *hlp[] ← {"I␣need␣x␣and␣y␣numbers␣for␣this␣part␣of␣the␣path.",
        "The␣value␣I␣found␣(see␣above)␣was␣no␣good;",
        "so␣I'll␣try␣to␣keep␣going␣by␣using␣zero␣instead.",
        "(Chapter␣27␣of␣The␣METAFONTbook␣explains␣that",
        "you␣might␣want␣to␣type␣`I␣??""?'␣now.)", Λ};
    mp_disp_err(mp, Λ);
    mp_back_error(mp, "Undefined␣coordinates␣have␣been␣replaced␣by␣(0,0)", hlp, true);
    mp_get_x_next(mp); mp_flush_cur_exp(mp, new_expr); set_number_to_zero(mp→cur_x);
    set_number_to_zero(mp→cur_y);
  }
  else {
    p ← value_node(cur_exp_node());
      ▷ Make sure that both x and y parts of p are known; copy them into cur_x and cur_y ◁
    if (mp_type(x_part(p)) ≡ mp_known) {
      number_clone(mp→cur_x, value_number(x_part(p)));
    }
    else {
      const char *hlp[] ← {"I␣need␣a␣`known'␣x␣value␣for␣this␣part␣of␣the␣path.",
          "The␣value␣I␣found␣(see␣above)␣was␣no␣good;",
          "so␣I'll␣try␣to␣keep␣going␣by␣using␣zero␣instead.",
          "(Chapter␣27␣of␣The␣METAFONTbook␣explains␣that",
          "you␣might␣want␣to␣type␣`I␣??""?'␣now.)", Λ};
      mp_disp_err(mp, x_part(p));
      mp_back_error(mp, "Undefined␣x␣coordinate␣has␣been␣replaced␣by␣0", hlp, true);
      mp_get_x_next(mp); mp_recycle_value(mp, x_part(p)); set_number_to_zero(mp→cur_x);
    }
    if (mp_type(y_part(p)) ≡ mp_known) {
      number_clone(mp→cur_y, value_number(y_part(p)));
    }
    else {
      const char *hlp[] ← {"I␣need␣a␣`known'␣y␣value␣for␣this␣part␣of␣the␣path.",
          "The␣value␣I␣found␣(see␣above)␣was␣no␣good;",
          "so␣I'll␣try␣to␣keep␣going␣by␣using␣zero␣instead.",
          "(Chapter␣27␣of␣The␣METAFONTbook␣explains␣that",
          "you␣might␣want␣to␣type␣`I␣??""?'␣now.)", Λ};
      mp_disp_err(mp, y_part(p));
      mp_back_error(mp, "Undefined␣y␣coordinate␣has␣been␣replaced␣by␣0", hlp, true);
      mp_get_x_next(mp); mp_recycle_value(mp, y_part(p)); set_number_to_zero(mp→cur_y);
    }
    mp_flush_cur_exp(mp, new_expr);
  }
}
```

954. The *scan_direction* subroutine looks at the directional information that is enclosed in braces, and also scans ahead to the following character. A type code is returned, either *open* (if the direction was $(0,0)$), or *curl* (if the direction was a curl of known value *cur_exp*), or *given* (if the direction is given by the *angle* value that now appears in *cur_exp*).

There's nothing difficult about this subroutine, but the program is rather lengthy because a variety of potential errors need to be nipped in the bud.

```
static quarterword mp_scan_direction(MP mp)
{
  int t;    ▷ the type of information found ◁
  mp_get_x_next(mp);
  if (cur_cmd() ≡ mp_curl_command) {    ▷ Scan a curl specification ◁
    mp_get_x_next(mp); mp_scan_expression(mp);
    if ((mp→cur_exp.type ≠ mp_known) ∨ (number_negative(cur_exp_value_number()))) {
      mp_value new_expr;
      const char *hlp[] ← {"A␣curl␣must␣be␣a␣known,␣nonnegative␣number.", Λ};
      memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
      set_number_to_unity(new_expr.data.n); mp_disp_err(mp, Λ);
      mp_back_error(mp, "Improper␣curl␣has␣been␣replaced␣by␣1", hlp, true); mp_get_x_next(mp);
      mp_flush_cur_exp(mp, new_expr);
    }
    t ← mp_curl;
  }
  else {    ▷ Scan a given direction ◁
    mp_scan_expression(mp);
    if (mp→cur_exp.type > mp_pair_type) {    ▷ Get given directions separated by commas ◁
      mp_number xx;
      new_number(xx);
      if (mp→cur_exp.type ≠ mp_known) {
        mp_value new_expr;
        const char *hlp[] ← {"I␣need␣a␣‘known’␣x␣value␣for␣this␣part␣of␣the␣path.",
            "The␣value␣I␣found␣(see␣above)␣was␣no␣good;",
            "so␣I’ll␣try␣to␣keep␣going␣by␣using␣zero␣instead.",
            "(Chapter␣27␣of␣The␣METAFONTbook␣explains␣that",
            "you␣might␣want␣to␣type␣‘I␣??""?’␣now.)", Λ};
        memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
        set_number_to_zero(new_expr.data.n); mp_disp_err(mp, Λ);
        mp_back_error(mp, "Undefined␣x␣coordinate␣has␣been␣replaced␣by␣0", hlp, true);
        mp_get_x_next(mp); mp_flush_cur_exp(mp, new_expr);
      }
      number_clone(xx, cur_exp_value_number());
      if (cur_cmd() ≠ mp_comma) {
        const char *hlp[] ← {"I’ve␣got␣the␣x␣coordinate␣of␣a␣path␣direction;",
            "will␣look␣for␣the␣y␣coordinate␣next.", Λ};
        mp_back_error(mp, "Missing␣‘,’␣has␣been␣inserted", hlp, true);
      }
      mp_get_x_next(mp); mp_scan_expression(mp);
      if (mp→cur_exp.type ≠ mp_known) {
        mp_value new_expr;
        const char *hlp[] ← {"I␣need␣a␣‘known’␣y␣value␣for␣this␣part␣of␣the␣path.",
            "The␣value␣I␣found␣(see␣above)␣was␣no␣good;",
            "so␣I’ll␣try␣to␣keep␣going␣by␣using␣zero␣instead.",
```

```
            "(Chapter␣27␣of␣The␣METAFONTbook␣explains␣that",
            "you␣might␣want␣to␣type␣‘I␣??""?’␣now.)", Λ};
        memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
        set_number_to_zero(new_expr.data.n); mp_disp_err(mp, Λ);
        mp_back_error(mp, "Undefined␣y␣coordinate␣has␣been␣replaced␣by␣0", hlp, true);
        mp_get_x_next(mp); mp_flush_cur_exp(mp, new_expr);
      }
      number_clone(mp→cur_y, cur_exp_value_number()); number_clone(mp→cur_x, xx);
      free_number(xx);
    }
    else {
      mp_known_pair(mp);
    }
    if (number_zero(mp→cur_x) ∧ number_zero(mp→cur_y)) t ← mp_open;
    else {
      mp_number narg;
      new_angle(narg); n_arg(narg, mp→cur_x, mp→cur_y); t ← mp_given;
      set_cur_exp_value_number(narg); free_number(narg);
    }
  }
  if (cur_cmd() ≠ mp_right_brace) {
    const char *hlp[] ← {"I’ve␣scanned␣a␣direction␣spec␣for␣part␣of␣a␣path,",
        "so␣a␣right␣brace␣should␣have␣come␣next.", "I␣shall␣pretend␣that␣one␣was␣there.",
        Λ};
    mp_back_error(mp, "Missing␣‘}’␣has␣been␣inserted", hlp, true);
  }
  mp_get_x_next(mp); return (quarterword) t;
}
```

955. Finally, we sometimes need to scan an expression whose value is supposed to be either *true_code* or *false_code*.

```
#define mp_get_boolean(mp)
        do {
          mp_get_x_next(mp); mp_scan_expression(mp);
          if (mp→cur_exp.type ≠ mp_boolean_type) {
            do_boolean_error(mp);
          }
        } while (0)
```

⟨ Declare the basic parsing subroutines 934 ⟩ +≡

```
static void do_boolean_error(MP mp)
{
  mp_value new_expr;
  const char *hlp[] ← {"The␣expression␣shown␣above␣should␣have␣had␣a␣definite",
      "true-or-false␣value.␣I’m␣changing␣it␣to␣‘false’.", Λ};
  memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n); mp_disp_err(mp, Λ);
  set_number_from_boolean(new_expr.data.n, mp_false_code);
  mp_back_error(mp, "Undefined␣condition␣will␣be␣treated␣as␣‘false’", hlp, true);
  mp_get_x_next(mp); mp_flush_cur_exp(mp, new_expr); mp→cur_exp.type ← mp_boolean_type;
}
```

956. ⟨ Declarations 10 ⟩ +≡
static void *do_boolean_error*(**MP** *mp*);

957. Doing the operations. The purpose of parsing is primarily to permit people to avoid piles of parentheses. But the real work is done after the structure of an expression has been recognized; that's when new expressions are generated. We turn now to the guts of METAPOST, which handles individual operators that have come through the parsing mechanism.

We'll start with the easy ones that take no operands, then work our way up to operators with one and ultimately two arguments. In other words, we will write the three procedures *do_nullary*, *do_unary*, and *do_binary* that are invoked periodically by the expression scanners.

First let's make sure that all of the primitive operators are in the hash table. Although *scan_primary* and its relatives made use of the *cmd* code for these operators, the *do* routines base everything on the *mod* code. For example, *do_binary* doesn't care whether the operation it performs is a *primary_binary* or *secondary_binary*, etc.

⟨ Put each of METAPOST's primitives into the hash table 204 ⟩ +≡

```
mp_primitive(mp, "true", mp_nullary, mp_true_code);
mp_primitive(mp, "false", mp_nullary, mp_false_code);
mp_primitive(mp, "nullpicture", mp_nullary, mp_null_picture_code);
mp_primitive(mp, "nullpen", mp_nullary, mp_null_pen_code);
mp_primitive(mp, "readstring", mp_nullary, mp_read_string_op);
mp_primitive(mp, "pencircle", mp_nullary, mp_pen_circle);
mp_primitive(mp, "normaldeviate", mp_nullary, mp_normal_deviate);
mp_primitive(mp, "readfrom", mp_unary, mp_read_from_op);
mp_primitive(mp, "closefrom", mp_unary, mp_close_from_op);
mp_primitive(mp, "odd", mp_unary, mp_odd_op); mp_primitive(mp, "known", mp_unary, mp_known_op);
mp_primitive(mp, "unknown", mp_unary, mp_unknown_op);
mp_primitive(mp, "not", mp_unary, mp_not_op); mp_primitive(mp, "decimal", mp_unary, mp_decimal);
mp_primitive(mp, "reverse", mp_unary, mp_reverse);
mp_primitive(mp, "makepath", mp_unary, mp_make_path_op);
mp_primitive(mp, "makepen", mp_unary, mp_make_pen_op);
mp_primitive(mp, "oct", mp_unary, mp_oct_op); mp_primitive(mp, "hex", mp_unary, mp_hex_op);
mp_primitive(mp, "ASCII", mp_unary, mp_ASCII_op);
mp_primitive(mp, "char", mp_unary, mp_char_op);
mp_primitive(mp, "length", mp_unary, mp_length_op);
mp_primitive(mp, "turningnumber", mp_unary, mp_turning_op);
mp_primitive(mp, "xpart", mp_unary, mp_x_part); mp_primitive(mp, "ypart", mp_unary, mp_y_part);
mp_primitive(mp, "xxpart", mp_unary, mp_xx_part);
mp_primitive(mp, "xypart", mp_unary, mp_xy_part);
mp_primitive(mp, "yxpart", mp_unary, mp_yx_part);
mp_primitive(mp, "yypart", mp_unary, mp_yy_part);
mp_primitive(mp, "redpart", mp_unary, mp_red_part);
mp_primitive(mp, "greenpart", mp_unary, mp_green_part);
mp_primitive(mp, "bluepart", mp_unary, mp_blue_part);
mp_primitive(mp, "cyanpart", mp_unary, mp_cyan_part);
mp_primitive(mp, "magentapart", mp_unary, mp_magenta_part);
mp_primitive(mp, "yellowpart", mp_unary, mp_yellow_part);
mp_primitive(mp, "blackpart", mp_unary, mp_black_part);
mp_primitive(mp, "greypart", mp_unary, mp_grey_part);
mp_primitive(mp, "colormodel", mp_unary, mp_color_model_part);
mp_primitive(mp, "fontpart", mp_unary, mp_font_part);
mp_primitive(mp, "textpart", mp_unary, mp_text_part);
mp_primitive(mp, "prescriptpart", mp_unary, mp_prescript_part);
mp_primitive(mp, "postscriptpart", mp_unary, mp_postscript_part);
mp_primitive(mp, "pathpart", mp_unary, mp_path_part);
mp_primitive(mp, "penpart", mp_unary, mp_pen_part);
```

```
mp_primitive(mp, "dashpart", mp_unary, mp_dash_part);
mp_primitive(mp, "sqrt", mp_unary, mp_sqrt_op); mp_primitive(mp, "mexp", mp_unary, mp_m_exp_op);
mp_primitive(mp, "mlog", mp_unary, mp_m_log_op); mp_primitive(mp, "sind", mp_unary, mp_sin_d_op);
mp_primitive(mp, "cosd", mp_unary, mp_cos_d_op); mp_primitive(mp, "floor", mp_unary, mp_floor_op);
mp_primitive(mp, "uniformdeviate", mp_unary, mp_uniform_deviate);
mp_primitive(mp, "charexists", mp_unary, mp_char_exists_op);
mp_primitive(mp, "fontsize", mp_unary, mp_font_size);
mp_primitive(mp, "llcorner", mp_unary, mp_ll_corner_op);
mp_primitive(mp, "lrcorner", mp_unary, mp_lr_corner_op);
mp_primitive(mp, "ulcorner", mp_unary, mp_ul_corner_op);
mp_primitive(mp, "urcorner", mp_unary, mp_ur_corner_op);
mp_primitive(mp, "arclength", mp_unary, mp_arc_length);
mp_primitive(mp, "angle", mp_unary, mp_angle_op);
mp_primitive(mp, "cycle", mp_cycle, mp_cycle_op);
mp_primitive(mp, "stroked", mp_unary, mp_stroked_op);
mp_primitive(mp, "filled", mp_unary, mp_filled_op);
mp_primitive(mp, "textual", mp_unary, mp_textual_op);
mp_primitive(mp, "clipped", mp_unary, mp_clipped_op);
mp_primitive(mp, "bounded", mp_unary, mp_bounded_op);
mp_primitive(mp, "+", mp_plus_or_minus, mp_plus);
mp_primitive(mp, "-", mp_plus_or_minus, mp_minus);
mp_primitive(mp, "*", mp_secondary_binary, mp_times); mp_primitive(mp, "/", mp_slash, mp_over);
mp→frozen_slash ← mp_frozen_primitive(mp, "/", mp_slash, mp_over);
mp_primitive(mp, "++", mp_tertiary_binary, mp_pythag_add);
mp_primitive(mp, "+-+", mp_tertiary_binary, mp_pythag_sub);
mp_primitive(mp, "or", mp_tertiary_binary, mp_or_op);
mp_primitive(mp, "and", mp_and_command, mp_and_op);
mp_primitive(mp, "<", mp_expression_binary, mp_less_than);
mp_primitive(mp, "<=", mp_expression_binary, mp_less_or_equal);
mp_primitive(mp, ">", mp_expression_binary, mp_greater_than);
mp_primitive(mp, ">=", mp_expression_binary, mp_greater_or_equal);
mp_primitive(mp, "=", mp_equals, mp_equal_to);
mp_primitive(mp, "<>", mp_expression_binary, mp_unequal_to);
mp_primitive(mp, "substring", mp_primary_binary, mp_substring_of);
mp_primitive(mp, "subpath", mp_primary_binary, mp_subpath_of);
mp_primitive(mp, "directiontime", mp_primary_binary, mp_direction_time_of);
mp_primitive(mp, "point", mp_primary_binary, mp_point_of);
mp_primitive(mp, "precontrol", mp_primary_binary, mp_precontrol_of);
mp_primitive(mp, "postcontrol", mp_primary_binary, mp_postcontrol_of);
mp_primitive(mp, "penoffset", mp_primary_binary, mp_pen_offset_of);
mp_primitive(mp, "arctime", mp_primary_binary, mp_arc_time_of);
mp_primitive(mp, "mpversion", mp_nullary, mp_version);
mp_primitive(mp, "&", mp_ampersand, mp_concatenate);
mp_primitive(mp, "rotated", mp_secondary_binary, mp_rotated_by);
mp_primitive(mp, "slanted", mp_secondary_binary, mp_slanted_by);
mp_primitive(mp, "scaled", mp_secondary_binary, mp_scaled_by);
mp_primitive(mp, "shifted", mp_secondary_binary, mp_shifted_by);
mp_primitive(mp, "transformed", mp_secondary_binary, mp_transformed_by);
mp_primitive(mp, "xscaled", mp_secondary_binary, mp_x_scaled);
mp_primitive(mp, "yscaled", mp_secondary_binary, mp_y_scaled);
mp_primitive(mp, "zscaled", mp_secondary_binary, mp_z_scaled);
mp_primitive(mp, "infont", mp_secondary_binary, mp_in_font);
```

```
mp_primitive(mp, "intersectiontimes", mp_tertiary_binary, mp_intersect);
mp_primitive(mp, "envelope", mp_primary_binary, mp_envelope_of);
mp_primitive(mp, "boundingpath", mp_primary_binary, mp_boundingpath_of);
mp_primitive(mp, "glyph", mp_primary_binary, mp_glyph_infont);
mp_primitive(mp, "interval_get_left_endpoint", mp_unary, mp_m_get_left_endpoint_op);
  ▷ math interval new primitives ◁
mp_primitive(mp, "interval_get_right_endpoint", mp_unary, mp_m_get_right_endpoint_op);
  ▷ math interval new primitives ◁
mp_primitive(mp, "interval_set", mp_unary, mp_interval_set_op);   ▷ math interval new primitives ◁
```

958. ⟨ Cases of *print_cmd_mod* for symbolic printing of primitives 239 ⟩ +≡

```
case mp_nullary: case mp_unary: case mp_primary_binary: case mp_secondary_binary:
  case mp_tertiary_binary: case mp_expression_binary: case mp_cycle: case mp_plus_or_minus:
  case mp_slash: case mp_ampersand: case mp_equals: case mp_and_command:
  mp_print_op(mp, (quarterword) m); break;
```

959. OK, let's look at the simplest *do* procedure first.

```
⟨ Declare nullary action procedure 960 ⟩;
static void mp_do_nullary(MP mp, quarterword c)
{
  check_arith();
  if (number_greater(internal_value(mp_tracing_commands), two_t))
    mp_show_cmd_mod(mp, mp_nullary, c);
  switch (c) {
  case mp_true_code: case mp_false_code: mp→cur_exp.type ← mp_boolean_type;
    set_cur_exp_value_boolean(c); break;
  case mp_null_picture_code: mp→cur_exp.type ← mp_picture_type;
    set_cur_exp_node((mp_node) mp_get_edge_header_node(mp));
    mp_init_edges(mp, (mp_edge_header_node) cur_exp_node()); break;
  case mp_null_pen_code: mp→cur_exp.type ← mp_pen_type;
    set_cur_exp_knot(mp_get_pen_circle(mp, zero_t)); break;
  case mp_normal_deviate:
    {
      mp_number r;
      new_number(r);    ▷ mp_norm_rand(mp, &r); ◁
      m_norm_rand(r); mp→cur_exp.type ← mp_known; set_cur_exp_value_number(r); free_number(r);
    }
    break;
  case mp_pen_circle: mp→cur_exp.type ← mp_pen_type;
    set_cur_exp_knot(mp_get_pen_circle(mp, unity_t)); break;
  case mp_version: mp→cur_exp.type ← mp_string_type;
    set_cur_exp_str(mp_intern(mp, metapost_version)); break;
  case mp_read_string_op:    ▷ Read a string from the terminal ◁
    if (mp→noninteractive ∨ mp→interaction ≤ mp_nonstop_mode)
      mp_fatal_error(mp, "***␣(cannot␣readstring␣in␣nonstop␣modes)");
    mp_begin_file_reading(mp); name ← is_read; limit ← start; prompt_input(""); mp_finish_read(mp);
    break;
  }    ▷ there are no other cases ◁
  check_arith();
}
```

960. ⟨ Declare nullary action procedure 960 ⟩ ≡

```
static void mp_finish_read(MP mp)
{    ▷ copy buffer line to cur_exp ◁
  size_t k;
  str_room(((int) mp→last − (int) start));
  for (k ← (size_t) start; k < mp→last; k++) {
    append_char(mp→buffer[k]);
  }
  mp_end_file_reading(mp); mp→cur_exp.type ← mp_string_type; set_cur_exp_str(mp_make_string(mp));
}
```

This code is used in section 959.

961. Things get a bit more interesting when there's an operand. The operand to *do_unary* appears in *cur_type* and *cur_exp*.

This complicated if test makes sure that any *bounds* or *clip* picture objects that get passed into **within** do not raise an error when queried using the color part primitives (this is needed for backward compatibility) .

```
#define cur_pic_item mp_link(edge_list(cur_exp_node()))
#define pict_color_type(A)
        ((cur_pic_item ≠ Λ) ∧ ((¬has_color(cur_pic_item)) ∨ (((mp_color_model(cur_pic_item) ≡ A) ∨
            ((mp_color_model(cur_pic_item) ≡ mp_uninitialized_model) ∧
            (number_to_scaled(internal_value(mp_default_color_model))/
            number_to_scaled(unity_t)) ≡ (A))))))
#define boolean_reset(A)
        if ((A)) set_cur_exp_value_boolean(mp_true_code);
        else set_cur_exp_value_boolean(mp_false_code)
#define type_range(A, B)
        {
          if ((mp→cur_exp.type ≥ (A)) ∧ (mp→cur_exp.type ≤ (B)))
            set_number_from_boolean(new_expr.data.n, mp_true_code);
          else set_number_from_boolean(new_expr.data.n, mp_false_code);
          mp_flush_cur_exp(mp, new_expr); mp→cur_exp.type ← mp_boolean_type;
        }
#define type_test(A)
        {
          if (mp→cur_exp.type ≡ (mp_variable_type)(A))
            set_number_from_boolean(new_expr.data.n, mp_true_code);
          else set_number_from_boolean(new_expr.data.n, mp_false_code);
          mp_flush_cur_exp(mp, new_expr); mp→cur_exp.type ← mp_boolean_type;
        }

  ⟨Declare unary action procedures 962⟩;
  static void mp_do_unary(MP mp, quarterword c)
  {
    mp_node p;    ▷ for list manipulation ◁
    mp_value new_expr;
    check_arith();
    if (number_greater(internal_value(mp_tracing_commands), two_t)) {
        ▷ Trace the current unary operation ◁
      mp_begin_diagnostic(mp); mp_print_nl(mp, "{"); mp_print_op(mp, c);
      mp_print_char(mp, xord('(')); mp_print_exp(mp, Λ, 0);    ▷ show the operand, but not verbosely ◁
      mp_print(mp, ")}"); mp_end_diagnostic(mp, false);
    }
    switch (c) {
    case mp_plus:
      if (mp→cur_exp.type < mp_color_type) mp_bad_unary(mp, mp_plus);
      break;
    case mp_minus: negate_cur_expr(mp); break;
    case mp_not_op:
      if (mp→cur_exp.type ≠ mp_boolean_type) {
        mp_bad_unary(mp, mp_not_op);
      }
      else {
        halfword bb;
        if (cur_exp_value_boolean() ≡ mp_true_code) bb ← mp_false_code;
```

```
        else bb ← mp_true_code;
        set_cur_exp_value_boolean(bb);
      }
      break;
    case mp_sqrt_op: case mp_m_exp_op: case mp_m_log_op: case mp_sin_d_op: case mp_cos_d_op:
      case mp_floor_op: case mp_uniform_deviate: case mp_odd_op: case mp_char_exists_op:
      case mp_m_get_left_endpoint_op:    ▷ math interval new primitives ◁
      case mp_m_get_right_endpoint_op:    ▷ math interval new primitives ◁
      if (mp→cur_exp.type ≠ mp_known) {
        mp_bad_unary(mp, c);
      }
      else {
        switch (c) {
        case mp_sqrt_op:
          {
            mp_number r1;
            new_number(r1); square_rt(r1, cur_exp_value_number()); set_cur_exp_value_number(r1);
            free_number(r1);
          }
          break;
        case mp_m_exp_op:
          {
            mp_number r1;
            new_number(r1); m_exp(r1, cur_exp_value_number()); set_cur_exp_value_number(r1);
            free_number(r1);
          }
          break;
        case mp_m_log_op:
          {
            mp_number r1;
            new_number(r1); m_log(r1, cur_exp_value_number()); set_cur_exp_value_number(r1);
            free_number(r1);
          }
          break;
        case mp_sin_d_op: case mp_cos_d_op:
          {
            mp_number n_sin, n_cos, arg1, arg2;
            new_number(arg1); new_number(arg2); new_fraction(n_sin); new_fraction(n_cos);
              ▷ results computed by n_sin_cos ◁
            number_clone(arg1, cur_exp_value_number()); number_clone(arg2, unity_t);
            number_multiply_int(arg2, 360); number_modulo(arg1, arg2); convert_scaled_to_angle(arg1);
            n_sin_cos(arg1, n_cos, n_sin);
            if (c ≡ mp_sin_d_op) {
              fraction_to_round_scaled(n_sin); set_cur_exp_value_number(n_sin);
            }
            else {
              fraction_to_round_scaled(n_cos); set_cur_exp_value_number(n_cos);
            }
            free_number(arg1); free_number(arg2); free_number(n_sin); free_number(n_cos);
          }
          break;
```

```
      case mp_floor_op:
        {
          mp_number vvx;
          new_number(vvx); number_clone(vvx, cur_exp_value_number()); floor_scaled(vvx);
          set_cur_exp_value_number(vvx); free_number(vvx);
        }
        break;
      case mp_uniform_deviate:
        {
          mp_number vvx;
          new_number(vvx);    ▷ mp_unif_rand(mp, &vvx, cur_exp_value_number()); ◁
          m_unif_rand(vvx, cur_exp_value_number()); set_cur_exp_value_number(vvx);
          free_number(vvx);
        }
        break;
      case mp_odd_op:
        {
          integer vvx ← odd(round_unscaled(cur_exp_value_number()));
          boolean_reset(vvx); mp→cur_exp.type ← mp_boolean_type;
        }
        break;
      case mp_char_exists_op:    ▷ Determine if a character has been shipped out ◁
        set_cur_exp_value_scaled(round_unscaled(cur_exp_value_number()) % 256);
        if (number_negative(cur_exp_value_number())) {
          halfword vv ← number_to_scaled(cur_exp_value_number());
          set_cur_exp_value_scaled(vv + 256);
        }
        boolean_reset(mp→char_exists[number_to_scaled(cur_exp_value_number())]);
        mp→cur_exp.type ← mp_boolean_type; break;
      case mp_m_get_left_endpoint_op:    ▷ math interval new primitives ◁
        {
          mp_number r1;
          new_number(r1); m_get_left_endpoint(r1, cur_exp_value_number());
          set_cur_exp_value_number(r1); free_number(r1);
        }
        break;
      case mp_m_get_right_endpoint_op:    ▷ math interval new primitives ◁
        {
          mp_number r1;
          new_number(r1); m_get_right_endpoint(r1, cur_exp_value_number());
          set_cur_exp_value_number(r1); free_number(r1);
        }
        break;
      }    ▷ there are no other cases ◁
    }
    break;
  case mp_interval_set_op:    ▷ math interval new primitives ◁
    if (mp_nice_pair(mp, cur_exp_node(), mp→cur_exp.type)) {
      mp_number ret_val;
      memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
      new_number(ret_val); p ← value_node(cur_exp_node());
```

```
      m_interval_set(ret_val, value_number(x_part(p)), value_number(y_part(p)));
      number_clone(new_expr.data.n, ret_val); free_number(ret_val); mp_flush_cur_exp(mp, new_expr);
    }
    else {
      mp_bad_unary(mp, mp_interval_set_op);
    }
    break;
  case mp_angle_op:
    if (mp_nice_pair(mp, cur_exp_node(), mp→cur_exp.type)) {
      mp_number narg;
      memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n); new_angle(narg);
      p ← value_node(cur_exp_node()); n_arg(narg, value_number(x_part(p)), value_number(y_part(p)));
      number_clone(new_expr.data.n, narg); convert_angle_to_scaled(new_expr.data.n);
      free_number(narg); mp_flush_cur_exp(mp, new_expr);
    }
    else {
      mp_bad_unary(mp, mp_angle_op);
    }
    break;
  case mp_x_part: case mp_y_part:
    if ((mp→cur_exp.type ≡ mp_pair_type) ∨ (mp→cur_exp.type ≡ mp_transform_type))
      mp_take_part(mp, c);
    else if (mp→cur_exp.type ≡ mp_picture_type) mp_take_pict_part(mp, c);
    else mp_bad_unary(mp, c);
    break;
  case mp_xx_part: case mp_xy_part: case mp_yx_part: case mp_yy_part:
    if (mp→cur_exp.type ≡ mp_transform_type) mp_take_part(mp, c);
    else if (mp→cur_exp.type ≡ mp_picture_type) mp_take_pict_part(mp, c);
    else mp_bad_unary(mp, c);
    break;
  case mp_red_part: case mp_green_part: case mp_blue_part:
    if (mp→cur_exp.type ≡ mp_color_type) mp_take_part(mp, c);
    else if (mp→cur_exp.type ≡ mp_picture_type) {
      if pict_color_type (mp_rgb_model)mp_take_pict_part(mp, c);
      else mp_bad_color_part(mp, c);
    }
    else mp_bad_unary(mp, c);
    break;
  case mp_cyan_part: case mp_magenta_part: case mp_yellow_part: case mp_black_part:
    if (mp→cur_exp.type ≡ mp_cmykcolor_type) mp_take_part(mp, c);
    else if (mp→cur_exp.type ≡ mp_picture_type) {
      if pict_color_type (mp_cmyk_model)mp_take_pict_part(mp, c);
      else mp_bad_color_part(mp, c);
    }
    else mp_bad_unary(mp, c);
    break;
  case mp_grey_part:
    if (mp→cur_exp.type ≡ mp_known) ;
    else if (mp→cur_exp.type ≡ mp_picture_type) {
      if pict_color_type (mp_grey_model)mp_take_pict_part(mp, c);
      else mp_bad_color_part(mp, c);
    }
```

```
    else mp_bad_unary(mp, c);
    break;
  case mp_color_model_part:
    if (mp→cur_exp.type ≡ mp_picture_type) mp_take_pict_part(mp, c);
    else mp_bad_unary(mp, c);
    break;
  case mp_font_part: case mp_text_part: case mp_path_part: case mp_pen_part: case mp_dash_part:
    case mp_prescript_part: case mp_postscript_part:
    if (mp→cur_exp.type ≡ mp_picture_type) mp_take_pict_part(mp, c);
    else mp_bad_unary(mp, c);
    break;
  case mp_char_op:
    if (mp→cur_exp.type ≠ mp_known) {
      mp_bad_unary(mp, mp_char_op);
    }
    else {
      int vv ← round_unscaled(cur_exp_value_number()) % 256;
      set_cur_exp_value_scaled(vv); mp→cur_exp.type ← mp_string_type;
      if (number_negative(cur_exp_value_number())) {
        vv ← number_to_scaled(cur_exp_value_number()) + 256; set_cur_exp_value_scaled(vv);
      }
      {
        unsigned char ss[2];
        ss[0] ← (unsigned char) number_to_scaled(cur_exp_value_number()); ss[1] ← '\0';
        set_cur_exp_str(mp_rtsl(mp, (char *) ss, 1));
      }
    }
    break;
  case mp_decimal:
    if (mp→cur_exp.type ≠ mp_known) {
      mp_bad_unary(mp, mp_decimal);
    }
    else {
      mp→old_setting ← mp→selector; mp→selector ← new_string;
      print_number(cur_exp_value_number()); set_cur_exp_str(mp_make_string(mp));
      mp→selector ← mp→old_setting; mp→cur_exp.type ← mp_string_type;
    }
    break;
  case mp_oct_op: case mp_hex_op: case mp_ASCII_op:
    if (mp→cur_exp.type ≠ mp_string_type) mp_bad_unary(mp, c);
    else mp_str_to_num(mp, c);
    break;
  case mp_font_size:
    if (mp→cur_exp.type ≠ mp_string_type) {
      mp_bad_unary(mp, mp_font_size);
    }
    else {     ▷ Find the design size of the font whose name is cur_exp ◁
        ▷ One simple application of find_font is the implementation of the font_size operator that gets the
          design size for a given font name. ◁
      memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
      set_number_from_scaled(new_expr.data.n, (mp→font_dsize[mp_find_font(mp, mp_str(mp,
          cur_exp_str()))] + 8)/16); mp_flush_cur_exp(mp, new_expr);
```

```
    }
    break;
case mp_length_op:    ▷ The length operation is somewhat unusual in that it applies to a variety of
        different types of operands. ◁
    switch (mp→cur_exp.type) {
    case mp_string_type: memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
      number_clone(new_expr.data.n, unity_t);
      number_multiply_int(new_expr.data.n, cur_exp_str()→len); mp_flush_cur_exp(mp, new_expr);
      break;
    case mp_path_type: memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
      mp_path_length(mp, &new_expr.data.n); mp_flush_cur_exp(mp, new_expr); break;
    case mp_known: set_cur_exp_value_number(cur_exp_value_number());
      number_abs(cur_exp_value_number()); break;
    case mp_picture_type: memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
      mp_pict_length(mp, &new_expr.data.n); mp_flush_cur_exp(mp, new_expr); break;
    default:
      if (mp_nice_pair(mp, cur_exp_node(), mp→cur_exp.type)) {
        memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
        pyth_add(new_expr.data.n, value_number(x_part(value_node(cur_exp_node()))),
            value_number(y_part(value_node(cur_exp_node())))); mp_flush_cur_exp(mp, new_expr);
      }
      else mp_bad_unary(mp, c);
      break;
    }
    break;
case mp_turning_op:
    if (mp→cur_exp.type ≡ mp_pair_type) {
      memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
      set_number_to_zero(new_expr.data.n); mp_flush_cur_exp(mp, new_expr);
    }
    else if (mp→cur_exp.type ≠ mp_path_type) {
      mp_bad_unary(mp, mp_turning_op);
    }
    else if (mp_left_type(cur_exp_knot()) ≡ mp_endpoint) {
      memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
      new_expr.data.p ← Λ; mp_flush_cur_exp(mp, new_expr);    ▷ not a cyclic path ◁
    }
    else {
      memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
      mp_turn_cycles_wrapper(mp, &new_expr.data.n, cur_exp_knot());
      mp_flush_cur_exp(mp, new_expr);
    }
    break;
case mp_boolean_type: memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
    type_range(mp_boolean_type, mp_unknown_boolean); break;
case mp_string_type: memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
    type_range(mp_string_type, mp_unknown_string); break;
case mp_pen_type: memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
    type_range(mp_pen_type, mp_unknown_pen); break;
case mp_path_type: memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
    type_range(mp_path_type, mp_unknown_path); break;
```

case $mp\_picture\_type$: $memset(\&new\_expr, 0,$ **sizeof** (**mp_value**)); $new\_number(new\_expr.data.n)$;
  $type\_range(mp\_picture\_type, mp\_unknown\_picture)$; **break**;
case $mp\_transform\_type$: **case** mp_color_type: **case** $mp\_cmykcolor\_type$: **case** mp_pair_type:
  $memset(\&new\_expr, 0,$ **sizeof** (**mp_value**)); $new\_number(new\_expr.data.n)$; $type\_test(c)$; **break**;
case $mp\_numeric\_type$: $memset(\&new\_expr, 0,$ **sizeof** (**mp_value**)); $new\_number(new\_expr.data.n)$;
  $type\_range(mp\_known, mp\_independent)$; **break**;
case mp_known_op: **case** $mp\_unknown\_op$: $mp\_test\_known(mp, c)$; **break**;
case mp_cycle_op: $memset(\&new\_expr, 0,$ **sizeof** (**mp_value**)); $new\_number(new\_expr.data.n)$;
  if $(mp\rightarrow cur\_exp.type \neq mp\_path\_type)$ $set\_number\_from\_boolean(new\_expr.data.n, mp\_false\_code)$;
  else if $(mp\_left\_type(cur\_exp\_knot()) \neq mp\_endpoint)$
    $set\_number\_from\_boolean(new\_expr.data.n, mp\_true\_code)$;
  else $set\_number\_from\_boolean(new\_expr.data.n, mp\_false\_code)$;
  $mp\_flush\_cur\_exp(mp, new\_expr)$; $mp\rightarrow cur\_exp.type \leftarrow mp\_boolean\_type$; **break**;
case mp_arc_length:
  if $(mp\rightarrow cur\_exp.type \equiv mp\_pair\_type)$ $mp\_pair\_to\_path(mp)$;
  if $(mp\rightarrow cur\_exp.type \neq mp\_path\_type)$ {
    $mp\_bad\_unary(mp, mp\_arc\_length)$;
  }
  else {
    $memset(\&new\_expr, 0,$ **sizeof** (**mp_value**)); $new\_number(new\_expr.data.n)$;
    $mp\_get\_arc\_length(mp, \&new\_expr.data.n, cur\_exp\_knot())$; $mp\_flush\_cur\_exp(mp, new\_expr)$;
  }
  break;
case mp_filled_op: **case** $mp\_stroked\_op$: **case** $mp\_textual\_op$: **case** $mp\_clipped\_op$: **case** $mp\_bounded\_op$:
    ▷ Here we use the fact that $c - filled\_op + fill\_code$ is the desired graphical object $type$. ◁
  $memset(\&new\_expr, 0,$ **sizeof** (**mp_value**)); $new\_number(new\_expr.data.n)$;
  if $(mp\rightarrow cur\_exp.type \neq mp\_picture\_type)$ {
    $set\_number\_from\_boolean(new\_expr.data.n, mp\_false\_code)$;
  }
  else if $(mp\_link(edge\_list(cur\_exp\_node())) \equiv \Lambda)$ {
    $set\_number\_from\_boolean(new\_expr.data.n, mp\_false\_code)$;
  }
  else if $(mp\_type(mp\_link(edge\_list(cur\_exp\_node()))) \equiv$ (**mp_variable_type**)$(c + mp\_fill\_node\_type -$
      $mp\_filled\_op))$ {
    $set\_number\_from\_boolean(new\_expr.data.n, mp\_true\_code)$;
  }
  else {
    $set\_number\_from\_boolean(new\_expr.data.n, mp\_false\_code)$;
  }
  $mp\_flush\_cur\_exp(mp, new\_expr)$; $mp\rightarrow cur\_exp.type \leftarrow mp\_boolean\_type$; **break**;
case $mp\_make\_pen\_op$:
  if $(mp\rightarrow cur\_exp.type \equiv mp\_pair\_type)$ $mp\_pair\_to\_path(mp)$;
  if $(mp\rightarrow cur\_exp.type \neq mp\_path\_type)$ $mp\_bad\_unary(mp, mp\_make\_pen\_op)$;
  else {
    $mp\rightarrow cur\_exp.type \leftarrow mp\_pen\_type$; $set\_cur\_exp\_knot(mp\_make\_pen(mp, cur\_exp\_knot(), true))$;
  }
  break;
case $mp\_make\_path\_op$:
  if $(mp\rightarrow cur\_exp.type \neq mp\_pen\_type)$ {
    $mp\_bad\_unary(mp, mp\_make\_path\_op)$;
  }
  else {

```
        mp→cur_exp.type ← mp_path_type;  mp_make_path(mp, cur_exp_knot());
      }
      break;
    case mp_reverse:
      if (mp→cur_exp.type ≡ mp_path_type) {
        mp_knot pk ← mp_htap_ypoc(mp, cur_exp_knot());
        if (mp_right_type(pk) ≡ mp_endpoint) pk ← mp_next_knot(pk);
        mp_toss_knot_list(mp, cur_exp_knot());  set_cur_exp_knot(pk);
      }
      else if (mp→cur_exp.type ≡ mp_pair_type) {
        mp_pair_to_path(mp);
      }
      else {
        mp_bad_unary(mp, mp_reverse);
      }
      break;
    case mp_ll_corner_op:
      if (¬mp_get_cur_bbox(mp)) mp_bad_unary(mp, mp_ll_corner_op);
      else mp_pair_value(mp, mp_minx, mp_miny);
      break;
    case mp_lr_corner_op:
      if (¬mp_get_cur_bbox(mp)) mp_bad_unary(mp, mp_lr_corner_op);
      else mp_pair_value(mp, mp_maxx, mp_miny);
      break;
    case mp_ul_corner_op:
      if (¬mp_get_cur_bbox(mp)) mp_bad_unary(mp, mp_ul_corner_op);
      else mp_pair_value(mp, mp_minx, mp_maxy);
      break;
    case mp_ur_corner_op:
      if (¬mp_get_cur_bbox(mp)) mp_bad_unary(mp, mp_ur_corner_op);
      else mp_pair_value(mp, mp_maxx, mp_maxy);
      break;
    case mp_read_from_op: case mp_close_from_op:
      if (mp→cur_exp.type ≠ mp_string_type) mp_bad_unary(mp, c);
      else mp_do_read_or_close(mp, c);
      break;
    }    ▷ there are no other cases ◁
    check_arith();
  }
```

962. The *nice_pair* function returns *true* if both components of a pair are known.

⟨ Declare unary action procedures 962 ⟩ ≡

```
static boolean mp_nice_pair(MP mp, mp_node p, quarterword t)
{
  (void) mp;
  if (t ≡ mp_pair_type) {
    p ← value_node(p);
    if (mp_type(x_part(p)) ≡ mp_known)
      if (mp_type(y_part(p)) ≡ mp_known) return true;
  }
  return false;
}
```

See also sections 963, 964, 965, 966, 967, 968, 971, 975, 976, 977, 978, 979, 980, 982, 983, 984, 985, 986, and 987.

This code is used in section 961.

963. The *nice_color_or_pair* function is analogous except that it also accepts fully known colors.

⟨ Declare unary action procedures 962 ⟩ +≡

```
static boolean mp_nice_color_or_pair(MP mp, mp_node p, quarterword t)
{
  mp_node q;

  (void) mp;
  switch (t) {
  case mp_pair_type: q ← value_node(p);
    if (mp_type(x_part(q)) ≡ mp_known)
      if (mp_type(y_part(q)) ≡ mp_known) return true;
    break;
  case mp_color_type: q ← value_node(p);
    if (mp_type(red_part(q)) ≡ mp_known)
      if (mp_type(green_part(q)) ≡ mp_known)
        if (mp_type(blue_part(q)) ≡ mp_known) return true;
    break;
  case mp_cmykcolor_type: q ← value_node(p);
    if (mp_type(cyan_part(q)) ≡ mp_known)
      if (mp_type(magenta_part(q)) ≡ mp_known)
        if (mp_type(yellow_part(q)) ≡ mp_known)
          if (mp_type(black_part(q)) ≡ mp_known) return true;
    break;
  }
  return false;
}
```

964. ⟨ Declare unary action procedures 962 ⟩ +≡

```
static void mp_print_known_or_unknown_type(MP mp, quarterword t, mp_node v)
{
  mp_print_char(mp, xord('('));
  if (t > mp_known) mp_print(mp, "unknown␣numeric");
  else {
    if ((t ≡ mp_pair_type) ∨ (t ≡ mp_color_type) ∨ (t ≡ mp_cmykcolor_type))
      if (¬mp_nice_color_or_pair(mp, v, t)) mp_print(mp, "unknown␣");
    mp_print_type(mp, t);
  }
  mp_print_char(mp, xord(')'));
}
```

965. ⟨ Declare unary action procedures 962 ⟩ +≡

```
static void mp_bad_unary(MP mp, quarterword c)
{
  char msg[256];
  mp_string sname;
  int old_setting ← mp→selector;
  const char *hlp[] ← {"I'm␣afraid␣I␣don't␣know␣how␣to␣apply␣that␣operation␣to␣that",
      "particular␣type.␣Continue,␣and␣I'll␣simply␣return␣the",
      "argument␣(shown␣above)␣as␣the␣result␣of␣the␣operation.", Λ};
  mp→selector ← new_string; mp_print_op(mp, c);
  mp_print_known_or_unknown_type(mp, mp→cur_exp.type, cur_exp_node());
  sname ← mp_make_string(mp); mp→selector ← old_setting;
  mp_snprintf(msg, 256, "Not␣implemented:␣%s", mp_str(mp, sname)); delete_str_ref(sname);
  mp_disp_err(mp, Λ); mp_back_error(mp, msg, hlp, true); mp_get_x_next(mp);
}
```

966. Negation is easy except when the current expression is of type *independent*, or when it is a pair with one or more *independent* components.

⟨ Declare unary action procedures 962 ⟩ +≡

```
static void mp_negate_dep_list(MP mp, mp_value_node p)
{
  (void) mp;
  while (1) {
    number_negate(dep_value(p));
    if (dep_info(p) ≡ Λ) return;
    p ← (mp_value_node) mp_link(p);
  }
}
```

967. It is tempting to argue that the negative of an independent variable is an independent variable, hence we don't have to do anything when negating it. The fallacy is that other dependent variables pointing to the current expression must change the sign of their coefficients if we make no change to the current expression.

Instead, we work around the problem by copying the current expression and recycling it afterwards (cf. the *stash_in* routine).

```
#define negate_value(A)
        if (mp_type(A) ≡ mp_known) {
          set_value_number(A, (value_number(A)));   ▷ to clear the rest ◁
          number_negate(value_number(A));
        }
        else {
          mp_negate_dep_list(mp, (mp_value_node) dep_list((mp_value_node) A));
        }
⟨Declare unary action procedures 962⟩ +≡
  static void negate_cur_expr(MP mp)
  {
    mp_node p, q, r;   ▷ for list manipulation ◁
    switch (mp→cur_exp.type) {
    case mp_color_type: case mp_cmykcolor_type: case mp_pair_type: case mp_independent:
      q ← cur_exp_node(); mp_make_exp_copy(mp, q);
      if (mp→cur_exp.type ≡ mp_dependent) {
        mp_negate_dep_list(mp, (mp_value_node) dep_list((mp_value_node) cur_exp_node()));
      }
      else if (mp→cur_exp.type ≤ mp_pair_type) {
          ▷ mp_color_type mp_cmykcolor_type, or mp_pair_type ◁
        p ← value_node(cur_exp_node());
        switch (mp→cur_exp.type) {
        case mp_pair_type: r ← x_part(p); negate_value(r); r ← y_part(p); negate_value(r); break;
        case mp_color_type: r ← red_part(p); negate_value(r); r ← green_part(p); negate_value(r);
          r ← blue_part(p); negate_value(r); break;
        case mp_cmykcolor_type: r ← cyan_part(p); negate_value(r); r ← magenta_part(p);
          negate_value(r); r ← yellow_part(p); negate_value(r); r ← black_part(p); negate_value(r);
          break;
        default:   ▷ there are no other valid cases, but please the compiler ◁
          break;
        }
      }   ▷ if cur_type ← mp_known then cur_exp ← 0 ◁
      mp_recycle_value(mp, q); mp_free_value_node(mp, q); break;
    case mp_dependent: case mp_proto_dependent:
      mp_negate_dep_list(mp, (mp_value_node) dep_list((mp_value_node) cur_exp_node())); break;
    case mp_known:
      if (is_number(cur_exp_value_number())) number_negate(cur_exp_value_number());
      break;
    default: mp_bad_unary(mp, mp_minus); break;
    }
  }
```

968. If the current expression is a pair, but the context wants it to be a path, we call *pair_to_path*.

⟨ Declare unary action procedures 962 ⟩ +≡

```
static void mp_pair_to_path(MP mp)
{
  set_cur_exp_knot(mp_pair_to_knot(mp)); mp→cur_exp.type ← mp_path_type;
}
```

969. ⟨ Declarations 10 ⟩ +≡

```
static void mp_bad_color_part(MP mp, quarterword c);
```

970.

```
static void mp_bad_color_part(MP mp, quarterword c)
{
  mp_node p;    ▷ the big node ◁
  mp_value new_expr;
  char msg[256];
  int old_setting;
  mp_string sname;
  const char *hlp[] ← {
      "You␣can␣only␣ask␣for␣the␣redpart,␣greenpart,␣bluepart␣of␣a␣rgb␣object,",
      "the␣cyanpart,␣magentapart,␣yellowpart␣or␣blackpart␣of␣a␣cmyk␣object,␣",
      "or␣the␣greypart␣of␣a␣grey␣object.␣No␣mixing␣and␣matching,␣please.", Λ};
  memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
  p ← mp_link(edge_list(cur_exp_node())); mp_disp_err(mp, Λ); old_setting ← mp→selector;
  mp→selector ← new_string; mp_print_op(mp, c); sname ← mp_make_string(mp);
  mp→selector ← old_setting;
  if (mp_color_model(p) ≡ mp_grey_model)
    mp_snprintf(msg, 256, "Wrong␣picture␣color␣model:␣%s␣of␣grey␣object", mp_str(mp, sname));
  else if (mp_color_model(p) ≡ mp_cmyk_model)
    mp_snprintf(msg, 256, "Wrong␣picture␣color␣model:␣%s␣of␣cmyk␣object", mp_str(mp, sname));
  else if (mp_color_model(p) ≡ mp_rgb_model)
    mp_snprintf(msg, 256, "Wrong␣picture␣color␣model:␣%s␣of␣rgb␣object", mp_str(mp, sname));
  else if (mp_color_model(p) ≡ mp_no_model) mp_snprintf(msg, 256,
        "Wrong␣picture␣color␣model:␣%s␣of␣marking␣object", mp_str(mp, sname));
  else mp_snprintf(msg, 256, "Wrong␣picture␣color␣model:␣%s␣of␣defaulted␣object", mp_str(mp,
        sname));
  delete_str_ref(sname); mp_error(mp, msg, hlp, true);
  if (c ≡ mp_black_part) number_clone(new_expr.data.n, unity_t);
  else set_number_to_zero(new_expr.data.n);
  mp_flush_cur_exp(mp, new_expr);
}
```

971. In the following procedure, *cur_exp* points to a capsule, which points to a big node. We want to delete all but one part of the big node.

⟨ Declare unary action procedures 962 ⟩ +≡
static void *mp_take_part*(**MP** *mp*, **quarterword** *c*)
{
  mp_node *p*; ▷ the big node ◁
  $p \leftarrow$ *value_node*(*cur_exp_node*()); *set_value_node*(*mp*→*temp_val*, *p*);
  mp_type(*mp*→*temp_val*) ← *mp*→*cur_exp*.*type*; *mp_link*(*p*) ← *mp*→*temp_val*;
  mp_free_value_node(*mp*, *cur_exp_node*());
  switch (*c*) {
  case *mp_x_part*:
    if (*mp*→*cur_exp*.*type* ≡ *mp_pair_type*) *mp_make_exp_copy*(*mp*, *x_part*(*p*));
    else *mp_make_exp_copy*(*mp*, *tx_part*(*p*));
    break;
  case *mp_y_part*:
    if (*mp*→*cur_exp*.*type* ≡ *mp_pair_type*) *mp_make_exp_copy*(*mp*, *y_part*(*p*));
    else *mp_make_exp_copy*(*mp*, *ty_part*(*p*));
    break;
  case *mp_xx_part*: *mp_make_exp_copy*(*mp*, *xx_part*(*p*)); **break**;
  case *mp_xy_part*: *mp_make_exp_copy*(*mp*, *xy_part*(*p*)); **break**;
  case *mp_yx_part*: *mp_make_exp_copy*(*mp*, *yx_part*(*p*)); **break**;
  case *mp_yy_part*: *mp_make_exp_copy*(*mp*, *yy_part*(*p*)); **break**;
  case *mp_red_part*: *mp_make_exp_copy*(*mp*, *red_part*(*p*)); **break**;
  case *mp_green_part*: *mp_make_exp_copy*(*mp*, *green_part*(*p*)); **break**;
  case *mp_blue_part*: *mp_make_exp_copy*(*mp*, *blue_part*(*p*)); **break**;
  case *mp_cyan_part*: *mp_make_exp_copy*(*mp*, *cyan_part*(*p*)); **break**;
  case *mp_magenta_part*: *mp_make_exp_copy*(*mp*, *magenta_part*(*p*)); **break**;
  case *mp_yellow_part*: *mp_make_exp_copy*(*mp*, *yellow_part*(*p*)); **break**;
  case *mp_black_part*: *mp_make_exp_copy*(*mp*, *black_part*(*p*)); **break**;
  }
  mp_recycle_value(*mp*, *mp*→*temp_val*);
}

972. ⟨ Initialize table entries 186 ⟩ +≡
mp→*temp_val* ← *mp_get_value_node*(*mp*); *mp_name_type*(*mp*→*temp_val*) ← *mp_capsule*;

973. ⟨ Free table entries 187 ⟩ +≡
mp_free_value_node(*mp*, *mp*→*temp_val*);

974. ⟨ Declarations 10 ⟩ +≡
static mp_edge_header_node *mp_scale_edges*(**MP** *mp*, **mp_number** *se_sf*, **mp_edge_header_node** *se_pic*);

975. ⟨ Declare unary action procedures 962 ⟩ +≡

```
static void mp_take_pict_part(MP mp, quarterword c)
{
  mp_node p;    ▷ first graphical object in cur_exp ◁
  mp_value new_expr;
  memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
  p ← mp_link(edge_list(cur_exp_node()));
  if (p ≠ Λ) {
    switch (c) {
    case mp_x_part: case mp_y_part: case mp_xx_part: case mp_xy_part: case mp_yx_part:
      case mp_yy_part:
      if (mp_type(p) ≡ mp_text_node_type) {
        mp_text_node p0 ← (mp_text_node) p;
        switch (c) {
        case mp_x_part: number_clone(new_expr.data.n, p0→tx); break;
        case mp_y_part: number_clone(new_expr.data.n, p0→ty); break;
        case mp_xx_part: number_clone(new_expr.data.n, p0→txx); break;
        case mp_xy_part: number_clone(new_expr.data.n, p0→txy); break;
        case mp_yx_part: number_clone(new_expr.data.n, p0→tyx); break;
        case mp_yy_part: number_clone(new_expr.data.n, p0→tyy); break;
        }
        mp_flush_cur_exp(mp, new_expr);
      }
      else goto NOT_FOUND;
      break;
    case mp_red_part: case mp_green_part: case mp_blue_part:
      if (has_color(p)) {
        switch (c) {
        case mp_red_part: number_clone(new_expr.data.n, ((mp_stroked_node) p)→red); break;
        case mp_green_part: number_clone(new_expr.data.n, ((mp_stroked_node) p)→green); break;
        case mp_blue_part: number_clone(new_expr.data.n, ((mp_stroked_node) p)→blue); break;
        }
        mp_flush_cur_exp(mp, new_expr);
      }
      else goto NOT_FOUND;
      break;
    case mp_cyan_part: case mp_magenta_part: case mp_yellow_part: case mp_black_part:
      if (has_color(p)) {
        if (mp_color_model(p) ≡ mp_uninitialized_model ∧ c ≡ mp_black_part) {
          set_number_to_unity(new_expr.data.n);
        }
        else {
          switch (c) {
          case mp_cyan_part: number_clone(new_expr.data.n, ((mp_stroked_node) p)→cyan); break;
          case mp_magenta_part: number_clone(new_expr.data.n, ((mp_stroked_node) p)→magenta);
            break;
          case mp_yellow_part: number_clone(new_expr.data.n, ((mp_stroked_node) p)→yellow);
            break;
          case mp_black_part: number_clone(new_expr.data.n, ((mp_stroked_node) p)→black); break;
          }
        }
        mp_flush_cur_exp(mp, new_expr);
```

```
  }
  else goto NOT_FOUND;
  break;
case mp_grey_part:
  if (has_color(p)) {
    number_clone(new_expr.data.n, ((mp_stroked_node) p)→grey);
    mp_flush_cur_exp(mp, new_expr);
  }
  else goto NOT_FOUND;
  break;
case mp_color_model_part:
  if (has_color(p)) {
    if (mp_color_model(p) ≡ mp_uninitialized_model) {
      number_clone(new_expr.data.n, internal_value(mp_default_color_model));
    }
    else {
      number_clone(new_expr.data.n, unity_t);
      number_multiply_int(new_expr.data.n, mp_color_model(p));
    }
    mp_flush_cur_exp(mp, new_expr);
  }
  else goto NOT_FOUND;
  break;
case mp_text_part:
  if (mp_type(p) ≠ mp_text_node_type) goto NOT_FOUND;
  else {
    new_expr.data.str ← mp_text_p(p); add_str_ref(new_expr.data.str);
    mp_flush_cur_exp(mp, new_expr); mp→cur_exp.type ← mp_string_type;
  }
  break;
case mp_prescript_part:
  if (¬has_color(p)) {
    goto NOT_FOUND;
  }
  else {
    if (mp_pre_script(p)) {
      new_expr.data.str ← mp_pre_script(p); add_str_ref(new_expr.data.str);
    }
    else {
      new_expr.data.str ← mp_rts(mp, "");
    }
    mp_flush_cur_exp(mp, new_expr); mp→cur_exp.type ← mp_string_type;
  }
  break;
case mp_postscript_part:
  if (¬has_color(p)) {
    goto NOT_FOUND;
  }
  else {
    if (mp_post_script(p)) {
      new_expr.data.str ← mp_post_script(p); add_str_ref(new_expr.data.str);
    }
```

```
      else {
        new_expr.data.str ← mp_rts(mp, "");
      }
      mp_flush_cur_exp(mp, new_expr);  mp→cur_exp.type ← mp_string_type;
    }
    break;
  case mp_font_part:
    if (mp_type(p) ≠ mp_text_node_type) goto NOT_FOUND;
    else {
      new_expr.data.str ← mp_rts(mp, mp→font_name[mp_font_n(p)]);
      add_str_ref(new_expr.data.str);  mp_flush_cur_exp(mp, new_expr);
      mp→cur_exp.type ← mp_string_type;
    }
    break;
  case mp_path_part:
    if (mp_type(p) ≡ mp_text_node_type) {
      goto NOT_FOUND;
    }
    else if (is_stop(p)) {
      mp_confusion(mp, "pict");
    }
    else {
      new_expr.data.node ← Λ;
      switch (mp_type(p)) {
      case mp_fill_node_type: new_expr.data.p ← mp_copy_path(mp, mp_path_p((mp_fill_node) p));
        break;
      case mp_stroked_node_type:
        new_expr.data.p ← mp_copy_path(mp, mp_path_p((mp_stroked_node) p));  break;
      case mp_start_bounds_node_type:
        new_expr.data.p ← mp_copy_path(mp, mp_path_p((mp_start_bounds_node) p));  break;
      case mp_start_clip_node_type:
        new_expr.data.p ← mp_copy_path(mp, mp_path_p((mp_start_clip_node) p));  break;
      default: assert(0); break;
      }
      mp_flush_cur_exp(mp, new_expr);  mp→cur_exp.type ← mp_path_type;
    }
    break;
  case mp_pen_part:
    if (¬has_pen(p)) {
      goto NOT_FOUND;
    }
    else {
      switch (mp_type(p)) {
      case mp_fill_node_type:
        if (mp_pen_p((mp_fill_node) p) ≡ Λ) goto NOT_FOUND;
        else {
          new_expr.data.p ← copy_pen(mp_pen_p((mp_fill_node) p));
          mp_flush_cur_exp(mp, new_expr);  mp→cur_exp.type ← mp_pen_type;
        }
        break;
      case mp_stroked_node_type:
        if (mp_pen_p((mp_stroked_node) p) ≡ Λ) goto NOT_FOUND;
```

```
            else {
              new_expr.data.p ← copy_pen(mp_pen_p((mp_stroked_node) p));
              mp_flush_cur_exp(mp, new_expr); mp→cur_exp.type ← mp_pen_type;
            }
            break;
          default: assert(0); break;
          }
        }
        break;
      case mp_dash_part:
        if (mp_type(p) ≠ mp_stroked_node_type) {
          goto NOT_FOUND;
        }
        else {
          if (mp_dash_p(p) ≡ Λ) {
            goto NOT_FOUND;
          }
          else {
            add_edge_ref(mp_dash_p(p)); new_expr.data.node ← (mp_node) mp_scale_edges(mp,
                ((mp_stroked_node) p)→dash_scale, (mp_edge_header_node) mp_dash_p(p));
            mp_flush_cur_exp(mp, new_expr); mp→cur_exp.type ← mp_picture_type;
          }
        }
        break;
      }   ▷ all cases have been enumerated ◁
      return;
    }
  NOT_FOUND:   ▷ Convert the current expression to a NULL value appropriate for c ◁
    switch (c) {
    case mp_text_part: case mp_font_part: case mp_prescript_part: case mp_postscript_part:
      new_expr.data.str ← mp_rts(mp, ""); mp_flush_cur_exp(mp, new_expr);
      mp→cur_exp.type ← mp_string_type; break;
    case mp_path_part: new_expr.data.p ← mp_new_knot(mp); mp_flush_cur_exp(mp, new_expr);
      mp_left_type(cur_exp_knot()) ← mp_endpoint; mp_right_type(cur_exp_knot()) ← mp_endpoint;
      mp_next_knot(cur_exp_knot()) ← cur_exp_knot(); set_number_to_zero(cur_exp_knot()→x_coord);
      set_number_to_zero(cur_exp_knot()→y_coord); mp_originator(cur_exp_knot()) ← mp_metapost_user;
      mp→cur_exp.type ← mp_path_type; break;
    case mp_pen_part: new_expr.data.p ← mp_get_pen_circle(mp, zero_t);
      mp_flush_cur_exp(mp, new_expr); mp→cur_exp.type ← mp_pen_type; break;
    case mp_dash_part: new_expr.data.node ← (mp_node) mp_get_edge_header_node(mp);
      mp_flush_cur_exp(mp, new_expr); mp_init_edges(mp, (mp_edge_header_node) cur_exp_node());
      mp→cur_exp.type ← mp_picture_type; break;
    default: set_number_to_zero(new_expr.data.n); mp_flush_cur_exp(mp, new_expr); break;
    }
  }
```

976. ⟨ Declare unary action procedures 962 ⟩ +≡

```
static void mp_str_to_num(MP mp, quarterword c)
{    ▷ converts a string to a number ◁
  integer n;    ▷ accumulator ◁
  ASCII_code m;    ▷ current character ◁
  unsigned k;    ▷ index into str_pool ◁
  int b;    ▷ radix of conversion ◁
  boolean bad_char;    ▷ did the string contain an invalid digit? ◁
  mp_value new_expr;

  memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
  if (c ≡ mp_ASCII_op) {
    if (cur_exp_str()→len ≡ 0) n ← −1;
    else n ← cur_exp_str()→str[0];
  }
  else {
    if (c ≡ mp_oct_op) b ← 8;
    else b ← 16;
    n ← 0; bad_char ← false;
    for (k ← 0; k < cur_exp_str()→len; k++) {
      m ← (ASCII_code)(*(cur_exp_str()→str + k));
      if ((m ≥ '0') ∧ (m ≤ '9')) m ← (ASCII_code)(m − '0');
      else if ((m ≥ 'A') ∧ (m ≤ 'F')) m ← (ASCII_code)(m − 'A' + 10);
      else if ((m ≥ 'a') ∧ (m ≤ 'f')) m ← (ASCII_code)(m − 'a' + 10);
      else {
        bad_char ← true; m ← 0;
      }
      if ((int) m ≥ b) {
        bad_char ← true; m ← 0;
      }
      if (n < 32768/b) n ← n * b + m;
      else n ← 32767;
    }    ▷ Give error messages if bad_char or n ≥ 4096 ◁
    if (bad_char) {
      const char *hlp[] ← {"I␣zeroed␣out␣characters␣that␣weren't␣hex␣digits.", Λ};
      if (c ≡ mp_oct_op) {
        hlp[0] ← "I␣zeroed␣out␣characters␣that␣weren't␣in␣the␣range␣0..7.";
      }
      mp_disp_err(mp, Λ); mp_back_error(mp, "String␣contains␣illegal␣digits", hlp, true);
      mp_get_x_next(mp);
    }
    if ((n > 4095)) {    ▷ TODO: this is scaled specific ◁
      if (number_positive(internal_value(mp_warning_check))) {
        char msg[256];
        const char *hlp[] ← {"I␣have␣trouble␣with␣numbers␣greater␣than␣4095;␣watch␣out.",
            "(Set␣warningcheck:=0␣to␣suppress␣this␣message.)", Λ};
        mp_snprintf(msg, 256, "Number␣too␣large␣(%d)", (int) n); mp_back_error(mp, msg, hlp, true);
        mp_get_x_next(mp);
      }
    }
  }
```

number_clone(*new_expr.data.n*, *unity_t*); *number_multiply_int*(*new_expr.data.n*, *n*);
mp_flush_cur_exp(*mp*, *new_expr*);
}

977. ⟨Declare unary action procedures 962⟩ +≡
static void *mp_path_length*(**MP** *mp*, **mp_number** $*n$)
{ ▷ computes the length of the current path ◁
mp_knot *p*; ▷ traverser ◁
set_number_to_zero($*n$); $p \leftarrow$ *cur_exp_knot*( );
if (*mp_left_type*(*p*) ≡ *mp_endpoint*) {
number_substract($*n$, *unity_t*); ▷ -unity ◁
}
do {
$p \leftarrow$ *mp_next_knot*(*p*); *number_add*($*n$, *unity_t*);
} **while** ($p \neq$ *cur_exp_knot*( ));
}

978. ⟨Declare unary action procedures 962⟩ +≡
static void *mp_pict_length*(**MP** *mp*, **mp_number** $*n$)
{ ▷ counts interior components in picture *cur_exp* ◁
mp_node *p*; ▷ traverser ◁
set_number_to_zero($*n$); $p \leftarrow$ *mp_link*(*edge_list*(*cur_exp_node*( )));
if ($p \neq \Lambda$) {
if (*is_start_or_stop*(*p*))
if (*mp_skip_1component*(*mp*, *p*) ≡ Λ) $p \leftarrow$ *mp_link*(*p*);
while ($p \neq \Lambda$) {
if (¬*is_start_or_stop*(*p*)) $p \leftarrow$ *mp_link*(*p*);
else if (¬*is_stop*(*p*)) $p \leftarrow$ *mp_skip_1component*(*mp*, *p*);
else return;
number_add($*n$, *unity_t*);
}
}
}

979. The function *an_angle* returns the value of the *angle* primitive, or 0 if the argument is *origin*.
⟨Declare unary action procedures 962⟩ +≡
static void *mp_an_angle*(**MP** *mp*, **mp_number** $*ret$, **mp_number** *xpar*, **mp_number** *ypar*)
{
set_number_to_zero($*ret$);
if ((¬(*number_zero*(*xpar*) ∧ *number_zero*(*ypar*)))) {
n_arg($*ret$, *xpar*, *ypar*);
}
}

980. The actual turning number is (for the moment) computed in a C function that receives eight integers corresponding to the four controlling points, and returns a single angle. Besides those, we have to account for discrete moves at the actual points.

#**define** *mp_floor*(a) $((a) \geq 0\ ?\ (\mathbf{int})(a) : -(\mathbf{int})(-(a)))$
#**define** *bezier_error* $(720 * (256 * 256 * 16)) + 1$
#**define** *mp_sign*(v) $((v) > 0\ ?\ 1 : ((v) < 0\ ?\ -1 : 0))$
#**define** *mp_out*(A) $(\mathbf{double})((A)/16)$

⟨ Declare unary action procedures 962 ⟩ +≡

static void *mp_bezier_slope*(**MP** *mp*, **mp_number** **ret*, **mp_number** `AX`, **mp_number** `AY`, **mp_number** `BX`, **mp_number** `BY`, **mp_number** `CX`, **mp_number** `CY`, **mp_number** `DX`, **mp_number** `DY`);

981. **static void** *mp_bezier_slope*(**MP** *mp*, **mp_number** **ret*, **mp_number** AX, **mp_number** AY, **mp_number** BX, **mp_number** BY, **mp_number** CX, **mp_number** CY, **mp_number** DX, **mp_number** DY)

```
{
  double a, b, c;
  mp_number deltax, deltay;
  double ax, ay, bx, by, cx, cy, dx, dy;
  mp_number xi, xo, xm;
  double res ← 0;
  ax ← number_to_double(AX); ay ← number_to_double(AY); bx ← number_to_double(BX);
  by ← number_to_double(BY); cx ← number_to_double(CX); cy ← number_to_double(CY);
  dx ← number_to_double(DX); dy ← number_to_double(DY); new_number(deltax); new_number(deltay);
  set_number_from_substraction(deltax, BX, AX); set_number_from_substraction(deltay, BY, AY);
  if (number_zero(deltax) ∧ number_zero(deltay)) {
    set_number_from_substraction(deltax, CX, AX); set_number_from_substraction(deltay, CY, AY);
  }
  if (number_zero(deltax) ∧ number_zero(deltay)) {
    set_number_from_substraction(deltax, DX, AX); set_number_from_substraction(deltay, DY, AY);
  }
  new_number(xi); new_number(xm); new_number(xo); mp_an_angle(mp, &xi, deltax, deltay);
  set_number_from_substraction(deltax, CX, BX); set_number_from_substraction(deltay, CY, BY);
  mp_an_angle(mp, &xm, deltax, deltay);    ▷ !!! never used? ◁
  set_number_from_substraction(deltax, DX, CX); set_number_from_substraction(deltay, DY, CY);
  if (number_zero(deltax) ∧ number_zero(deltay)) {
    set_number_from_substraction(deltax, DX, BX); set_number_from_substraction(deltay, DY, BY);
  }
  if (number_zero(deltax) ∧ number_zero(deltay)) {
    set_number_from_substraction(deltax, DX, AX); set_number_from_substraction(deltay, DY, AY);
  }
  mp_an_angle(mp, &xo, deltax, deltay); a ← (bx − ax) ∗ (cy − by) − (cx − bx) ∗ (by − ay);
    ▷ a = (bp-ap)x(cp-bp); ◁
  b ← (bx − ax) ∗ (dy − cy) − (by − ay) ∗ (dx − cx);    ▷ b = (bp-ap)x(dp-cp); ◁
  c ← (cx − bx) ∗ (dy − cy) − (dx − cx) ∗ (cy − by);    ▷ c = (cp-bp)x(dp-cp); ◁
  if ((a ≡ 0) ∧ (c ≡ 0)) {
    res ← (b ≡ 0 ? 0 : (mp_out(number_to_double(xo)) − mp_out(number_to_double(xi))));
  }
  else if ((a ≡ 0) ∨ (c ≡ 0)) {
    if ((mp_sign(b) ≡ mp_sign(a)) ∨ (mp_sign(b) ≡ mp_sign(c))) {
      res ← mp_out(number_to_double(xo)) − mp_out(number_to_double(xi));    ▷ ? ◁
      if (res < −180.0) res += 360.0;
      else if (res > 180.0) res −= 360.0;
    }
    else {
      res ← mp_out(number_to_double(xo)) − mp_out(number_to_double(xi));    ▷ ? ◁
    }
  }
  else if ((mp_sign(a) ∗ mp_sign(c)) < 0) {
    res ← mp_out(number_to_double(xo)) − mp_out(number_to_double(xi));    ▷ ? ◁
    if (res < −180.0) res += 360.0;
    else if (res > 180.0) res −= 360.0;
  }
  else {
```

```
    if (mp_sign(a) ≡ mp_sign(b)) {
      res ← mp_out(number_to_double(xo)) − mp_out(number_to_double(xi));    ▷ ? ◁
      if (res < −180.0) res += 360.0;
      else if (res > 180.0) res −= 360.0;
    }
    else {
      if ((b ∗ b) ≡ (4 ∗ a ∗ c)) {
        res ← (double) bezier_error;
      }
      else if ((b ∗ b) < (4 ∗ a ∗ c)) {
        res ← mp_out(number_to_double(xo)) − mp_out(number_to_double(xi));    ▷ ? ◁
        if (res ≤ 0.0 ∧ res > −180.0) res += 360.0;
        else if (res ≥ 0.0 ∧ res < 180.0) res −= 360.0;
      }
      else {
        res ← mp_out(number_to_double(xo)) − mp_out(number_to_double(xi));
        if (res < −180.0) res += 360.0;
        else if (res > 180.0) res −= 360.0;
      }
    }
  }
  free_number(deltax); free_number(deltay); free_number(xi); free_number(xo); free_number(xm);
  set_number_from_double(∗ret, res); convert_scaled_to_angle(∗ret);
}
```

982.

```
#define p_nextnext mp_next_knot(mp_next_knot(p))
#define p_next mp_next_knot(p)

⟨ Declare unary action procedures 962 ⟩ +≡
  static void mp_turn_cycles(MP mp, mp_number *turns, mp_knot c)
  {
    mp_angle res, ang;   ▷ the angles of intermediate results ◁
    mp_knot p;   ▷ for running around the path ◁
    mp_number xp, yp;   ▷ coordinates of next point ◁
    mp_number x, y;   ▷ helper coordinates ◁
    mp_number arg1, arg2;
    mp_angle in_angle, out_angle;   ▷ helper angles ◁
    mp_angle seven_twenty_deg_t, neg_one_eighty_deg_t;
    unsigned old_setting;   ▷ saved selector setting ◁
    set_number_to_zero(*turns); new_number(arg1); new_number(arg2); new_number(xp);
    new_number(yp); new_number(x); new_number(y); new_angle(in_angle); new_angle(out_angle);
    new_angle(ang); new_angle(res); new_angle(seven_twenty_deg_t); new_angle(neg_one_eighty_deg_t);
    number_clone(seven_twenty_deg_t, three_sixty_deg_t); number_double(seven_twenty_deg_t);
    number_clone(neg_one_eighty_deg_t, one_eighty_deg_t); number_negate(neg_one_eighty_deg_t); p ← c;
    old_setting ← mp→selector; mp→selector ← term_only;
    if (number_greater(internal_value(mp_tracing_commands), unity_t)) {
      mp_begin_diagnostic(mp); mp_print_nl(mp, ""); mp_end_diagnostic(mp, false);
    }
    do {
      number_clone(xp, p_next→x_coord); number_clone(yp, p_next→y_coord); mp_bezier_slope(mp, &ang,
          p→x_coord, p→y_coord, p→right_x, p→right_y, p_next→left_x, p_next→left_y, xp, yp);
      if (number_greater(ang, seven_twenty_deg_t)) {
        mp_error(mp, "Strange␣path", Λ, true); mp→selector ← old_setting; set_number_to_zero(*turns);
        goto DONE;
      }
      number_add(res, ang);
      if (number_greater(res, one_eighty_deg_t)) {
        number_substract(res, three_sixty_deg_t); number_add(*turns, unity_t);
      }
      if (number_lessequal(res, neg_one_eighty_deg_t)) {
        number_add(res, three_sixty_deg_t); number_substract(*turns, unity_t);
      }   ▷ incoming angle at next point ◁
      number_clone(x, p_next→left_x); number_clone(y, p_next→left_y);
      if (number_equal(xp, x) ∧ number_equal(yp, y)) {
        number_clone(x, p→right_x); number_clone(y, p→right_y);
      }
      if (number_equal(xp, x) ∧ number_equal(yp, y)) {
        number_clone(x, p→x_coord); number_clone(y, p→y_coord);
      }
      set_number_from_substraction(arg1, xp, x); set_number_from_substraction(arg2, yp, y);
      mp_an_angle(mp, &in_angle, arg1, arg2);   ▷ outgoing angle at next point ◁
      number_clone(x, p_next→right_x); number_clone(y, p_next→right_y);
      if (number_equal(xp, x) ∧ number_equal(yp, y)) {
        number_clone(x, p_nextnext→left_x); number_clone(y, p_nextnext→left_y);
      }
      if (number_equal(xp, x) ∧ number_equal(yp, y)) {
```

```
        number_clone(x, p_nextnext→x_coord); number_clone(y, p_nextnext→y_coord);
      }
      set_number_from_substraction(arg1, x, xp); set_number_from_substraction(arg2, y, yp);
      mp_an_angle(mp, &out_angle, arg1, arg2); set_number_from_substraction(ang, out_angle, in_angle);
      mp_reduce_angle(mp, &ang);
      if (number_nonzero(ang)) {
        number_add(res, ang);
        if (number_greaterequal(res, one_eighty_deg_t)) {
          number_substract(res, three_sixty_deg_t); number_add(*turns, unity_t);
        }
        if (number_lessequal(res, neg_one_eighty_deg_t)) {
          number_add(res, three_sixty_deg_t); number_substract(*turns, unity_t);
        }
      }
      p ← mp_next_knot(p);
    } while (p ≠ c);
    mp→selector ← old_setting;
  DONE: free_number(xp); free_number(yp); free_number(x); free_number(y);
    free_number(seven_twenty_deg_t); free_number(neg_one_eighty_deg_t); free_number(in_angle);
    free_number(out_angle); free_number(ang); free_number(res); free_number(arg1); free_number(arg2);
  }
```

983. ⟨ Declare unary action procedures 962 ⟩ +≡

```
  static void mp_turn_cycles_wrapper(MP mp, mp_number *ret, mp_knot c)
  {
    if (mp_next_knot(c) ≡ c) {    ▷ one-knot paths always have a turning number of 1 ◁
      set_number_to_unity(*ret);
    }
    else {
      mp_turn_cycles(mp, ret, c);
    }
  }
```

984. ⟨ Declare unary action procedures 962 ⟩ +≡

```
static void mp_test_known(MP mp, quarterword c)
{
  int b;    ▷ is the current expression known? ◁
  mp_node p;    ▷ location in a big node ◁
  mp_value new_expr;
  memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n); b ← mp_false_code;
  switch (mp→cur_exp.type) {
  case mp_vacuous: case mp_boolean_type: case mp_string_type: case mp_pen_type: case mp_path_type:
    case mp_picture_type: case mp_known: b ← mp_true_code; break;
  case mp_transform_type: p ← value_node(cur_exp_node());
    if (mp_type(tx_part(p)) ≠ mp_known) break;
    if (mp_type(ty_part(p)) ≠ mp_known) break;
    if (mp_type(xx_part(p)) ≠ mp_known) break;
    if (mp_type(xy_part(p)) ≠ mp_known) break;
    if (mp_type(yx_part(p)) ≠ mp_known) break;
    if (mp_type(yy_part(p)) ≠ mp_known) break;
    b ← mp_true_code; break;
  case mp_color_type: p ← value_node(cur_exp_node());
    if (mp_type(red_part(p)) ≠ mp_known) break;
    if (mp_type(green_part(p)) ≠ mp_known) break;
    if (mp_type(blue_part(p)) ≠ mp_known) break;
    b ← mp_true_code; break;
  case mp_cmykcolor_type: p ← value_node(cur_exp_node());
    if (mp_type(cyan_part(p)) ≠ mp_known) break;
    if (mp_type(magenta_part(p)) ≠ mp_known) break;
    if (mp_type(yellow_part(p)) ≠ mp_known) break;
    if (mp_type(black_part(p)) ≠ mp_known) break;
    b ← mp_true_code; break;
  case mp_pair_type: p ← value_node(cur_exp_node());
    if (mp_type(x_part(p)) ≠ mp_known) break;
    if (mp_type(y_part(p)) ≠ mp_known) break;
    b ← mp_true_code; break;
  default: break;
  }
  if (c ≡ mp_known_op) {
    set_number_from_boolean(new_expr.data.n, b);
  }
  else {
    if (b ≡ mp_true_code) {
      set_number_from_boolean(new_expr.data.n, mp_false_code);
    }
    else {
      set_number_from_boolean(new_expr.data.n, mp_true_code);
    }
  }
  mp_flush_cur_exp(mp, new_expr); cur_exp_node() ← Λ;
    ▷ !! do not replace with set_cur_exp_node() !! ◁
  mp→cur_exp.type ← mp_boolean_type;
}
```

985. The *pair_value* routine changes the current expression to a given ordered pair of values.

⟨ Declare unary action procedures 962 ⟩ +≡

```
static void mp_pair_value(MP mp, mp_number x, mp_number y)
{
  mp_node p;    ▷ a pair node ◁
  mp_value new_expr;
  mp_number x1, y1;
  new_number(x1); new_number(y1); number_clone(x1, x); number_clone(y1, y);
  memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
  p ← mp_get_value_node(mp); new_expr.type ← mp_type(p); new_expr.data.node ← p;
  mp_flush_cur_exp(mp, new_expr); mp→cur_exp.type ← mp_pair_type; mp_name_type(p) ← mp_capsule;
  mp_init_pair_node(mp, p); p ← value_node(p); mp_type(x_part(p)) ← mp_known;
  set_value_number(x_part(p), x1); mp_type(y_part(p)) ← mp_known; set_value_number(y_part(p), y1);
  free_number(x1); free_number(y1);
}
```

986. Here is a function that sets *minx*, *maxx*, *miny*, *maxy* to the bounding box of the current expression. The boolean result is *false* if the expression has the wrong type.

⟨ Declare unary action procedures 962 ⟩ +≡

```
static boolean mp_get_cur_bbox(MP mp)
{
  switch (mp→cur_exp.type) {
  case mp_picture_type:
    {
      mp_edge_header_node p0 ← (mp_edge_header_node) cur_exp_node();
      mp_set_bbox(mp, p0, true);
      if (number_greater(p0→minx, p0→maxx)) {
        set_number_to_zero(mp_minx); set_number_to_zero(mp_maxx); set_number_to_zero(mp_miny);
        set_number_to_zero(mp_maxy);
      }
      else {
        number_clone(mp_minx, p0→minx); number_clone(mp_maxx, p0→maxx);
        number_clone(mp_miny, p0→miny); number_clone(mp_maxy, p0→maxy);
      }
    }
    break;
  case mp_path_type: mp_path_bbox(mp, cur_exp_knot()); break;
  case mp_pen_type: mp_pen_bbox(mp, cur_exp_knot()); break;
  default: return false;
  }
  return true;
}
```

987. Here is a routine that interprets *cur_exp* as a file name and tries to read a line from the file or to close the file.

⟨ Declare unary action procedures 962 ⟩ +≡

```
static void mp_do_read_or_close(MP mp, quarterword c)
{
  mp_value new_expr;
  readf_index n, n0;    ▷ indices for searching rd_fname ◁
  memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
    ▷ Find the n where rd_fname[n] ← cur_exp; if cur_exp must be inserted, call start_read_input and
      goto found or not_found ◁
    ▷ Free slots in the rd_file and rd_fname arrays are marked with NULL's in rd_fname. ◁
  {
    char *fn;
    n ← mp→read_files; n0 ← mp→read_files; fn ← mp_xstrdup(mp, mp_str(mp, cur_exp_str()));
    while (mp_xstrcmp(fn, mp→rd_fname[n]) ≠ 0) {
      if (n > 0) {
        decr(n);
      }
      else if (c ≡ mp_close_from_op) {
        goto CLOSE_FILE;
      }
      else {
        if (n0 ≡ mp→read_files) {
          if (mp→read_files < mp→max_read_files) {
            incr(mp→read_files);
          }
          else {
            void **rd_file;
            char **rd_fname;
            readf_index l, k;
            l ← mp→max_read_files + (mp→max_read_files/4);
            rd_file ← xmalloc((l + 1), sizeof(void *)); rd_fname ← xmalloc((l + 1), sizeof(char *));
            for (k ← 0; k ≤ l; k++) {
              if (k ≤ mp→max_read_files) {
                rd_file[k] ← mp→rd_file[k]; rd_fname[k] ← mp→rd_fname[k];
              }
              else {
                rd_file[k] ← 0; rd_fname[k] ← Λ;
              }
            }
            xfree(mp→rd_file); xfree(mp→rd_fname); mp→max_read_files ← l; mp→rd_file ← rd_file;
            mp→rd_fname ← rd_fname;
          }
        }
        n ← n0;
        if (mp_start_read_input(mp, fn, n)) goto FOUND;
        else goto NOT_FOUND;
      }
      if (mp→rd_fname[n] ≡ Λ) {
        n0 ← n;
      }
```

```
      }
      if (c ≡ mp_close_from_op) {
        (mp→close_file)(mp, mp→rd_file[n]); goto NOT_FOUND;
      }
    }
    mp_begin_file_reading(mp); name ← is_read;
    if (mp_input_ln(mp, mp→rd_file[n])) goto FOUND;
    mp_end_file_reading(mp);
  NOT_FOUND:    ▷ Record the end of file and set cur_exp to a dummy value ◁
    xfree(mp→rd_fname[n]); mp→rd_fname[n] ← Λ;
    if (n ≡ mp→read_files − 1) mp→read_files ← n;
    if (c ≡ mp_close_from_op) goto CLOSE_FILE;
    new_expr.data.str ← mp→eof_line; add_str_ref(new_expr.data.str); mp_flush_cur_exp(mp, new_expr);
    mp→cur_exp.type ← mp_string_type; return;
  CLOSE_FILE: mp_flush_cur_exp(mp, new_expr); mp→cur_exp.type ← mp_vacuous; return;
  FOUND: mp_flush_cur_exp(mp, new_expr); mp_finish_read(mp);
  }
```

988. The string denoting end-of-file is a one-byte string at position zero, by definition. I have to cheat a little here because

⟨ Global variables 18 ⟩ +≡
  mp_string *eof_line*;

989. ⟨ Set initial values of key variables 42 ⟩ +≡
  mp→eof_line ← *mp_rtsl*(*mp*, "\0", 1); *mp→eof_line→refs* ← MAX_STR_REF;

990. Finally, we have the operations that combine a capsule p with the current expression.

Several of the binary operations are potentially complicated by the fact that *independent* values can sneak into capsules. For example, we've seen an instance of this difficulty in the unary operation of negation. In order to reduce the number of cases that need to be handled, we first change the two operands (if necessary) to rid them of *independent* components. The original operands are put into capsules called *old_p* and *old_exp*, which will be recycled after the binary operation has been safely carried out.

```
#define binary_return
    {
      mp_finish_binary(mp, old_p, old_exp); return;
    }
⟨Declare binary action procedures 991⟩;
static void mp_finish_binary(MP mp, mp_node old_p, mp_node old_exp)
{
  check_arith();    ▷ Recycle any sidestepped independent capsules ◁
  if (old_p ≠ Λ) {
    mp_recycle_value(mp, old_p); mp_free_value_node(mp, old_p);
  }
  if (old_exp ≠ Λ) {
    mp_recycle_value(mp, old_exp); mp_free_value_node(mp, old_exp);
  }
}
static void mp_do_binary(MP mp, mp_node p, integer c)
{
  mp_node q, r, rr;    ▷ for list manipulation ◁
  mp_node old_p, old_exp;    ▷ capsules to recycle ◁
  mp_value new_expr;
  check_arith();
  if (number_greater(internal_value(mp_tracing_commands), two_t)) {
      ▷ Trace the current binary operation ◁
    mp_begin_diagnostic(mp); mp_print_nl(mp, "{("); mp_print_exp(mp, p, 0);
      ▷ show the operand, but not verbosely ◁
    mp_print_char(mp, xord(')')); mp_print_op(mp, (quarterword) c);
    mp_print_char(mp, xord('(')); mp_print_exp(mp, Λ, 0); mp_print(mp, ")}");
    mp_end_diagnostic(mp, false);
  }    ▷ Sidestep independent cases in capsule p ◁    ▷ A big node is considered to be "tarnished" if it
         contains at least one independent component. We will define a simple function called 'tarnished'
         that returns Λ if and only if its argument is not tarnished. ◁
  switch (mp_type(p)) {
  case mp_transform_type: case mp_color_type: case mp_cmykcolor_type: case mp_pair_type:
    old_p ← mp_tarnished(mp, p); break;
  case mp_independent: old_p ← MP_VOID; break;
  default: old_p ← Λ; break;
  }
  if (old_p ≠ Λ) {
    q ← mp_stash_cur_exp(mp); old_p ← p; mp_make_exp_copy(mp, old_p); p ← mp_stash_cur_exp(mp);
    mp_unstash_cur_exp(mp, q);
  }    ▷ Sidestep independent cases in the current expression ◁
  switch (mp→cur_exp.type) {
  case mp_transform_type: case mp_color_type: case mp_cmykcolor_type: case mp_pair_type:
    old_exp ← mp_tarnished(mp, cur_exp_node()); break;
  case mp_independent: old_exp ← MP_VOID; break;
```

```
default: old_exp ← Λ; break;
}
if (old_exp ≠ Λ) {
  old_exp ← cur_exp_node( ); mp_make_exp_copy(mp, old_exp);
}
switch (c) {
case mp_plus: case mp_minus:    ▷ Add or subtract the current expression from p ◁
  if ((mp→cur_exp.type < mp_color_type) ∨ (mp_type(p) < mp_color_type)) {
    mp_bad_binary(mp, p, (quarterword) c);
  }
  else {
    quarterword cc ← (quarterword) c;
    if ((mp→cur_exp.type > mp_pair_type) ∧ (mp_type(p) > mp_pair_type)) {
      mp_add_or_subtract(mp, p, Λ, cc);
    }
    else {
      if (mp→cur_exp.type ≠ mp_type(p)) {
        mp_bad_binary(mp, p, cc);
      }
      else {
        q ← value_node(p); r ← value_node(cur_exp_node( ));
        switch (mp→cur_exp.type) {
        case mp_pair_type: mp_add_or_subtract(mp, x_part(q), x_part(r), cc);
          mp_add_or_subtract(mp, y_part(q), y_part(r), cc); break;
        case mp_color_type: mp_add_or_subtract(mp, red_part(q), red_part(r), cc);
          mp_add_or_subtract(mp, green_part(q), green_part(r), cc);
          mp_add_or_subtract(mp, blue_part(q), blue_part(r), cc); break;
        case mp_cmykcolor_type: mp_add_or_subtract(mp, cyan_part(q), cyan_part(r), cc);
          mp_add_or_subtract(mp, magenta_part(q), magenta_part(r), cc);
          mp_add_or_subtract(mp, yellow_part(q), yellow_part(r), cc);
          mp_add_or_subtract(mp, black_part(q), black_part(r), cc); break;
        case mp_transform_type: mp_add_or_subtract(mp, tx_part(q), tx_part(r), cc);
          mp_add_or_subtract(mp, ty_part(q), ty_part(r), cc);
          mp_add_or_subtract(mp, xx_part(q), xx_part(r), cc);
          mp_add_or_subtract(mp, xy_part(q), xy_part(r), cc);
          mp_add_or_subtract(mp, yx_part(q), yx_part(r), cc);
          mp_add_or_subtract(mp, yy_part(q), yy_part(r), cc); break;
        default:    ▷ there are no other valid cases, but please the compiler ◁
          break;
        }
      }
    }
  }
  break;
case mp_less_than: case mp_less_or_equal: case mp_greater_than: case mp_greater_or_equal:
  case mp_equal_to: case mp_unequal_to: check_arith( );
    ▷ at this point arith_error should be false? ◁
  if ((mp→cur_exp.type > mp_pair_type) ∧ (mp_type(p) > mp_pair_type)) {
    mp_add_or_subtract(mp, p, Λ, mp_minus);    ▷ cur_exp: ← (p) − cur_exp ◁
  }
  else if (mp→cur_exp.type ≠ mp_type(p)) {
    mp_bad_binary(mp, p, (quarterword) c); goto DONE;
```

```
}
else if (mp→cur_exp.type ≡ mp_string_type) {
   memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
   set_number_from_scaled(new_expr.data.n, mp_str_vs_str(mp, value_str(p), cur_exp_str()));
   mp_flush_cur_exp(mp, new_expr);
}
else if ((mp→cur_exp.type ≡ mp_unknown_string) ∨ (mp→cur_exp.type ≡ mp_unknown_boolean)) {
      ▷ Check if unknowns have been equated ◁
      ▷ When two unknown strings are in the same ring, we know that they are equal. Otherwise, we
        don't know whether they are equal or not, so we make no change. ◁
   q ← value_node(cur_exp_node());
   while ((q ≠ cur_exp_node()) ∧ (q ≠ p)) q ← value_node(q);
   if (q ≡ p) {
      memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
      set_cur_exp_node(Λ); mp_flush_cur_exp(mp, new_expr);
   }
}
else if ((mp→cur_exp.type ≤ mp_pair_type) ∧ (mp→cur_exp.type ≥ mp_transform_type)) {
      ▷ Reduce comparison of big nodes to comparison of scalars ◁    ▷ In the following, the while
        loops exist just so that break can be used, each loop runs exactly once. ◁
   quarterword part_type;

   q ← value_node(p); r ← value_node(cur_exp_node()); part_type ← 0;
   switch (mp→cur_exp.type) {
   case mp_pair_type:
      while (part_type ≡ 0) {
         rr ← x_part(r); part_type ← mp_x_part; mp_add_or_subtract(mp, x_part(q), rr, mp_minus);
         if (mp_type(rr) ≠ mp_known ∨ ¬number_zero(value_number(rr))) break;
         rr ← y_part(r); part_type ← mp_y_part; mp_add_or_subtract(mp, y_part(q), rr, mp_minus);
         if (mp_type(rr) ≠ mp_known ∨ ¬number_zero(value_number(rr))) break;
      }
      mp_take_part(mp, part_type); break;
   case mp_color_type:
      while (part_type ≡ 0) {
         rr ← red_part(r); part_type ← mp_red_part;
         mp_add_or_subtract(mp, red_part(q), rr, mp_minus);
         if (mp_type(rr) ≠ mp_known ∨ ¬number_zero(value_number(rr))) break;
         rr ← green_part(r); part_type ← mp_green_part;
         mp_add_or_subtract(mp, green_part(q), rr, mp_minus);
         if (mp_type(rr) ≠ mp_known ∨ ¬number_zero(value_number(rr))) break;
         rr ← blue_part(r); part_type ← mp_blue_part;
         mp_add_or_subtract(mp, blue_part(q), rr, mp_minus);
         if (mp_type(rr) ≠ mp_known ∨ ¬number_zero(value_number(rr))) break;
      }
      mp_take_part(mp, part_type); break;
   case mp_cmykcolor_type:
      while (part_type ≡ 0) {
         rr ← cyan_part(r); part_type ← mp_cyan_part;
         mp_add_or_subtract(mp, cyan_part(q), rr, mp_minus);
         if (mp_type(rr) ≠ mp_known ∨ ¬number_zero(value_number(rr))) break;
         rr ← magenta_part(r); part_type ← mp_magenta_part;
         mp_add_or_subtract(mp, magenta_part(q), rr, mp_minus);
         if (mp_type(rr) ≠ mp_known ∨ ¬number_zero(value_number(rr))) break;
```

```
        rr ← yellow_part(r); part_type ← mp_yellow_part;
        mp_add_or_subtract(mp, yellow_part(q), rr, mp_minus);
        if (mp_type(rr) ≠ mp_known ∨ ¬number_zero(value_number(rr))) break;
        rr ← black_part(r); part_type ← mp_black_part;
        mp_add_or_subtract(mp, black_part(q), rr, mp_minus);
        if (mp_type(rr) ≠ mp_known ∨ ¬number_zero(value_number(rr))) break;
      }
      mp_take_part(mp, part_type); break;
    case mp_transform_type:
      while (part_type ≡ 0) {
        rr ← tx_part(r); part_type ← mp_x_part; mp_add_or_subtract(mp, tx_part(q), rr, mp_minus);
        if (mp_type(rr) ≠ mp_known ∨ ¬number_zero(value_number(rr))) break;
        rr ← ty_part(r); part_type ← mp_y_part; mp_add_or_subtract(mp, ty_part(q), rr, mp_minus);
        if (mp_type(rr) ≠ mp_known ∨ ¬number_zero(value_number(rr))) break;
        rr ← xx_part(r); part_type ← mp_xx_part;
        mp_add_or_subtract(mp, xx_part(q), rr, mp_minus);
        if (mp_type(rr) ≠ mp_known ∨ ¬number_zero(value_number(rr))) break;
        rr ← xy_part(r); part_type ← mp_xy_part;
        mp_add_or_subtract(mp, xy_part(q), rr, mp_minus);
        if (mp_type(rr) ≠ mp_known ∨ ¬number_zero(value_number(rr))) break;
        rr ← yx_part(r); part_type ← mp_yx_part;
        mp_add_or_subtract(mp, yx_part(q), rr, mp_minus);
        if (mp_type(rr) ≠ mp_known ∨ ¬number_zero(value_number(rr))) break;
        rr ← yy_part(r); part_type ← mp_yy_part;
        mp_add_or_subtract(mp, yy_part(q), rr, mp_minus);
        if (mp_type(rr) ≠ mp_known ∨ ¬number_zero(value_number(rr))) break;
      }
      mp_take_part(mp, part_type); break;
    default: assert(0);     ▷ TODO: mp→cur_exp.type > mp_transform_node_type ? ◁
      break;
    }
  }
  else if (mp→cur_exp.type ≡ mp_boolean_type) {
    memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
    set_number_from_boolean(new_expr.data.n,
        number_to_scaled(cur_exp_value_number()) − number_to_scaled(value_number(p)));
    mp_flush_cur_exp(mp, new_expr);
  }
  else {
    mp_bad_binary(mp, p, (quarterword) c); goto DONE;
  }    ▷ Compare the current expression with zero ◁
  if (mp→cur_exp.type ≠ mp_known) {
    const char *hlp[] ← {"Oh␣dear.␣I␣can\'t␣decide␣if␣the␣expression␣above␣is␣positive,",
        "negative,␣or␣zero.␣So␣this␣comparison␣test␣won't␣be␣`true'.", Λ};
    if (mp→cur_exp.type < mp_known) {
      mp_disp_err(mp, p); hlp[0] ← "The␣quantities␣shown␣above␣have␣not␣been␣equated.";
      hlp[1] ← Λ;
    }
    mp_disp_err(mp, Λ); memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
    set_number_from_boolean(new_expr.data.n, mp_false_code);
    mp_back_error(mp, "Unknown␣relation␣will␣be␣considered␣false", hlp, true);
    mp_get_x_next(mp); mp_flush_cur_exp(mp, new_expr);
```

```
  }
  else {
    switch (c) {
    case mp_less_than: boolean_reset(number_negative(cur_exp_value_number())); break;
    case mp_less_or_equal: boolean_reset(number_nonpositive(cur_exp_value_number())); break;
    case mp_greater_than: boolean_reset(number_positive(cur_exp_value_number())); break;
    case mp_greater_or_equal: boolean_reset(number_nonnegative(cur_exp_value_number())); break;
    case mp_equal_to: boolean_reset(number_zero(cur_exp_value_number())); break;
    case mp_unequal_to: boolean_reset(number_nonzero(cur_exp_value_number())); break;
    }    ▷ there are no other cases ◁
  }
  mp→cur_exp.type ← mp_boolean_type;
DONE: mp→arith_error ← false;    ▷ ignore overflow in comparisons ◁
  break;
case mp_and_op: case mp_or_op:
    ▷ Here we use the sneaky fact that and_op − false_code ← or_op − true_code ◁
  if ((mp_type(p) ≠ mp_boolean_type) ∨ (mp→cur_exp.type ≠ mp_boolean_type))
    mp_bad_binary(mp, p, (quarterword) c);
  else if (number_to_boolean(p→data.n) ≡ c + mp_false_code − mp_and_op) {
    set_cur_exp_value_boolean(number_to_boolean(p→data.n));
  }
  break;
case mp_times:
  if ((mp→cur_exp.type < mp_color_type) ∨ (mp_type(p) < mp_color_type)) {
    mp_bad_binary(mp, p, mp_times);
  }
  else if ((mp→cur_exp.type ≡ mp_known) ∨ (mp_type(p) ≡ mp_known)) {
      ▷ Multiply when at least one operand is known ◁
    mp_number vv;
    new_fraction(vv);
    if (mp_type(p) ≡ mp_known) {
      number_clone(vv, value_number(p)); mp_free_value_node(mp, p);
    }
    else {
      number_clone(vv, cur_exp_value_number()); mp_unstash_cur_exp(mp, p);
    }
    if (mp→cur_exp.type ≡ mp_known) {
      mp_number ret;
      new_number(ret); take_scaled(ret, cur_exp_value_number(), vv); set_cur_exp_value_number(ret);
      free_number(ret);
    }
    else if (mp→cur_exp.type ≡ mp_pair_type) {
      mp_dep_mult(mp, (mp_value_node) x_part(value_node(cur_exp_node())), vv, true);
      mp_dep_mult(mp, (mp_value_node) y_part(value_node(cur_exp_node())), vv, true);
    }
    else if (mp→cur_exp.type ≡ mp_color_type) {
      mp_dep_mult(mp, (mp_value_node) red_part(value_node(cur_exp_node())), vv, true);
      mp_dep_mult(mp, (mp_value_node) green_part(value_node(cur_exp_node())), vv, true);
      mp_dep_mult(mp, (mp_value_node) blue_part(value_node(cur_exp_node())), vv, true);
    }
    else if (mp→cur_exp.type ≡ mp_cmykcolor_type) {
```

```
        mp_dep_mult(mp, (mp_value_node) cyan_part(value_node(cur_exp_node())), vv, true);
        mp_dep_mult(mp, (mp_value_node) magenta_part(value_node(cur_exp_node())), vv, true);
        mp_dep_mult(mp, (mp_value_node) yellow_part(value_node(cur_exp_node())), vv, true);
        mp_dep_mult(mp, (mp_value_node) black_part(value_node(cur_exp_node())), vv, true);
      }
      else {
        mp_dep_mult(mp, Λ, vv, true);
      }
      free_number(vv); binary_return;
    }
    else if ((mp_nice_color_or_pair(mp, p,
          mp_type(p)) ∧ (mp→cur_exp.type > mp_pair_type)) ∨ (mp_nice_color_or_pair(mp,
          cur_exp_node(), mp→cur_exp.type) ∧ (mp_type(p) > mp_pair_type))) {
      mp_hard_times(mp, p); binary_return;
    }
    else {
      mp_bad_binary(mp, p, mp_times);
    }
    break;
  case mp_over:
    if ((mp→cur_exp.type ≠ mp_known) ∨ (mp_type(p) < mp_color_type)) {
      mp_bad_binary(mp, p, mp_over);
    }
    else {
      mp_number v_n;
      new_number(v_n); number_clone(v_n, cur_exp_value_number()); mp_unstash_cur_exp(mp, p);
      if (number_zero(v_n)) {    ▷ Squeal about division by zero ◁
        const char *hlp[] ← {"You're␣trying␣to␣divide␣the␣quantity␣shown␣above␣the␣error",
            "message␣by␣zero.␣I'm␣going␣to␣divide␣it␣by␣one␣instead.", Λ};
        mp_disp_err(mp, Λ); mp_back_error(mp, "Division␣by␣zero", hlp, true); mp_get_x_next(mp);
      }
      else {
        if (mp→cur_exp.type ≡ mp_known) {
          mp_number ret;
          new_number(ret); make_scaled(ret, cur_exp_value_number(), v_n);
          set_cur_exp_value_number(ret); free_number(ret);
        }
        else if (mp→cur_exp.type ≡ mp_pair_type) {
          mp_dep_div(mp, (mp_value_node) x_part(value_node(cur_exp_node())), v_n);
          mp_dep_div(mp, (mp_value_node) y_part(value_node(cur_exp_node())), v_n);
        }
        else if (mp→cur_exp.type ≡ mp_color_type) {
          mp_dep_div(mp, (mp_value_node) red_part(value_node(cur_exp_node())), v_n);
          mp_dep_div(mp, (mp_value_node) green_part(value_node(cur_exp_node())), v_n);
          mp_dep_div(mp, (mp_value_node) blue_part(value_node(cur_exp_node())), v_n);
        }
        else if (mp→cur_exp.type ≡ mp_cmykcolor_type) {
          mp_dep_div(mp, (mp_value_node) cyan_part(value_node(cur_exp_node())), v_n);
          mp_dep_div(mp, (mp_value_node) magenta_part(value_node(cur_exp_node())), v_n);
          mp_dep_div(mp, (mp_value_node) yellow_part(value_node(cur_exp_node())), v_n);
          mp_dep_div(mp, (mp_value_node) black_part(value_node(cur_exp_node())), v_n);
```

```
        }
        else {
          mp_dep_div(mp, Λ, v_n);
        }
      }
      free_number(v_n); binary_return;
    }
    break;
  case mp_pythag_add: case mp_pythag_sub:
    if ((mp→cur_exp.type ≡ mp_known) ∧ (mp_type(p) ≡ mp_known)) {
      mp_number r;
      new_number(r);
      if (c ≡ mp_pythag_add) {
        pyth_add(r, value_number(p), cur_exp_value_number());
      }
      else {
        pyth_sub(r, value_number(p), cur_exp_value_number());
      }
      set_cur_exp_value_number(r); free_number(r);
    }
    else mp_bad_binary(mp, p, (quarterword) c);
    break;
  case mp_rotated_by: case mp_slanted_by: case mp_scaled_by: case mp_shifted_by:
    case mp_transformed_by: case mp_x_scaled: case mp_y_scaled: case mp_z_scaled:
      ▷ The next few sections of the program deal with affine transformations of coordinate data. ◁
    if (mp_type(p) ≡ mp_path_type) {
      path_trans((quarterword) c, p); binary_return;
    }
    else if (mp_type(p) ≡ mp_pen_type) {
      pen_trans((quarterword) c, p); set_cur_exp_knot(mp_convex_hull(mp, cur_exp_knot()));
        ▷ rounding error could destroy convexity ◁
      binary_return;
    }
    else if ((mp_type(p) ≡ mp_pair_type) ∨ (mp_type(p) ≡ mp_transform_type)) {
      mp_big_trans(mp, p, (quarterword) c);
    }
    else if (mp_type(p) ≡ mp_picture_type) {
      mp_do_edges_trans(mp, p, (quarterword) c); binary_return;
    }
    else {
      mp_bad_binary(mp, p, (quarterword) c);
    }
    break;
  case mp_concatenate:
    if ((mp→cur_exp.type ≡ mp_string_type) ∧ (mp_type(p) ≡ mp_string_type)) {
      mp_string str ← mp_cat(mp, value_str(p), cur_exp_str());
      delete_str_ref(cur_exp_str()); set_cur_exp_str(str);
    }
    else mp_bad_binary(mp, p, mp_concatenate);
    break;
  case mp_substring_of:
    if (mp_nice_pair(mp, p, mp_type(p)) ∧ (mp→cur_exp.type ≡ mp_string_type)) {
```

```
        mp_string str ← mp_chop_string(mp, cur_exp_str( ),
              round_unscaled(value_number(x_part(value_node(p)))),
              round_unscaled(value_number(y_part(value_node(p)))));
        delete_str_ref(cur_exp_str( )); set_cur_exp_str(str);
      }
      else mp_bad_binary(mp, p, mp_substring_of);
      break;
    case mp_subpath_of:
      if (mp→cur_exp.type ≡ mp_pair_type) mp_pair_to_path(mp);
      if (mp_nice_pair(mp, p, mp_type(p)) ∧ (mp→cur_exp.type ≡ mp_path_type))
        mp_chop_path(mp, value_node(p));
      else mp_bad_binary(mp, p, mp_subpath_of);
      break;
    case mp_point_of: case mp_precontrol_of: case mp_postcontrol_of:
      if (mp→cur_exp.type ≡ mp_pair_type) mp_pair_to_path(mp);
      if ((mp→cur_exp.type ≡ mp_path_type) ∧ (mp_type(p) ≡ mp_known))
        mp_find_point(mp, value_number(p), (quarterword) c);
      else mp_bad_binary(mp, p, (quarterword) c);
      break;
    case mp_pen_offset_of:
      if ((mp→cur_exp.type ≡ mp_pen_type) ∧ mp_nice_pair(mp, p, mp_type(p)))
        mp_set_up_offset(mp, value_node(p));
      else mp_bad_binary(mp, p, mp_pen_offset_of);
      break;
    case mp_direction_time_of:
      if (mp→cur_exp.type ≡ mp_pair_type) mp_pair_to_path(mp);
      if ((mp→cur_exp.type ≡ mp_path_type) ∧ mp_nice_pair(mp, p, mp_type(p)))
        mp_set_up_direction_time(mp, value_node(p));
      else mp_bad_binary(mp, p, mp_direction_time_of);
      break;
    case mp_envelope_of:
      if ((mp_type(p) ≠ mp_pen_type) ∨ (mp→cur_exp.type ≠ mp_path_type))
        mp_bad_binary(mp, p, mp_envelope_of);
      else mp_set_up_envelope(mp, p);
      break;
    case mp_boundingpath_of:
      if ((mp_type(p) ≠ mp_pen_type) ∨ (mp→cur_exp.type ≠ mp_path_type))
        mp_bad_binary(mp, p, mp_boundingpath_of);
      else mp_set_up_boundingpath(mp, p);
      break;
    case mp_glyph_infont:
      if ((mp_type(p) ≠ mp_string_type ∧ mp_type(p) ≠ mp_known) ∨ (mp→cur_exp.type ≠ mp_string_type))
        mp_bad_binary(mp, p, mp_glyph_infont);
      else mp_set_up_glyph_infont(mp, p);
      break;
    case mp_arc_time_of:
      if (mp→cur_exp.type ≡ mp_pair_type) mp_pair_to_path(mp);
      if ((mp→cur_exp.type ≡ mp_path_type) ∧ (mp_type(p) ≡ mp_known)) {
        memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
        mp_get_arc_time(mp, &new_expr.data.n, cur_exp_knot( ), value_number(p));
        mp_flush_cur_exp(mp, new_expr);
      }
```

```
      else {
        mp_bad_binary(mp, p, (quarterword) c);
      }
      break;
    case mp_intersect:
      if (mp_type(p) ≡ mp_pair_type) {
        q ← mp_stash_cur_exp(mp); mp_unstash_cur_exp(mp, p); mp_pair_to_path(mp);
        p ← mp_stash_cur_exp(mp); mp_unstash_cur_exp(mp, q);
      }
      if (mp→cur_exp.type ≡ mp_pair_type) mp_pair_to_path(mp);
      if ((mp→cur_exp.type ≡ mp_path_type) ∧ (mp_type(p) ≡ mp_path_type)) {
        mp_number arg1, arg2;
        new_number(arg1); new_number(arg2); mp_path_intersection(mp, value_knot(p), cur_exp_knot());
        number_clone(arg1, mp→cur_t); number_clone(arg2, mp→cur_tt); mp_pair_value(mp, arg1, arg2);
        free_number(arg1); free_number(arg2);
      }
      else {
        mp_bad_binary(mp, p, mp_intersect);
      }
      break;
    case mp_in_font:
      if ((mp→cur_exp.type ≠ mp_string_type) ∨ mp_type(p) ≠ mp_string_type) {
        mp_bad_binary(mp, p, mp_in_font);
      }
      else {
        mp_do_infont(mp, p); binary_return;
      }
      break;
    }   ▷ there are no other cases ◁
    mp_recycle_value(mp, p); mp_free_value_node(mp, p);   ▷ return to avoid this ◁
    mp_finish_binary(mp, old_p, old_exp);
}
```

991. ⟨Declare binary action procedures 991⟩ ≡

```
static void mp_bad_binary(MP mp, mp_node p, quarterword c)
{
  char msg[256];
  mp_string sname;
  int old_setting ← mp→selector;
  const char *hlp[] ← {"I'm␣afraid␣I␣don't␣know␣how␣to␣apply␣that␣operation␣to␣that",
      "combination␣of␣types.␣Continue,␣and␣I'll␣return␣the␣second",
      "argument␣(see␣above)␣as␣the␣result␣of␣the␣operation.", Λ};
  mp→selector ← new_string;
  if (c ≥ mp_min_of) mp_print_op(mp, c);
  mp_print_known_or_unknown_type(mp, mp_type(p), p);
  if (c ≥ mp_min_of) mp_print(mp, "of");
  else mp_print_op(mp, c);
  mp_print_known_or_unknown_type(mp, mp→cur_exp.type, cur_exp_node());
  sname ← mp_make_string(mp); mp→selector ← old_setting;
  mp_snprintf(msg, 256, "Not␣implemented:␣%s", mp_str(mp, sname)); delete_str_ref(sname);
  mp_disp_err(mp, p); mp_disp_err(mp, Λ); mp_back_error(mp, msg, hlp, true); mp_get_x_next(mp);
}
static void mp_bad_envelope_pen(MP mp)
{
  const char *hlp[] ← {"I'm␣afraid␣I␣don't␣know␣how␣to␣apply␣that␣operation␣to␣that",
      "combination␣of␣types.␣Continue,␣and␣I'll␣return␣the␣second",
      "argument␣(see␣above)␣as␣the␣result␣of␣the␣operation.", Λ};
  mp_disp_err(mp, Λ); mp_disp_err(mp, Λ);
  mp_back_error(mp, "Not␣implemented:␣envelope(elliptical␣pen)of(path)", hlp, true);
  mp_get_x_next(mp);
}
```

See also sections 992, 993, 995, 998, 999, 1000, 1007, 1008, 1009, 1010, 1011, 1021, 1029, 1030, 1031, 1032, and 1033.
This code is used in section 990.

992. ⟨ Declare binary action procedures 991 ⟩ +≡

```
static mp_node mp_tarnished(MP mp, mp_node p)
{
  mp_node q;    ▷ beginning of the big node ◁
  mp_node r;    ▷ moving value node pointer ◁
  (void) mp; q ← value_node(p);
  switch (mp_type(p)) {
  case mp_pair_type: r ← x_part(q);
    if (mp_type(r) ≡ mp_independent) return MP_VOID;
    r ← y_part(q);
    if (mp_type(r) ≡ mp_independent) return MP_VOID;
    break;
  case mp_color_type: r ← red_part(q);
    if (mp_type(r) ≡ mp_independent) return MP_VOID;
    r ← green_part(q);
    if (mp_type(r) ≡ mp_independent) return MP_VOID;
    r ← blue_part(q);
    if (mp_type(r) ≡ mp_independent) return MP_VOID;
    break;
  case mp_cmykcolor_type: r ← cyan_part(q);
    if (mp_type(r) ≡ mp_independent) return MP_VOID;
    r ← magenta_part(q);
    if (mp_type(r) ≡ mp_independent) return MP_VOID;
    r ← yellow_part(q);
    if (mp_type(r) ≡ mp_independent) return MP_VOID;
    r ← black_part(q);
    if (mp_type(r) ≡ mp_independent) return MP_VOID;
    break;
  case mp_transform_type: r ← tx_part(q);
    if (mp_type(r) ≡ mp_independent) return MP_VOID;
    r ← ty_part(q);
    if (mp_type(r) ≡ mp_independent) return MP_VOID;
    r ← xx_part(q);
    if (mp_type(r) ≡ mp_independent) return MP_VOID;
    r ← xy_part(q);
    if (mp_type(r) ≡ mp_independent) return MP_VOID;
    r ← yx_part(q);
    if (mp_type(r) ≡ mp_independent) return MP_VOID;
    r ← yy_part(q);
    if (mp_type(r) ≡ mp_independent) return MP_VOID;
    break;
  default:    ▷ there are no other valid cases, but please the compiler ◁
    break;
  }
  return Λ;
}
```

993. The first argument to *add_or_subtract* is the location of a value node in a capsule or pair node that will soon be recycled. The second argument is either a location within a pair or transform node of *cur_exp*, or it is NULL (which means that *cur_exp* itself should be the second argument). The third argument is either *plus* or *minus*.

The sum or difference of the numeric quantities will replace the second operand. Arithmetic overflow may go undetected; users aren't supposed to be monkeying around with really big values.

⟨Declare binary action procedures 991⟩ +≡
  ⟨Declare the procedure called *dep_finish* 994⟩;
  static void *mp_add_or_subtract*(**MP** *mp*, **mp_node** *p*, **mp_node** *q*, **quarterword** *c*)
  {
    mp_variable_type *s*, *t*;   ▷ operand types ◁
    mp_value_node *r*;   ▷ dependency list traverser ◁
    mp_value_node *v* ← Λ;   ▷ second operand value for dep lists ◁
    mp_number *vv*;   ▷ second operand value for known values ◁
    new_number(*vv*);
    if (*q* ≡ Λ) {
      t ← *mp*→*cur_exp*.*type*;
      if (*t* < *mp_dependent*) *number_clone*(*vv*, *cur_exp_value_number*());
      else *v* ← (**mp_value_node**) *dep_list*((**mp_value_node**) *cur_exp_node*());
    }
    else {
      t ← *mp_type*(*q*);
      if (*t* < *mp_dependent*) *number_clone*(*vv*, *value_number*(*q*));
      else *v* ← (**mp_value_node**) *dep_list*((**mp_value_node**) *q*);
    }
    if (*t* ≡ *mp_known*) {
      mp_value_node *qq* ← (**mp_value_node**) *q*;
      if (*c* ≡ *mp_minus*) *number_negate*(*vv*);
      if (*mp_type*(*p*) ≡ *mp_known*) {
        slow_add(*vv*, *value_number*(*p*), *vv*);
        if (*q* ≡ Λ) *set_cur_exp_value_number*(*vv*);
        else *set_value_number*(*q*, *vv*);
        free_number(*vv*); **return**;
      }   ▷ Add a known value to the constant term of *dep_list*(*p*) ◁
      r ← (**mp_value_node**) *dep_list*((**mp_value_node**) *p*);
      while (*dep_info*(*r*) ≠ Λ) *r* ← (**mp_value_node**) *mp_link*(*r*);
      slow_add(*vv*, *dep_value*(*r*), *vv*); *set_dep_value*(*r*, *vv*);
      if (*qq* ≡ Λ) {
        qq ← *mp_get_dep_node*(*mp*); *set_cur_exp_node*((**mp_node**) *qq*); *mp*→*cur_exp*.*type* ← *mp_type*(*p*);
        mp_name_type(*qq*) ← *mp_capsule*;   ▷ clang: never read: *q* ← (**mp_node**) *qq*; ◁
      }
      set_dep_list(*qq*, *dep_list*((**mp_value_node**) *p*)); *mp_type*(*qq*) ← *mp_type*(*p*);
      set_prev_dep(*qq*, *prev_dep*((**mp_value_node**) *p*));
      mp_link(*prev_dep*((**mp_value_node**) *p*)) ← (**mp_node**) *qq*; *mp_type*(*p*) ← *mp_known*;
        ▷ this will keep the recycler from collecting non-garbage ◁
    }
    else {
      if (*c* ≡ *mp_minus*) *mp_negate_dep_list*(*mp*, *v*);   ▷ Add operand *p* to the dependency list *v* ◁
          ▷ We prefer *dependent* lists to *mp_proto_dependent* ones, because it is nice to retain the extra accuracy of *fraction* coefficients. But we have to handle both kinds, and mixtures too. ◁
      if (*mp_type*(*p*) ≡ *mp_known*) {   ▷ Add the known *value*(*p*) to the constant term of *v* ◁

```
      while (dep_info(v) ≠ Λ) {
        v ← (mp_value_node) mp_link(v);
      }
      slow_add(vv, value_number(p), dep_value(v)); set_dep_value(v, vv);
    }
    else {
      s ← mp_type(p); r ← (mp_value_node) dep_list((mp_value_node) p);
      if (t ≡ mp_dependent) {
        if (s ≡ mp_dependent) {
          mp_number ret1, ret2;
          new_fraction(ret1); new_fraction(ret2); mp_max_coef(mp, &ret1, r);
          mp_max_coef(mp, &ret2, v); number_add(ret1, ret2); free_number(ret2);
          if (number_less(ret1, coef_bound_k)) {
            v ← mp_p_plus_q(mp, v, r, mp_dependent); free_number(ret1); goto DONE;
          }
          free_number(ret1);
        }    ▷ fix_needed will necessarily be false ◁
        t ← mp_proto_dependent; v ← mp_p_over_v(mp, v, unity_t, mp_dependent, mp_proto_dependent);
      }
      if (s ≡ mp_proto_dependent) v ← mp_p_plus_q(mp, v, r, mp_proto_dependent);
      else v ← mp_p_plus_fq(mp, v, unity_t, r, mp_proto_dependent, mp_dependent);
    DONE:    ▷ Output the answer, v (which might have become known) ◁
      if (q ≠ Λ) {
        mp_dep_finish(mp, v, (mp_value_node) q, t);
      }
      else {
        mp→cur_exp.type ← t; mp_dep_finish(mp, v, Λ, t);
      }
    }
  }
  free_number(vv);
}
```

994. Here's the current situation: The dependency list v of type t should either be put into the current expression (if $q \leftarrow \Lambda$) or into location q within a pair node (otherwise). The destination (*cur_exp* or q) formerly held a dependency list with the same final pointer as the list v.

⟨ Declare the procedure called *dep_finish* 994 ⟩ ≡

```
static void mp_dep_finish(MP mp, mp_value_node v, mp_value_node q, quarterword t)
{
  mp_value_node p;    ▷ the destination ◁
  if (q ≡ Λ) p ← (mp_value_node) cur_exp_node();
  else p ← q;
  set_dep_list(p, v); mp_type(p) ← t;
  if (dep_info(v) ≡ Λ) {
    mp_number vv;    ▷ the value, if it is known ◁
    new_number(vv); number_clone(vv, value_number(v));
    if (q ≡ Λ) {
      mp_value new_expr;
      memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
      number_clone(new_expr.data.n, vv); mp_flush_cur_exp(mp, new_expr);
    }
    else {
      mp_recycle_value(mp, (mp_node) p); mp_type(q) ← mp_known; set_value_number(q, vv);
    }
    free_number(vv);
  }
  else if (q ≡ Λ) {
    mp→cur_exp.type ← t;
  }
  if (mp→fix_needed) mp_fix_dependencies(mp);
}
```

This code is used in section 993.

995. ⟨ Declare binary action procedures 991 ⟩ +≡

```
static void mp_dep_mult(MP mp, mp_value_node p, mp_number v, boolean v_is_scaled)
{
  mp_value_node q;    ▷ the dependency list being multiplied by v ◁
  quarterword s, t;    ▷ its type, before and after ◁
  if (p ≡ Λ) {
    q ← (mp_value_node) cur_exp_node( );
  }
  else if (mp_type(p) ≠ mp_known) {
    q ← p;
  }
  else {
    {
      mp_number r1, arg1;
      new_number(arg1); number_clone(arg1, dep_value(p));
      if (v_is_scaled) {
        new_number(r1); take_scaled(r1, arg1, v);
      }
      else {
        new_fraction(r1); take_fraction(r1, arg1, v);
      }
      set_dep_value(p, r1); free_number(r1); free_number(arg1);
    }
    return;
  }
  t ← mp_type(q); q ← (mp_value_node) dep_list(q); s ← t;
  if (t ≡ mp_dependent) {
    if (v_is_scaled) {
      mp_number ab_vs_cd;
      mp_number arg1, arg2;
      new_number(ab_vs_cd); new_number(arg2); new_fraction(arg1); mp_max_coef(mp, &arg1, q);
      number_clone(arg2, v); number_abs(arg2);
      ab_vs_cd(ab_vs_cd, arg1, arg2, coef_bound_minus_1, unity_t); free_number(arg1);
      free_number(arg2);
      if (number_nonnegative(ab_vs_cd)) {
        t ← mp_proto_dependent;
      }
      free_number(ab_vs_cd);
    }
  }
  q ← mp_p_times_v(mp, q, v, s, t, v_is_scaled); mp_dep_finish(mp, q, p, t);
}
```

996. Here is a routine that is similar to *times*; but it is invoked only internally, when v is a *fraction* whose magnitude is at most 1, and when $cur\_type \ge mp\_color\_type$.

```
static void mp_frac_mult(MP mp, mp_number n, mp_number d)
{    ▷ multiplies cur_exp by n/d ◁
  mp_node old_exp;    ▷ a capsule to recycle ◁
  mp_number v;    ▷ n/d ◁
  new_fraction(v);
  if (number_greater(internal_value(mp_tracing_commands), two_t))
    ⟨Trace the fraction multiplication 997⟩
  switch (mp→cur_exp.type) {
  case mp_transform_type: case mp_color_type: case mp_cmykcolor_type: case mp_pair_type:
    old_exp ← mp_tarnished(mp, cur_exp_node()); break;
  case mp_independent: old_exp ← MP_VOID; break;
  default: old_exp ← Λ; break;
  }
  if (old_exp ≠ Λ) {
    old_exp ← cur_exp_node(); mp_make_exp_copy(mp, old_exp);
  }
  make_fraction(v, n, d);
  if (mp→cur_exp.type ≡ mp_known) {
    mp_number r1, arg1;
    new_fraction(r1); new_number(arg1); number_clone(arg1, cur_exp_value_number());
    take_fraction(r1, arg1, v); set_cur_exp_value_number(r1); free_number(r1); free_number(arg1);
  }
  else if (mp→cur_exp.type ≡ mp_pair_type) {
    mp_dep_mult(mp, (mp_value_node) x_part(value_node(cur_exp_node())), v, false);
    mp_dep_mult(mp, (mp_value_node) y_part(value_node(cur_exp_node())), v, false);
  }
  else if (mp→cur_exp.type ≡ mp_color_type) {
    mp_dep_mult(mp, (mp_value_node) red_part(value_node(cur_exp_node())), v, false);
    mp_dep_mult(mp, (mp_value_node) green_part(value_node(cur_exp_node())), v, false);
    mp_dep_mult(mp, (mp_value_node) blue_part(value_node(cur_exp_node())), v, false);
  }
  else if (mp→cur_exp.type ≡ mp_cmykcolor_type) {
    mp_dep_mult(mp, (mp_value_node) cyan_part(value_node(cur_exp_node())), v, false);
    mp_dep_mult(mp, (mp_value_node) magenta_part(value_node(cur_exp_node())), v, false);
    mp_dep_mult(mp, (mp_value_node) yellow_part(value_node(cur_exp_node())), v, false);
    mp_dep_mult(mp, (mp_value_node) black_part(value_node(cur_exp_node())), v, false);
  }
  else {
    mp_dep_mult(mp, Λ, v, false);
  }
  if (old_exp ≠ Λ) {
    mp_recycle_value(mp, old_exp); mp_free_value_node(mp, old_exp);
  }
  free_number(v);
}
```

997. ⟨ Trace the fraction multiplication 997 ⟩ ≡

```
{
  mp_begin_diagnostic(mp); mp_print_nl(mp, "{("); print_number(n); mp_print_char(mp, xord('/'));
  print_number(d); mp_print(mp, ")*("); mp_print_exp(mp, Λ, 0); mp_print(mp, ")}");
  mp_end_diagnostic(mp, false);
}
```

This code is used in section 996.

998. The *hard_times* routine multiplies a nice color or pair by a dependency list.

⟨ Declare binary action procedures 991 ⟩ +≡

```
static void mp_hard_times(MP mp, mp_node p)
{
  mp_value_node q;    ▷ a copy of the dependent variable p ◁
  mp_value_node pp;    ▷ for typecasting p ◁
  mp_node r;    ▷ a component of the big node for the nice color or pair ◁
  mp_number v;    ▷ the known value for r ◁
  new_number(v);
  if (mp_type(p) ≤ mp_pair_type) {
    q ← (mp_value_node) mp_stash_cur_exp(mp); mp_unstash_cur_exp(mp, p); p ← (mp_node) q;
  }    ▷ now cur_type ← mp_pair_type or cur_type ← mp_color_type or cur_type ← mp_cmykcolor_type ◁
  pp ← (mp_value_node) p;
  if (mp→cur_exp.type ≡ mp_pair_type) {
    r ← x_part(value_node(cur_exp_node())); number_clone(v, value_number(r));
    mp_new_dep(mp, r, mp_type(pp), mp_copy_dep_list(mp, (mp_value_node) dep_list(pp)));
    mp_dep_mult(mp, (mp_value_node) r, v, true); r ← y_part(value_node(cur_exp_node()));
    number_clone(v, value_number(r));
    mp_new_dep(mp, r, mp_type(pp), mp_copy_dep_list(mp, (mp_value_node) dep_list(pp)));
    mp_dep_mult(mp, (mp_value_node) r, v, true);
  }
  else if (mp→cur_exp.type ≡ mp_color_type) {
    r ← red_part(value_node(cur_exp_node())); number_clone(v, value_number(r));
    mp_new_dep(mp, r, mp_type(pp), mp_copy_dep_list(mp, (mp_value_node) dep_list(pp)));
    mp_dep_mult(mp, (mp_value_node) r, v, true); r ← green_part(value_node(cur_exp_node()));
    number_clone(v, value_number(r));
    mp_new_dep(mp, r, mp_type(pp), mp_copy_dep_list(mp, (mp_value_node) dep_list(pp)));
    mp_dep_mult(mp, (mp_value_node) r, v, true); r ← blue_part(value_node(cur_exp_node()));
    number_clone(v, value_number(r));
    mp_new_dep(mp, r, mp_type(pp), mp_copy_dep_list(mp, (mp_value_node) dep_list(pp)));
    mp_dep_mult(mp, (mp_value_node) r, v, true);
  }
  else if (mp→cur_exp.type ≡ mp_cmykcolor_type) {
    r ← cyan_part(value_node(cur_exp_node())); number_clone(v, value_number(r));
    mp_new_dep(mp, r, mp_type(pp), mp_copy_dep_list(mp, (mp_value_node) dep_list(pp)));
    mp_dep_mult(mp, (mp_value_node) r, v, true); r ← yellow_part(value_node(cur_exp_node()));
    number_clone(v, value_number(r));
    mp_new_dep(mp, r, mp_type(pp), mp_copy_dep_list(mp, (mp_value_node) dep_list(pp)));
    mp_dep_mult(mp, (mp_value_node) r, v, true); r ← magenta_part(value_node(cur_exp_node()));
    number_clone(v, value_number(r));
    mp_new_dep(mp, r, mp_type(pp), mp_copy_dep_list(mp, (mp_value_node) dep_list(pp)));
    mp_dep_mult(mp, (mp_value_node) r, v, true); r ← black_part(value_node(cur_exp_node()));
    number_clone(v, value_number(r));
    mp_new_dep(mp, r, mp_type(pp), mp_copy_dep_list(mp, (mp_value_node) dep_list(pp)));
    mp_dep_mult(mp, (mp_value_node) r, v, true);
  }
  free_number(v);
}
```

999. ⟨ Declare binary action procedures 991 ⟩ +≡

static void *mp_dep_div*(**MP** *mp*, **mp_value_node** *p*, **mp_number** *v*)
{
  mp_value_node *q*; ▷ the dependency list being divided by *v* ◁
  quarterword *s*, *t*; ▷ its type, before and after ◁
  if ($p \equiv \Lambda$) $q \leftarrow$ (**mp_value_node**) *cur_exp_node*( );
  else if (*mp_type*(*p*) $\neq$ *mp_known*) $q \leftarrow p$;
  else {
    mp_number *ret*;
    new_number(*ret*); *make_scaled*(*ret*, *value_number*(*p*), *v*); *set_value_number*(*p*, *ret*); *free_number*(*ret*);
    return;
  }
  $t \leftarrow$ *mp_type*(*q*); $q \leftarrow$ (**mp_value_node**) *dep_list*(*q*); $s \leftarrow t$;
  if ($t \equiv$ *mp_dependent*) {
    mp_number *ab_vs_cd*;
    mp_number *arg1*, *arg2*;
    new_number(*ab_vs_cd*); *new_number*(*arg2*); *new_fraction*(*arg1*); *mp_max_coef*(*mp*, &*arg1*, *q*);
    number_clone(*arg2*, *v*); *number_abs*(*arg2*);
    ab_vs_cd(*ab_vs_cd*, *arg1*, *unity_t*, *coef_bound_minus_1*, *arg2*); *free_number*(*arg1*); *free_number*(*arg2*);
    if (*number_nonnegative*(*ab_vs_cd*)) {
      $t \leftarrow$ *mp_proto_dependent*;
    }
    free_number(*ab_vs_cd*);
  }
  $q \leftarrow$ *mp_p_over_v*(*mp*, *q*, *v*, *s*, *t*); *mp_dep_finish*(*mp*, *q*, *p*, *t*);
}

1000. Let c be one of the eight transform operators. The procedure call *set_up_trans*(c) first changes *cur_exp* to a transform that corresponds to c and the original value of *cur_exp*. (In particular, *cur_exp* doesn't change at all if $c \leftarrow$ *transformed_by*.)

Then, if all components of the resulting transform are *known*, they are moved to the global variables *txx*, *txy*, *tyx*, *tyy*, *tx*, *ty*; and *cur_exp* is changed to the known value zero.

⟨Declare binary action procedures 991⟩ +≡

```
static void mp_set_up_trans(MP mp, quarterword c)
{
  mp_node p, q, r;   ▷ list manipulation registers ◁
  mp_value new_expr;
  memset(&new_expr, 0, sizeof(mp_value));
  if ((c ≠ mp_transformed_by) ∨ (mp→cur_exp.type ≠ mp_transform_type)) {
      ▷ Put the current transform into cur_exp ◁
    const char *hlp[] ← {"The␣expression␣shown␣above␣has␣the␣wrong␣type,",
        "so␣I␣can\'t␣transform␣anything␣using␣it.",
        "Proceed,␣and␣I'll␣omit␣the␣transformation.", Λ};
    p ← mp_stash_cur_exp(mp); set_cur_exp_node(mp_id_transform(mp));
    mp→cur_exp.type ← mp_transform_type; q ← value_node(cur_exp_node());
    switch (c) {
      ⟨For each of the eight cases, change the relevant fields of cur_exp and goto done; but do nothing
          if capsule p doesn't have the appropriate type 1004⟩;
    }   ▷ there are no other cases ◁
    mp_disp_err(mp, p); mp_back_error(mp, "Improper␣transformation␣argument", hlp, true);
    mp_get_x_next(mp);
  DONE: mp_recycle_value(mp, p); mp_free_value_node(mp, p);
  }   ▷ If the current transform is entirely known, stash it in global variables; otherwise return ◁
  q ← value_node(cur_exp_node());
  if (mp_type(tx_part(q)) ≠ mp_known) return;
  if (mp_type(ty_part(q)) ≠ mp_known) return;
  if (mp_type(xx_part(q)) ≠ mp_known) return;
  if (mp_type(xy_part(q)) ≠ mp_known) return;
  if (mp_type(yx_part(q)) ≠ mp_known) return;
  if (mp_type(yy_part(q)) ≠ mp_known) return;
  number_clone(mp→txx, value_number(xx_part(q))); number_clone(mp→txy, value_number(xy_part(q)));
  number_clone(mp→tyx, value_number(yx_part(q))); number_clone(mp→tyy, value_number(yy_part(q)));
  number_clone(mp→tx, value_number(tx_part(q))); number_clone(mp→ty, value_number(ty_part(q)));
  new_number(new_expr.data.n); set_number_to_zero(new_expr.data.n);
  mp_flush_cur_exp(mp, new_expr);
}
```

1001. ⟨Global variables 18⟩ +≡

```
mp_number txx;
mp_number txy;
mp_number tyx;
mp_number tyy;
mp_number tx;
mp_number ty;   ▷ current transform coefficients ◁
```

1002. ⟨Initialize table entries 186⟩ +≡

```
new_number(mp→txx); new_number(mp→txy); new_number(mp→tyx); new_number(mp→tyy);
new_number(mp→tx); new_number(mp→ty);
```

1003. ⟨ Free table entries 187 ⟩ +≡
free_number(*mp*→*txx*); *free_number*(*mp*→*txy*); *free_number*(*mp*→*tyx*); *free_number*(*mp*→*tyy*);
free_number(*mp*→*tx*); *free_number*(*mp*→*ty*);

1004. ⟨ For each of the eight cases, change the relevant fields of *cur_exp* and **goto** *done*; but do nothing if capsule p doesn't have the appropriate type 1004 ⟩ ≡

case *mp_rotated_by*:
  if (*mp_type*(p) ≡ *mp_known*) ⟨ Install sines and cosines, then **goto** *done* 1005 ⟩;
  break;
case *mp_slanted_by*:
  if (*mp_type*(p) > *mp_pair_type*) {
    mp_install(*mp*, *xy_part*(q), p); **goto** `DONE`;
  }
  break;
case *mp_scaled_by*:
  if (*mp_type*(p) > *mp_pair_type*) {
    mp_install(*mp*, *xx_part*(q), p); *mp_install*(*mp*, *yy_part*(q), p); **goto** `DONE`;
  }
  break;
case *mp_shifted_by*:
  if (*mp_type*(p) ≡ *mp_pair_type*) {
    r ← *value_node*(p); *mp_install*(*mp*, *tx_part*(q), *x_part*(r)); *mp_install*(*mp*, *ty_part*(q), *y_part*(r));
    goto `DONE`;
  }
  break;
case *mp_x_scaled*:
  if (*mp_type*(p) > *mp_pair_type*) {
    mp_install(*mp*, *xx_part*(q), p); **goto** `DONE`;
  }
  break;
case *mp_y_scaled*:
  if (*mp_type*(p) > *mp_pair_type*) {
    mp_install(*mp*, *yy_part*(q), p); **goto** `DONE`;
  }
  break;
case *mp_z_scaled*:
  if (*mp_type*(p) ≡ *mp_pair_type*) ⟨ Install a complex multiplier, then **goto** *done* 1006 ⟩;
  break;
case *mp_transformed_by*: **break**;

This code is used in section 1000.

1005. ⟨ Install sines and cosines, then **goto** *done* 1005 ⟩ ≡

```
{
  mp_number n_sin, n_cos, arg1, arg2;
  new_number(arg1); new_number(arg2); new_fraction(n_sin); new_fraction(n_cos);
    ▷ results computed by n_sin_cos ◁
  number_clone(arg2, unity_t); number_clone(arg1, value_number(p)); number_multiply_int(arg2, 360);
  number_modulo(arg1, arg2); convert_scaled_to_angle(arg1); n_sin_cos(arg1, n_cos, n_sin);
  fraction_to_round_scaled(n_sin); fraction_to_round_scaled(n_cos); set_value_number(xx_part(q), n_cos);
  set_value_number(yx_part(q), n_sin); set_value_number(xy_part(q), value_number(yx_part(q)));
  number_negate(value_number(xy_part(q))); set_value_number(yy_part(q), value_number(xx_part(q)));
  free_number(arg1); free_number(arg2); free_number(n_sin); free_number(n_cos); goto DONE;
}
```

This code is used in section 1004.

1006. ⟨ Install a complex multiplier, then **goto** *done* 1006 ⟩ ≡

```
{
  r ← value_node(p); mp_install(mp, xx_part(q), x_part(r)); mp_install(mp, yy_part(q), x_part(r));
  mp_install(mp, yx_part(q), y_part(r));
  if (mp_type(y_part(r)) ≡ mp_known) {
    set_value_number(y_part(r), value_number(y_part(r))); number_negate(value_number(y_part(r)));
  }
  else {
    mp_negate_dep_list(mp, (mp_value_node) dep_list((mp_value_node) y_part(r)));
  }
  mp_install(mp, xy_part(q), y_part(r)); goto DONE;
}
```

This code is used in section 1004.

1007. Procedure *set_up_known_trans* is like *set_up_trans*, but it insists that the transformation be entirely known.

⟨ Declare binary action procedures 991 ⟩ +≡

```
static void mp_set_up_known_trans(MP mp, quarterword c)
{
  mp_set_up_trans(mp, c);
  if (mp→cur_exp.type ≠ mp_known) {
    mp_value new_expr;
    const char *hlp[] ← {"I'm␣unable␣to␣apply␣a␣partially␣specified␣transformation",
        "except␣to␣a␣fully␣known␣pair␣or␣transform.",
        "Proceed,␣and␣I'll␣omit␣the␣transformation.", Λ};
    memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n); mp_disp_err(mp, Λ);
    set_number_to_zero(new_expr.data.n);
    mp_back_error(mp, "Transform␣components␣aren't␣all␣known", hlp, true); mp_get_x_next(mp);
    mp_flush_cur_exp(mp, new_expr); set_number_to_unity(mp→txx); set_number_to_zero(mp→txy);
    set_number_to_zero(mp→tyx); set_number_to_unity(mp→tyy); set_number_to_zero(mp→tx);
    set_number_to_zero(mp→ty);
  }
}
```

1008. Here's a procedure that applies the transform *txx* .. *ty* to a pair of coordinates in locations p and q.

⟨ Declare binary action procedures 991 ⟩ +≡

```
static void mp_number_trans(MP mp, mp_number *p, mp_number *q)
{
  mp_number r1, r2, v;
  new_number(r1); new_number(r2); new_number(v); take_scaled(r1, *p, mp→txx);
  take_scaled(r2, *q, mp→txy); number_add(r1, r2); set_number_from_addition(v, r1, mp→tx);
  take_scaled(r1, *p, mp→tyx); take_scaled(r2, *q, mp→tyy); number_add(r1, r2);
  set_number_from_addition(*q, r1, mp→ty); number_clone(*p, v); free_number(r1); free_number(r2);
  free_number(v);
}
```

1009. The simplest transformation procedure applies a transform to all coordinates of a path. The *path_trans*$(c)(p)$ macro applies a transformation defined by *cur_exp* and the transform operator c to the path p.

```
#define path_trans(A, B)
        {
          mp_set_up_known_trans(mp, (A)); mp_unstash_cur_exp(mp, (B));
          mp_do_path_trans(mp, cur_exp_knot());
        }
```

⟨ Declare binary action procedures 991 ⟩ +≡

```
static void mp_do_path_trans(MP mp, mp_knot p)
{
  mp_knot q;    ▷ list traverser ◁
  q ← p;
  do {
    if (mp_left_type(q) ≠ mp_endpoint) mp_number_trans(mp, &q→left_x, &q→left_y);
    mp_number_trans(mp, &q→x_coord, &q→y_coord);
    if (mp_right_type(q) ≠ mp_endpoint) mp_number_trans(mp, &q→right_x, &q→right_y);
    q ← mp_next_knot(q);
  } while (q ≠ p);
}
```

1010. Transforming a pen is very similar, except that there are no *mp_left_type* and *mp_right_type* fields.

```
#define pen_trans(A, B)
        {
          mp_set_up_known_trans(mp, (A)); mp_unstash_cur_exp(mp, (B));
          mp_do_pen_trans(mp, cur_exp_knot());
        }
```

⟨ Declare binary action procedures 991 ⟩ +≡

```
static void mp_do_pen_trans(MP mp, mp_knot p)
{
  mp_knot q;    ▷ list traverser ◁
  if (pen_is_elliptical(p)) {
    mp_number_trans(mp, &p→left_x, &p→left_y); mp_number_trans(mp, &p→right_x, &p→right_y);
  }
  q ← p;
  do {
    mp_number_trans(mp, &q→x_coord, &q→y_coord); q ← mp_next_knot(q);
  } while (q ≠ p);
}
```

1011. The next transformation procedure applies to edge structures. It will do any transformation, but the results may be substandard if the picture contains text that uses downloaded bitmap fonts. The binary action procedure is *do_edges_trans*, but we also need a function that just scales a picture. That routine is *scale_edges*. Both it and the underlying routine *edges_trans* should be thought of as procedures that update an edge structure h, except that they have to return a (possibly new) structure because of the need to call *private_edges*.

⟨Declare binary action procedures 991⟩ +≡

```
static mp_edge_header_node mp_edges_trans(MP mp, mp_edge_header_node h)
{
  mp_node q;    ▷ the object being transformed ◁
  mp_dash_node r, s;    ▷ for list manipulation ◁
  mp_number sx, sy;    ▷ saved transformation parameters ◁
  mp_number sqdet;    ▷ square root of determinant for dash_scale ◁
  mp_number sgndet;    ▷ sign of the determinant ◁

  h ← mp_private_edges(mp, h); new_number(sx); new_number(sy); new_number(sqdet);
  new_number(sgndet); mp_sqrt_det(mp, &sqdet, mp→txx, mp→txy, mp→tyx, mp→tyy);
  ab_vs_cd(sgndet, mp→txx, mp→tyy, mp→txy, mp→tyx);
  if (dash_list(h) ≠ mp→null_dash) {
    ⟨Try to transform the dash list of h 1012⟩;
  }
  ⟨Make the bounding box of h unknown if it can't be updated properly without scanning the whole
      structure 1015⟩;
  q ← mp_link(edge_list(h));
  while (q ≠ Λ) {
    ⟨Transform graphical object q 1018⟩;
    q ← mp_link(q);
  }
  free_number(sx); free_number(sy); free_number(sqdet); free_number(sgndet); return h;
}
static void mp_do_edges_trans(MP mp, mp_node p, quarterword c)
{
  mp_set_up_known_trans(mp, c);
  set_value_node(p, (mp_node) mp_edges_trans(mp, (mp_edge_header_node) value_node(p)));
  mp_unstash_cur_exp(mp, p);
}
static mp_edge_header_node mp_scale_edges(MP mp, mp_number se_sf, mp_edge_header_node
      se_pic)
{
  number_clone(mp→txx, se_sf); number_clone(mp→tyy, se_sf); set_number_to_zero(mp→txy);
  set_number_to_zero(mp→tyx); set_number_to_zero(mp→tx); set_number_to_zero(mp→ty);
  return mp_edges_trans(mp, se_pic);
}
```

1012. ⟨ Try to transform the dash list of h 1012 ⟩ ≡

```
if (number_nonzero(mp→txy) ∨ number_nonzero(mp→tyx) ∨ number_nonzero(mp→ty) ∨
        number_nonequalabs(mp→txx, mp→tyy)) {
    mp_flush_dash_list(mp, h);
}
else {
    mp_number abs_tyy, ret;

    new_number(abs_tyy);
    if (number_negative(mp→txx)) ⟨ Reverse the dash list of h 1013 ⟩
    ⟨ Scale the dash list by txx and shift it by tx 1014 ⟩;
    number_clone(abs_tyy, mp→tyy); number_abs(abs_tyy); new_number(ret);
    take_scaled(ret, h→dash_y, abs_tyy); number_clone(h→dash_y, ret); free_number(ret);
    free_number(abs_tyy);
}
```

This code is used in section 1011.

1013. ⟨ Reverse the dash list of h 1013 ⟩ ≡

```
{
    r ← dash_list(h); set_dash_list(h, mp→null_dash);
    while (r ≠ mp→null_dash) {
        s ← r; r ← (mp_dash_node) mp_link(r); number_swap(s→start_x, s→stop_x);
        mp_link(s) ← (mp_node) dash_list(h); set_dash_list(h, s);
    }
}
```

This code is used in section 1012.

1014. ⟨ Scale the dash list by txx and shift it by tx 1014 ⟩ ≡

```
r ← dash_list(h);
{
    mp_number arg1;

    new_number(arg1);
    while (r ≠ mp→null_dash) {
        take_scaled(arg1, r→start_x, mp→txx); set_number_from_addition(r→start_x, arg1, mp→tx);
        take_scaled(arg1, r→stop_x, mp→txx); set_number_from_addition(r→stop_x, arg1, mp→tx);
        r ← (mp_dash_node) mp_link(r);
    }
    free_number(arg1);
}
```

This code is used in section 1012.

1015. ⟨ Make the bounding box of h unknown if it can't be updated properly without scanning the whole structure 1015 ⟩ ≡

```
if (number_zero(mp→txx) ∧ number_zero(mp→tyy))
    ⟨ Swap the x and y parameters in the bounding box of h 1016 ⟩
else if (number_nonzero(mp→txy) ∨ number_nonzero(mp→tyx)) {
    mp_init_bbox(mp, h); goto DONE1;
}
if (number_lessequal(h→minx, h→maxx))
    ⟨ Scale the bounding box by txx + txy and tyx + tyy; then shift by (tx, ty) 1017 ⟩
DONE1:
```

This code is used in section 1011.

1016. ⟨ Swap the x and y parameters in the bounding box of h 1016 ⟩ ≡

```
{
  number_swap(h→minx, h→miny);  number_swap(h→maxx, h→maxy);
}
```

This code is used in section 1015.

1017. The sum "$txx + txy$" is whichever of txx or txy is nonzero. The other sum is similar.

⟨ Scale the bounding box by $txx + txy$ and $tyx + tyy$; then shift by (tx, ty) 1017 ⟩ ≡

```
{
  mp_number tot, ret;
  new_number(tot); new_number(ret); set_number_from_addition(tot, mp→txx, mp→txy);
  take_scaled(ret, h→minx, tot);  set_number_from_addition(h→minx, ret, mp→tx);
  take_scaled(ret, h→maxx, tot);  set_number_from_addition(h→maxx, ret, mp→tx);
  set_number_from_addition(tot, mp→tyx, mp→tyy);  take_scaled(ret, h→miny, tot);
  set_number_from_addition(h→miny, ret, mp→ty);  take_scaled(ret, h→maxy, tot);
  set_number_from_addition(h→maxy, ret, mp→ty);  set_number_from_addition(tot, mp→txx, mp→txy);
  if (number_negative(tot)) {
    number_swap(h→minx, h→maxx);
  }
  set_number_from_addition(tot, mp→tyx, mp→tyy);
  if (number_negative(tot)) {
    number_swap(h→miny, h→maxy);
  }
  free_number(ret); free_number(tot);
}
```

This code is used in section 1015.

1018. Now we ready for the main task of transforming the graphical objects in edge structure h.

⟨ Transform graphical object q 1018 ⟩ ≡
  switch (*mp_type*(q)) {
  case *mp_fill_node_type*:
    {
      mp_fill_node qq ← (**mp_fill_node**) q;
      mp_do_path_trans(*mp*, *mp_path_p*(qq));
      ⟨ Transform *mp_pen_p*(qq), making sure polygonal pens stay counter-clockwise 1019 ⟩;
    }
    break;
  case *mp_stroked_node_type*:
    {
      mp_stroked_node qq ← (**mp_stroked_node**) q;
      mp_do_path_trans(*mp*, *mp_path_p*(qq));
      ⟨ Transform *mp_pen_p*(qq), making sure polygonal pens stay counter-clockwise 1019 ⟩;
    }
    break;
  case *mp_start_clip_node_type*: *mp_do_path_trans*(*mp*, *mp_path_p*((**mp_start_clip_node**) q)); **break**;
  case *mp_start_bounds_node_type*: *mp_do_path_trans*(*mp*, *mp_path_p*((**mp_start_bounds_node**) q));
    break;
  case *mp_text_node_type*: ⟨ Transform the compact transformation 1020 ⟩;
    break;
  case *mp_stop_clip_node_type*: **case** *mp_stop_bounds_node_type*: **break**;
  default: ▷ there are no other valid cases, but please the compiler ◁
    break;
  }

This code is used in section 1011.

1019. Note that the shift parameters (*tx*, *ty*) apply only to the path being stroked. The *dash_scale* has to be adjusted to scale the dash lengths in *mp_dash_p*(q) since the PostScript output procedures will try to compensate for the transformation we are applying to *mp_pen_p*(q). Since this compensation is based on the square root of the determinant, *sqdet* is the appropriate factor.

We pass the mptrap test only if *dash_scale* is not adjusted, nowadays (backend is changed?)

⟨ Transform *mp_pen_p*(qq), making sure polygonal pens stay counter-clockwise 1019 ⟩ ≡
  if (*mp_pen_p*(qq) ≠ Λ) {
    number_clone(*sx*, *mp*→*tx*); *number_clone*(*sy*, *mp*→*ty*); *set_number_to_zero*(*mp*→*tx*);
    set_number_to_zero(*mp*→*ty*); *mp_do_pen_trans*(*mp*, *mp_pen_p*(qq));
    if (*number_nonzero*(*sqdet*) ∧ ((*mp_type*(q) ≡ *mp_stroked_node_type*) ∧ (*mp_dash_p*(q) ≠ Λ))) {
      mp_number *ret*;
      new_number(*ret*); *take_scaled*(*ret*, ((**mp_stroked_node**) q)→*dash_scale*, *sqdet*);
      number_clone(((**mp_stroked_node**) q)→*dash_scale*, *ret*); *free_number*(*ret*);
    }
    if (¬*pen_is_elliptical*(*mp_pen_p*(qq)))
      if (*number_negative*(*sgndet*))
        mp_pen_p(qq) ← *mp_make_pen*(*mp*, *mp_copy_path*(*mp*, *mp_pen_p*(qq)), *true*);
          ▷ this unreverses the pen ◁
    number_clone(*mp*→*tx*, *sx*); *number_clone*(*mp*→*ty*, *sy*);
  }

This code is used in section 1018.

1020. ⟨ Transform the compact transformation 1020 ⟩ ≡
$mp\_number\_trans(mp, \&((\textbf{mp\_text\_node})\, q)\to tx, \&((\textbf{mp\_text\_node})\, q)\to ty)$; $number\_clone(sx, mp\to tx)$; $number\_clone(sy, mp\to ty)$; $set\_number\_to\_zero(mp\to tx)$; $set\_number\_to\_zero(mp\to ty)$;
$mp\_number\_trans(mp, \&((\textbf{mp\_text\_node})\, q)\to txx, \&((\textbf{mp\_text\_node})\, q)\to tyx)$;
$mp\_number\_trans(mp, \&((\textbf{mp\_text\_node})\, q)\to txy, \&((\textbf{mp\_text\_node})\, q)\to tyy)$;
$number\_clone(mp\to tx, sx)$; $number\_clone(mp\to ty, sy)$

This code is used in section 1018.

1021. The hard cases of transformation occur when big nodes are involved, and when some of their components are unknown.

⟨ Declare binary action procedures 991 ⟩ +≡
⟨ Declare subroutines needed by *big_trans* 1023 ⟩;

```
static void mp_big_trans(MP mp, mp_node p, quarterword c)
{
  mp_node q, r, pp, qq;   ▷ list manipulation registers ◁
  q ← value_node(p);
  if (mp_type(q) ≡ mp_pair_node_type) {
    if (mp_type(x_part(q)) ≠ mp_known ∨ mp_type(y_part(q)) ≠ mp_known) {
      ⟨ Transform an unknown big node and return 1022 ⟩;
    }
  }
  else {   ▷ mp_transform_type ◁
    if (mp_type(tx_part(q)) ≠ mp_known ∨ mp_type(ty_part(q)) ≠ mp_known ∨ mp_type(xx_part(q)) ≠
          mp_known ∨ mp_type(xy_part(q)) ≠ mp_known ∨ mp_type(yx_part(q)) ≠
          mp_known ∨ mp_type(yy_part(q)) ≠ mp_known) {
      ⟨ Transform an unknown big node and return 1022 ⟩;
    }
  }
  ⟨ Transform a known big node 1024 ⟩;
}   ▷ node p will now be recycled by do_binary ◁
```

1022. ⟨ Transform an unknown big node and **return** 1022 ⟩ ≡

```
{
  mp_set_up_known_trans(mp, c); mp_make_exp_copy(mp, p); r ← value_node(cur_exp_node());
  if (mp→cur_exp.type ≡ mp_transform_type) {
    mp_bilin1(mp, yy_part(r), mp→tyy, xy_part(q), mp→tyx, zero_t);
    mp_bilin1(mp, yx_part(r), mp→tyy, xx_part(q), mp→tyx, zero_t);
    mp_bilin1(mp, xy_part(r), mp→txx, yy_part(q), mp→txy, zero_t);
    mp_bilin1(mp, xx_part(r), mp→txx, yx_part(q), mp→txy, zero_t);
  }
  mp_bilin1(mp, y_part(r), mp→tyy, x_part(q), mp→tyx, mp→ty);
  mp_bilin1(mp, x_part(r), mp→txx, y_part(q), mp→txy, mp→tx); return;
}
```

This code is used in section 1021.

1023. Let p point to a value field inside a big node of *cur_exp*, and let q point to a another value field. The *bilin1* procedure replaces p by $p \cdot t + q \cdot u + \delta$.

⟨ Declare subroutines needed by *big_trans* 1023 ⟩ ≡

```
static void mp_bilin1(MP mp, mp_node p, mp_number t, mp_node q, mp_number u, mp_number
        delta_orig)
{
  mp_number delta;

  new_number(delta); number_clone(delta, delta_orig);
  if (¬number_equal(t, unity_t)) {
    mp_dep_mult(mp, (mp_value_node) p, t, true);
  }
  if (number_nonzero(u)) {
    if (mp_type(q) ≡ mp_known) {
      mp_number tmp;

      new_number(tmp); take_scaled(tmp, value_number(q), u); number_add(delta, tmp);
      free_number(tmp);
    }
    else {      ▷ Ensure that type(p) ← mp_proto_dependent ◁
      if (mp_type(p) ≠ mp_proto_dependent) {
        if (mp_type(p) ≡ mp_known) {
          mp_new_dep(mp, p, mp_type(p), mp_const_dependency(mp, value_number(p)));
        }
        else {
          set_dep_list((mp_value_node) p, mp_p_times_v(mp,
                (mp_value_node) dep_list((mp_value_node) p), unity_t, mp_dependent,
                mp_proto_dependent, true));
        }
        mp_type(p) ← mp_proto_dependent;
      }
      set_dep_list((mp_value_node) p, mp_p_plus_fq(mp,
            (mp_value_node) dep_list((mp_value_node) p), u,
            (mp_value_node) dep_list((mp_value_node) q), mp_proto_dependent, mp_type(q)));
    }
  }
  if (mp_type(p) ≡ mp_known) {
    set_value_number(p, value_number(p)); number_add(value_number(p), delta);
  }
  else {
    mp_number tmp;
    mp_value_node r;      ▷ list traverser ◁

    new_number(tmp); r ← (mp_value_node) dep_list((mp_value_node) p);
    while (dep_info(r) ≠ Λ) r ← (mp_value_node) mp_link(r);
    number_clone(tmp, value_number(r)); number_add(delta, tmp);
    if (r ≠ (mp_value_node) dep_list((mp_value_node) p)) set_value_number(r, delta);
    else {
      mp_recycle_value(mp, p); mp_type(p) ← mp_known; set_value_number(p, delta);
    }
    free_number(tmp);
  }
  if (mp→fix_needed) mp_fix_dependencies(mp);
  free_number(delta);
```

}

See also sections 1025, 1026, and 1028.

This code is used in section 1021.

1024. ⟨Transform a known big node 1024⟩ ≡

```
mp_set_up_trans(mp, c);
if (mp→cur_exp.type ≡ mp_known) ⟨Transform known by known 1027⟩
else {
  pp ← mp_stash_cur_exp(mp); qq ← value_node(pp); mp_make_exp_copy(mp, p);
  r ← value_node(cur_exp_node());
  if (mp→cur_exp.type ≡ mp_transform_type) {
    mp_bilin2(mp, yy_part(r), yy_part(qq), value_number(xy_part(q)), yx_part(qq), Λ);
    mp_bilin2(mp, yx_part(r), yy_part(qq), value_number(xx_part(q)), yx_part(qq), Λ);
    mp_bilin2(mp, xy_part(r), xx_part(qq), value_number(yy_part(q)), xy_part(qq), Λ);
    mp_bilin2(mp, xx_part(r), xx_part(qq), value_number(yx_part(q)), xy_part(qq), Λ);
  }
  mp_bilin2(mp, y_part(r), yy_part(qq), value_number(x_part(q)), yx_part(qq), y_part(qq));
  mp_bilin2(mp, x_part(r), xx_part(qq), value_number(y_part(q)), xy_part(qq), x_part(qq));
  mp_recycle_value(mp, pp); mp_free_value_node(mp, pp);
}
```

This code is used in section 1021.

1025. Let p be a *mp_proto_dependent* value whose dependency list ends at *dep_final*. The following procedure adds v times another numeric quantity to p.

⟨Declare subroutines needed by *big_trans* 1023⟩ +≡

```
static void mp_add_mult_dep(MP mp, mp_value_node p, mp_number v, mp_node r)
{
  if (mp_type(r) ≡ mp_known) {
    mp_number ret;

    new_number(ret); take_scaled(ret, value_number(r), v);
    set_dep_value(mp→dep_final, dep_value(mp→dep_final)); number_add(dep_value(mp→dep_final), ret);
    free_number(ret);
  }
  else {
    set_dep_list(p, mp_p_plus_fq(mp, (mp_value_node) dep_list(p), v,
        (mp_value_node) dep_list((mp_value_node) r), mp_proto_dependent, mp_type(r)));
    if (mp→fix_needed) mp_fix_dependencies(mp);
  }
}
```

1026. The *bilin2* procedure is something like *bilin1*, but with known and unknown quantities reversed. Parameter p points to a value field within the big node for *cur_exp*; and $type(p) \leftarrow mp\_known$. Parameters t and u point to value fields elsewhere; so does parameter q, unless it is Λ (which stands for zero). Location p will be replaced by $p \cdot t + v \cdot u + q$.

⟨ Declare subroutines needed by *big_trans* 1023 ⟩ +≡

```
static void mp_bilin2(MP mp, mp_node p, mp_node t, mp_number v, mp_node u, mp_node q)
{
  mp_number vv;   ▷ temporary storage for value(p) ◁
  new_number(vv); number_clone(vv, value_number(p));
  mp_new_dep(mp, p, mp_proto_dependent, mp_const_dependency(mp, zero_t));   ▷ this sets dep_final ◁
  if (number_nonzero(vv)) {
    mp_add_mult_dep(mp, (mp_value_node) p, vv, t);   ▷ dep_final doesn't change ◁
  }
  if (number_nonzero(v)) {
    mp_number arg1;
    new_number(arg1); number_clone(arg1, v); mp_add_mult_dep(mp, (mp_value_node) p, arg1, u);
    free_number(arg1);
  }
  if (q ≠ Λ) mp_add_mult_dep(mp, (mp_value_node) p, unity_t, q);
  if (dep_list((mp_value_node) p) ≡ (mp_node) mp→dep_final) {
    number_clone(vv, dep_value(mp→dep_final)); mp_recycle_value(mp, p); mp_type(p) ← mp_known;
    set_value_number(p, vv);
  }
  free_number(vv);
}
```

1027. ⟨ Transform known by known 1027 ⟩ ≡

```
{
  mp_make_exp_copy(mp, p); r ← value_node(cur_exp_node());
  if (mp→cur_exp.type ≡ mp_transform_type) {
    mp_bilin3(mp, yy_part(r), mp→tyy, value_number(xy_part(q)), mp→tyx, zero_t);
    mp_bilin3(mp, yx_part(r), mp→tyy, value_number(xx_part(q)), mp→tyx, zero_t);
    mp_bilin3(mp, xy_part(r), mp→txx, value_number(yy_part(q)), mp→txy, zero_t);
    mp_bilin3(mp, xx_part(r), mp→txx, value_number(yx_part(q)), mp→txy, zero_t);
  }
  mp_bilin3(mp, y_part(r), mp→tyy, value_number(x_part(q)), mp→tyx, mp→ty);
  mp_bilin3(mp, x_part(r), mp→txx, value_number(y_part(q)), mp→txy, mp→tx);
}
```

This code is used in section 1024.

1028. Finally, in *bilin3* everything is *known*.

⟨ Declare subroutines needed by *big_trans* 1023 ⟩ +≡

static void *mp_bilin3*(**MP** *mp*, **mp_node** *p*, **mp_number** *t*, **mp_number** *v*, **mp_number** *u*, **mp_number** *delta_orig*)

```
{
  mp_number delta;
  mp_number tmp;
  new_number(tmp); new_number(delta); number_clone(delta, delta_orig);
  if (¬number_equal(t, unity_t)) {
    take_scaled(tmp, value_number(p), t);
  }
  else {
    number_clone(tmp, value_number(p));
  }
  number_add(delta, tmp);
  if (number_nonzero(u)) {
    mp_number ret;
    new_number(ret); take_scaled(ret, v, u); set_value_number(p, delta);
    number_add(value_number(p), ret); free_number(ret);
  }
  else set_value_number(p, delta);
  free_number(tmp); free_number(delta);
}
```

1029. ⟨ Declare binary action procedures 991 ⟩ +≡

static void *mp_chop_path*(**MP** *mp*, **mp_node** *p*)
{
  mp_knot *q*; ▷ a knot in the original path ◁
  mp_knot *pp*, *qq*, *rr*, *ss*; ▷ link variables for copies of path nodes ◁
  mp_number *a*, *b*; ▷ indices for chopping ◁
  mp_number *l*;
  boolean *reversed*; ▷ was $a > b$? ◁

  new_number(*a*); *new_number*(*b*); *new_number*(*l*); *mp_path_length*(*mp*, &*l*);
  number_clone(*a*, *value_number*(*x_part*(*p*))); *number_clone*(*b*, *value_number*(*y_part*(*p*)));
  if (*number_lessequal*(*a*, *b*)) {
    reversed ← *false*;
  }
  else {
    reversed ← *true*; *number_swap*(*a*, *b*);
  } ▷ Dispense with the cases $a < 0$ and/or $b > l$ ◁
  if (*number_negative*(*a*)) {
    if (*mp_left_type*(*cur_exp_knot*( )) ≡ *mp_endpoint*) {
      set_number_to_zero(*a*);
      if (*number_negative*(*b*)) *set_number_to_zero*(*b*);
    }
    else {
      do {
        number_add(*a*, *l*); *number_add*(*b*, *l*);
      } **while** (*number_negative*(*a*)); ▷ a cycle always has length $l > 0$ ◁
    }
  }
  if (*number_greater*(*b*, *l*)) {
    if (*mp_left_type*(*cur_exp_knot*( )) ≡ *mp_endpoint*) {
      number_clone(*b*, *l*);
      if (*number_greater*(*a*, *l*)) *number_clone*(*a*, *l*);
    }
    else {
      while (*number_greaterequal*(*a*, *l*)) {
        number_substract(*a*, *l*); *number_substract*(*b*, *l*);
      }
    }
  }
  q ← *cur_exp_knot*( );
  while (*number_greaterequal*(*a*, *unity_t*)) {
    q ← *mp_next_knot*(*q*); *number_substract*(*a*, *unity_t*); *number_substract*(*b*, *unity_t*);
  }
  if (*number_equal*(*b*, *a*)) { ▷ Construct a path from *pp* to *qq* of length zero ◁
    if (*number_positive*(*a*)) {
      mp_number *arg1*;

      new_number(*arg1*); *number_clone*(*arg1*, *a*); *convert_scaled_to_fraction*(*arg1*);
      mp_split_cubic(*mp*, *q*, *arg1*); *free_number*(*arg1*); *q* ← *mp_next_knot*(*q*);
    }
    pp ← *mp_copy_knot*(*mp*, *q*); *qq* ← *pp*;
  }
  else { ▷ Construct a path from *pp* to *qq* of length $\lceil b \rceil$ ◁
    pp ← *mp_copy_knot*(*mp*, *q*); *qq* ← *pp*;

```
      do {
        q ← mp_next_knot(q); rr ← qq; qq ← mp_copy_knot(mp, q); mp_next_knot(rr) ← qq;
        number_substract(b, unity_t);
      } while (number_positive(b));
      if (number_positive(a)) {
        mp_number arg1;

        new_number(arg1); ss ← pp; number_clone(arg1, a); convert_scaled_to_fraction(arg1);
        mp_split_cubic(mp, ss, arg1); free_number(arg1); pp ← mp_next_knot(ss); mp_toss_knot(mp, ss);
        if (rr ≡ ss) {
          mp_number arg1, arg2;

          new_number(arg1); new_number(arg2); set_number_from_substraction(arg1, unity_t, a);
          number_clone(arg2, b); make_scaled(b, arg2, arg1); free_number(arg1); free_number(arg2);
          rr ← pp;
        }
      }
      if (number_negative(b)) {
        mp_number arg1;

        new_number(arg1); set_number_from_addition(arg1, b, unity_t); convert_scaled_to_fraction(arg1);
        mp_split_cubic(mp, rr, arg1); free_number(arg1); mp_toss_knot(mp, qq); qq ← mp_next_knot(rr);
      }
    }
    mp_left_type(pp) ← mp_endpoint; mp_right_type(qq) ← mp_endpoint; mp_next_knot(qq) ← pp;
    mp_toss_knot_list(mp, cur_exp_knot());
    if (reversed) {
      set_cur_exp_knot(mp_next_knot(mp_htap_ypoc(mp, pp))); mp_toss_knot_list(mp, pp);
    }
    else {
      set_cur_exp_knot(pp);
    }
    free_number(l); free_number(a); free_number(b);
  }
```

1030. ⟨ Declare binary action procedures 991 ⟩ +≡

```
static void mp_set_up_offset(MP mp, mp_node p)
{
  mp_find_offset(mp, value_number(x_part(p)), value_number(y_part(p)), cur_exp_knot());
  mp_pair_value(mp, mp→cur_x, mp→cur_y);
}
static void mp_set_up_direction_time(MP mp, mp_node p)
{
  mp_value new_expr;
  memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
  mp_find_direction_time(mp, &new_expr.data.n, value_number(x_part(p)), value_number(y_part(p)),
      cur_exp_knot()); mp_flush_cur_exp(mp, new_expr);
}
static void mp_set_up_envelope(MP mp, mp_node p)
{
  unsigned char ljoin, lcap;
  mp_number miterlim;
  mp_knot q ← mp_copy_path(mp, cur_exp_knot());    ▷ the original path ◁
  new_number(miterlim);    ▷ TODO: accept elliptical pens for straight paths ◁
  if (pen_is_elliptical(value_knot(p))) {
    mp_bad_envelope_pen(mp); set_cur_exp_knot(q); mp→cur_exp.type ← mp_path_type; return;
  }
  if (number_greater(internal_value(mp_linejoin), unity_t)) ljoin ← 2;
  else if (number_positive(internal_value(mp_linejoin))) ljoin ← 1;
  else ljoin ← 0;
  if (number_greater(internal_value(mp_linecap), unity_t)) lcap ← 2;
  else if (number_positive(internal_value(mp_linecap))) lcap ← 1;
  else lcap ← 0;
  if (number_less(internal_value(mp_miterlimit), unity_t)) set_number_to_unity(miterlim);
  else number_clone(miterlim, internal_value(mp_miterlimit));
  set_cur_exp_knot(mp_make_envelope(mp, q, value_knot(p), ljoin, lcap, miterlim));
  mp→cur_exp.type ← mp_path_type;
}
static void mp_set_up_boundingpath(MP mp, mp_node p)
{
  unsigned char ljoin, lcap;
  mp_number miterlim;
  mp_knot q ← mp_copy_path(mp, cur_exp_knot());    ▷ the original path ◁
  mp_knot pen;
  mp_knot qq;
  new_number(miterlim); pen ← (value_knot(p));    ▷ accept elliptical pens for s paths ◁
    ▷ using mp_make_path to convert an elliptical pen to a polygonal one. ◁
    ▷ The approximation of 8 knots should be good enough. ◁
  if (pen_is_elliptical(value_knot(p))) {
    mp_knot kp, kq;
    pen ← copy_pen(value_knot(p)); mp_make_path(mp, pen); kq ← pen;
    do {
      kp ← kq; kq ← mp_next_knot(kq); mp_prev_knot(kq) ← kp;
    } while (kq ≠ pen);
    mp_close_path_cycle(mp, kp, pen);
```

```
  }
  if (number_greater(internal_value(mp_linejoin), unity_t)) ljoin ← 2;
  else if (number_positive(internal_value(mp_linejoin))) ljoin ← 1;
  else ljoin ← 0;
  if (number_greater(internal_value(mp_linecap), unity_t)) lcap ← 2;
  else if (number_positive(internal_value(mp_linecap))) lcap ← 1;
  else lcap ← 0;
  if (number_less(internal_value(mp_miterlimit), unity_t)) set_number_to_unity(miterlim);
  else number_clone(miterlim, internal_value(mp_miterlimit));
  qq ← mp_make_envelope(mp, q, pen, ljoin, lcap, miterlim); set_cur_exp_knot(qq);
  mp→cur_exp.type ← mp_path_type;
  if (¬mp_get_cur_bbox(mp)) {
    mp_bad_binary(mp, p, mp_boundingpath_of); set_cur_exp_knot(q); mp→cur_exp.type ← mp_path_type;
    return;
  }
  else {
    mp_knot ll, lr, ur, ul;
    ll ← mp_new_knot(mp); lr ← mp_new_knot(mp); ur ← mp_new_knot(mp);
    ul ← mp_new_knot(mp);
    if (ll ≡ Λ ∨ lr ≡ Λ ∨ ur ≡ Λ ∨ ul ≡ Λ) {
      mp_bad_binary(mp, p, mp_boundingpath_of); set_cur_exp_knot(q);
      mp→cur_exp.type ← mp_path_type; return;
    }
    mp_left_type(ll) ← mp_endpoint; mp_right_type(ll) ← mp_endpoint;
    mp_originator(ll) ← mp_program_code; number_clone(ll→x_coord, mp_minx);
    number_clone(ll→y_coord, mp_miny); mp_originator(lr) ← mp_program_code;
    number_clone(lr→x_coord, mp_maxx); number_clone(lr→y_coord, mp_miny);
    mp_originator(ur) ← mp_program_code; number_clone(ur→x_coord, mp_maxx);
    number_clone(ur→y_coord, mp_maxy); mp_originator(ul) ← mp_program_code;
    number_clone(ul→x_coord, mp_minx); number_clone(ul→y_coord, mp_maxy); mp_next_knot(ll) ← lr;
    mp_next_knot(lr) ← ur; mp_next_knot(ur) ← ul; mp_close_path_cycle(mp, ul, ll);
    mp_make_path(mp, ll); mp→cur_exp.type ← mp_path_type; set_cur_exp_knot(ll);
    mp_free_path(mp, qq);
  }
}
```

1031. This is pretty straightforward. The one silly thing is that the output of *mp_ps_do_font_charstring* has to be un-exported.

⟨ Declare binary action procedures 991 ⟩ +≡

```
static void mp_set_up_glyph_infont(MP mp, mp_node p)
{
  mp_edge_object *h ← Λ;
  mp_ps_font *f ← Λ;
  char *n ← mp_str(mp, cur_exp_str());
  f ← mp_ps_font_parse(mp, (int) mp_find_font(mp, n));
  if (f ≠ Λ) {
    if (mp_type(p) ≡ mp_known) {
      int v ← round_unscaled(value_number(p));
      if (v < 0 ∨ v > 255) {
        char msg[256];
        mp_snprintf(msg, 256, "glyph␣index␣too␣high␣(%d)", v);  mp_error(mp, msg, Λ, true);
      }
      else {
        h ← mp_ps_font_charstring(mp, f, v);
      }
    }
    else {
      n ← mp_str(mp, value_str(p));  h ← mp_ps_do_font_charstring(mp, f, n);
    }
    mp_ps_font_free(mp, f);
  }
  if (h ≠ Λ) {
    set_cur_exp_node((mp_node) mp_gr_import(mp, h));
  }
  else {
    set_cur_exp_node((mp_node) mp_get_edge_header_node(mp));
    mp_init_edges(mp, (mp_edge_header_node) cur_exp_node());
  }
  mp→cur_exp.type ← mp_picture_type;
}
```

1032. ⟨ Declare binary action procedures 991 ⟩ +≡

```
static void mp_find_point(MP mp, mp_number v_orig, quarterword c)
{
  mp_knot p;    ▷ the path ◁
  mp_number n;    ▷ its length ◁
  mp_number v;

  new_number(v); new_number(n); number_clone(v, v_orig); p ← cur_exp_knot();
  if (mp_left_type(p) ≡ mp_endpoint) {
    set_number_to_unity(n); number_negate(n);
  }
  else {
    set_number_to_zero(n);
  }
  do {
    p ← mp_next_knot(p); number_add(n, unity_t);
  } while (p ≠ cur_exp_knot());
  if (number_zero(n)) {
    set_number_to_zero(v);
  }
  else if (number_negative(v)) {
    if (mp_left_type(p) ≡ mp_endpoint) {
      set_number_to_zero(v);
    }
    else {    ▷ v ← n − 1 − ((−v − 1) % n) ≡ −((−v − 1) % n) − 1 + n ◁
      number_negate(v); number_add_scaled(v, −1); number_modulo(v, n); number_negate(v);
      number_add_scaled(v, −1); number_add(v, n);
    }
  }
  else if (number_greater(v, n)) {
    if (mp_left_type(p) ≡ mp_endpoint) number_clone(v, n);
    else number_modulo(v, n);
  }
  p ← cur_exp_knot();
  while (number_greaterequal(v, unity_t)) {
    p ← mp_next_knot(p); number_substract(v, unity_t);
  }
  if (number_nonzero(v)) {    ▷ Insert a fractional node by splitting the cubic ◁
    convert_scaled_to_fraction(v); mp_split_cubic(mp, p, v); p ← mp_next_knot(p);
  }    ▷ Set the current expression to the desired path coordinates ◁
  switch (c) {
  case mp_point_of: mp_pair_value(mp, p→x_coord, p→y_coord); break;
  case mp_precontrol_of:
    if (mp_left_type(p) ≡ mp_endpoint) mp_pair_value(mp, p→x_coord, p→y_coord);
    else mp_pair_value(mp, p→left_x, p→left_y);
    break;
  case mp_postcontrol_of:
    if (mp_right_type(p) ≡ mp_endpoint) mp_pair_value(mp, p→x_coord, p→y_coord);
    else mp_pair_value(mp, p→right_x, p→right_y);
    break;
  }    ▷ there are no other cases ◁
  free_number(v); free_number(n);
}
```

1033. Function *new_text_node* owns the reference count for its second argument (the text string) but not its first (the font name).

⟨ Declare binary action procedures 991 ⟩ +≡

static void *mp_do_infont*(**MP** *mp*, **mp_node** *p*)
{
  mp_edge_header_node *q*;
  mp_value *new_expr*;

  memset(&*new_expr*, 0, **sizeof**(**mp_value**)); *new_number*(*new_expr*.*data*.*n*);
  q ← *mp_get_edge_header_node*(*mp*); *mp_init_edges*(*mp*, *q*); *add_str_ref*(*cur_exp_str*( ));
  mp_link(*obj_tail*(*q*)) ← *mp_new_text_node*(*mp*, *mp_str*(*mp*, *cur_exp_str*( )), *value_str*(*p*));
  obj_tail(*q*) ← *mp_link*(*obj_tail*(*q*)); *mp_free_value_node*(*mp*, *p*); *new_expr*.*data*.*node* ← (**mp_node**) *q*;
  mp_flush_cur_exp(*mp*, *new_expr*); *mp*→*cur_exp*.*type* ← *mp_picture_type*;
}

1034. Statements and commands. The chief executive of METAPOST is the *do_statement* routine, which contains the master switch that causes all the various pieces of METAPOST to do their things, in the right order.

In a sense, this is the grand climax of the program: It applies all the tools that we have worked so hard to construct. In another sense, this is the messiest part of the program: It necessarily refers to other pieces of code all over the place, so that a person can't fully understand what is going on without paging back and forth to be reminded of conventions that are defined elsewhere. We are now at the hub of the web.

The structure of *do_statement* itself is quite simple. The first token of the statement is fetched using *get_x_next*. If it can be the first token of an expression, we look for an equation, an assignment, or a title. Otherwise we use a **case** construction to branch at high speed to the appropriate routine for various and sundry other types of commands, each of which has an "action procedure" that does the necessary work.

The program uses the fact that

$$min\_primary\_command \leftarrow max\_statement\_command \leftarrow type\_name$$

to interpret a statement that starts with, e.g., '**string**', as a type declaration rather than a boolean expression.

```
static void worry_about_bad_statement(MP mp);
static void flush_unparsable_junk_after_statement(MP mp);

void mp_do_statement(MP mp)
{   ▷ governs METAPOST's activities ◁
  mp→cur_exp.type ← mp_vacuous; mp_get_x_next(mp);
  if (cur_cmd() > mp_max_primary_command) {
    worry_about_bad_statement(mp);
  }
  else if (cur_cmd() > mp_max_statement_command) {   ▷ Do an equation, assignment, title, or
        '⟨expression⟩ endgroup'; ◁   ▷ The most important statements begin with expressions ◁
    mp_value new_expr;

    mp→var_flag ← mp_assignment; mp_scan_expression(mp);
    if (cur_cmd() < mp_end_group) {
      if (cur_cmd() ≡ mp_equals) mp_do_equation(mp);
      else if (cur_cmd() ≡ mp_assignment) mp_do_assignment(mp);
      else if (mp→cur_exp.type ≡ mp_string_type) {   ▷ Do a title ◁
        if (number_positive(internal_value(mp_tracing_titles))) {
          mp_print_nl(mp, ""); mp_print_str(mp, cur_exp_str()); update_terminal();
        }
      }
      else if (mp→cur_exp.type ≠ mp_vacuous) {
        const char *hlp[] ← {"I␣couldn't␣find␣an␣'='␣or␣':='␣after␣the",
            "expression␣that␣is␣shown␣above␣this␣error␣message,",
            "so␣I␣guess␣I'll␣just␣ignore␣it␣and␣carry␣on.", Λ};

        mp_disp_err(mp, Λ); mp_back_error(mp, "Isolated␣expression", hlp, true);
        mp_get_x_next(mp);
      }
      memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
      set_number_to_zero(new_expr.data.n); mp_flush_cur_exp(mp, new_expr);
      mp→cur_exp.type ← mp_vacuous;
    }
  }
  else {   ▷ Do a statement that doesn't begin with an expression ◁   ▷ If do_statement ends with
      cur_cmd ← end_group, we should have cur_type ← mp_vacuous unless the statement was simply
      an expression; in the latter case, cur_type and cur_exp should represent that expression. ◁
```

```
      if (number_positive(internal_value(mp_tracing_commands))) show_cur_cmd_mod;
      switch (cur_cmd()) {
      case mp_type_name: mp_do_type_declaration(mp); break;
      case mp_macro_def:
        if (cur_mod() > var_def) mp_make_op_def(mp);
        else if (cur_mod() > end_def) mp_scan_def(mp);
        break;
      case mp_random_seed: mp_do_random_seed(mp); break;
      case mp_mode_command: mp_print_ln(mp); mp→interaction ← cur_mod();
        initialize_print_selector();
        if (mp→log_opened) mp→selector ← mp→selector + 2;
        mp_get_x_next(mp); break;
      case mp_protection_command: mp_do_protection(mp); break;
      case mp_delimiters: mp_def_delims(mp); break;
      case mp_save_command:
        do {
          mp_get_symbol(mp); mp_save_variable(mp, cur_sym()); mp_get_x_next(mp);
        } while (cur_cmd() ≡ mp_comma);
        break;
      case mp_interim_command: mp_do_interim(mp); break;
      case mp_let_command: mp_do_let(mp); break;
      case mp_new_internal: mp_do_new_internal(mp); break;
      case mp_show_command: mp_do_show_whatever(mp); break;
      case mp_add_to_command: mp_do_add_to(mp); break;
      case mp_bounds_command: mp_do_bounds(mp); break;
      case mp_ship_out_command: mp_do_ship_out(mp); break;
      case mp_every_job_command: mp_get_symbol(mp); mp→start_sym ← cur_sym();
        mp_get_x_next(mp); break;
      case mp_message_command: mp_do_message(mp); break;
      case mp_write_command: mp_do_write(mp); break;
      case mp_tfm_command: mp_do_tfm_command(mp); break;
      case mp_special_command:
        if (cur_mod() ≡ 0) mp_do_special(mp);
        else if (cur_mod() ≡ 1) mp_do_mapfile(mp);
        else mp_do_mapline(mp);
        break;
      default: break;    ▷ make the compiler happy ◁
      }
      mp→cur_exp.type ← mp_vacuous;
    }
    if (cur_cmd() < mp_semicolon) flush_unparsable_junk_after_statement(mp);
    mp→error_count ← 0;
  }
```

1035. ⟨ Declarations 10 ⟩ +≡
⟨ Declare action procedures for use by *do_statement* 1050 ⟩

1036. The only command codes > *max_primary_command* that can be present at the beginning of a statement are *semicolon* and higher; these occur when the statement is null.

```
static void worry_about_bad_statement(MP mp)
{
  if (cur_cmd() < mp_semicolon) {
    char msg[256];
    mp_string sname;
    int old_setting ← mp→selector;
    const char *hlp[] ← {"I␣was␣looking␣for␣the␣beginning␣of␣a␣new␣statement.",
        "If␣you␣just␣proceed␣without␣changing␣anything,␣I'll␣ignore",
        "everything␣up␣to␣the␣next␣`;'.␣Please␣insert␣a␣semicolon",
        "now␣in␣front␣of␣anything␣that␣you␣don't␣want␣me␣to␣delete.",
        "(See␣Chapter␣27␣of␣The␣METAFONTbook␣for␣an␣example.)", Λ};
    mp→selector ← new_string; mp_print_cmd_mod(mp, cur_cmd(), cur_mod());
    sname ← mp_make_string(mp); mp→selector ← old_setting;
    mp_snprintf(msg, 256, "A␣statement␣can't␣begin␣with␣`%s'", mp_str(mp, sname));
    delete_str_ref(sname); mp_back_error(mp, msg, hlp, true); mp_get_x_next(mp);
  }
}
```

1037. The help message printed here says that everything is flushed up to a semicolon, but actually the commands *end_group* and *stop* will also terminate a statement.

```
static void flush_unparsable_junk_after_statement(MP mp)
{
  const char *hlp[] ← {"I've␣just␣read␣as␣much␣of␣that␣statement␣as␣I␣could␣fathom,",
      "so␣a␣semicolon␣should␣have␣been␣next.␣It's␣very␣puzzling...",
      "but␣I'll␣try␣to␣get␣myself␣back␣together,␣by␣ignoring",
      "everything␣up␣to␣the␣next␣`;'.␣Please␣insert␣a␣semicolon",
      "now␣in␣front␣of␣anything␣that␣you␣don't␣want␣me␣to␣delete.",
      "(See␣Chapter␣27␣of␣The␣METAFONTbook␣for␣an␣example.)", Λ};
  mp_back_error(mp, "Extra␣tokens␣will␣be␣flushed", hlp, true); mp→scanner_status ← flushing;
  do {
    get_t_next(mp);
    if (cur_cmd() ≡ mp_string_token) {
      delete_str_ref(cur_mod_str());
    }
  } while (¬mp_end_of_statement);    ▷ cur_cmd ← semicolon, end_group, or stop ◁
  mp→scanner_status ← normal;
}
```

1038. Equations and assignments are performed by the pair of mutually recursive routines *do_equation* and *do_assignment*. These routines are called when *cur_cmd* ← *equals* and when *cur_cmd* ← *assignment*, respectively; the left-hand side is in *cur_type* and *cur_exp*, while the right-hand side is yet to be scanned. After the routines are finished, *cur_type* and *cur_exp* will be equal to the right-hand side (which will normally be equal to the left-hand side).

⟨ Declarations 10 ⟩ +≡
  ⟨ Declare the procedure called *make_eq* 1042 ⟩;
  static void *mp_do_equation*(**MP** *mp*);

1039. **static void** *trace_equation*(**MP** *mp*, **mp_node** *lhs*)

```
{
  mp_begin_diagnostic(mp); mp_print_nl(mp, "{("); mp_print_exp(mp, lhs, 0); mp_print(mp, ")=(");
  mp_print_exp(mp, Λ, 0); mp_print(mp, ")}"); mp_end_diagnostic(mp, false);
}
void mp_do_equation(MP mp)
{
  mp_node lhs;    ▷ capsule for the left-hand side ◁
  lhs ← mp_stash_cur_exp(mp); mp_get_x_next(mp); mp→var_flag ← mp_assignment;
  mp_scan_expression(mp);
  if (cur_cmd() ≡ mp_equals) mp_do_equation(mp);
  else if (cur_cmd() ≡ mp_assignment) mp_do_assignment(mp);
  if (number_greater(internal_value(mp_tracing_commands), two_t)) {
    trace_equation(mp, lhs);
  }
  if (mp→cur_exp.type ≡ mp_unknown_path) {
    if (mp_type(lhs) ≡ mp_pair_type) {
      mp_node p;    ▷ temporary register ◁
      p ← mp_stash_cur_exp(mp); mp_unstash_cur_exp(mp, lhs); lhs ← p;
    }    ▷ in this case make_eq will change the pair to a path ◁
  }
  mp_make_eq(mp, lhs);    ▷ equate lhs to (cur_type, cur_exp) ◁
}
```

1040. And *do_assignment* is similar to *do_equation*:

⟨ Declarations 10 ⟩ +≡
  static void *mp_do_assignment*(**MP** *mp*);

1041. **static void** *bad_lhs*(**MP** *mp*)

```
{
  const char *hlp[] ← {"I␣didn't␣find␣a␣variable␣name␣at␣the␣left␣of␣the␣`:=',",
      "so␣I'm␣going␣to␣pretend␣that␣you␣said␣`='␣instead.", Λ};
  mp_disp_err(mp, Λ); mp_error(mp, "Improper␣`:='␣will␣be␣changed␣to␣`='", hlp, true);
  mp_do_equation(mp);
}
static void bad_internal_assignment(MP mp, mp_node lhs)
{
  char msg[256];
  const char *hlp[] ← {"I␣can\'t␣set␣this␣internal␣quantity␣to␣anything␣but␣a␣known",
      "numeric␣value,␣so␣I'll␣have␣to␣ignore␣this␣assignment.", Λ};
  mp_disp_err(mp, Λ);
  if (internal_type(mp_sym_info(lhs)) ≡ mp_known) {
    mp_snprintf(msg, 256, "Internal␣quantity␣`%s'␣must␣receive␣a␣known␣numeric␣value",
        internal_name(mp_sym_info(lhs)));
  }
  else {
    mp_snprintf(msg, 256, "Internal␣quantity␣`%s'␣must␣receive␣a␣known␣string",
        internal_name(mp_sym_info(lhs)));
    hlp[1] ← "string,␣so␣I'll␣have␣to␣ignore␣this␣assignment.";
  }
  mp_back_error(mp, msg, hlp, true); mp_get_x_next(mp);
}
static void forbidden_internal_assignment(MP mp, mp_node lhs)
{
  char msg[256];
  const char *hlp[] ← {"I␣can\'t␣set␣this␣internal␣quantity␣to␣anything␣just␣yet",
      "(it␣is␣read-only),␣so␣I'll␣have␣to␣ignore␣this␣assignment.", Λ};
  mp_snprintf(msg, 256, "Internal␣quantity␣`%s'␣is␣read-only", internal_name(mp_sym_info(lhs)));
  mp_back_error(mp, msg, hlp, true); mp_get_x_next(mp);
}
static void bad_internal_assignment_precision(MP mp, mp_node lhs, mp_number min, mp_number
      max)
{
  char msg[256];
  char s[256];
  const char *hlp[] ← {"Precision␣values␣are␣limited␣by␣the␣current␣numbersystem.", Λ, Λ};
  mp_snprintf(msg, 256, "Bad␣'%s'␣has␣been␣ignored", internal_name(mp_sym_info(lhs)));
  mp_snprintf(s, 256, "Currently␣I␣am␣using␣'%s';␣the␣allowed␣precision␣range␣is␣[%s,%s].",
      mp_str(mp, internal_string(mp_number_system)), number_tostring(min), number_tostring(max));
  hlp[1] ← s; mp_back_error(mp, msg, hlp, true); mp_get_x_next(mp);
}
static void bad_expression_assignment(MP mp, mp_node lhs)
{
  const char *hlp[] ← {"It␣seems␣you␣did␣a␣nasty␣thing---probably␣by␣accident,",
      "but␣nevertheless␣you␣nearly␣hornswoggled␣me...",
      "While␣I␣was␣evaluating␣the␣right-hand␣side␣of␣this",
      "command,␣something␣happened,␣and␣the␣left-hand␣side",
      "is␣no␣longer␣a␣variable!␣So␣I␣won't␣change␣anything.", Λ};
```

```
    char *msg ← mp_obliterated(mp, lhs);
    mp_back_error(mp, msg, hlp, true); free(msg); mp_get_x_next(mp);
  }
  static void trace_assignment(MP mp, mp_node lhs)
  {
    mp_begin_diagnostic(mp); mp_print_nl(mp, "{");
    if (mp_name_type(lhs) ≡ mp_internal_sym) mp_print(mp, internal_name(mp_sym_info(lhs)));
    else mp_show_token_list(mp, lhs, Λ, 1000, 0);
    mp_print(mp, ":="); mp_print_exp(mp, Λ, 0); mp_print_char(mp, xord('}'));
    mp_end_diagnostic(mp, false);
  }
  void mp_do_assignment(MP mp)
  {
    if (mp→cur_exp.type ≠ mp_token_list) {
      bad_lhs(mp);
    }
    else {
      mp_node lhs;    ▷ token list for the left-hand side ◁
      lhs ← cur_exp_node(); mp→cur_exp.type ← mp_vacuous; mp_get_x_next(mp);
      mp→var_flag ← mp_assignment; mp_scan_expression(mp);
      if (cur_cmd() ≡ mp_equals) mp_do_equation(mp);
      else if (cur_cmd() ≡ mp_assignment) mp_do_assignment(mp);
      if (number_greater(internal_value(mp_tracing_commands), two_t)) {
        trace_assignment(mp, lhs);
      }
      if (mp_name_type(lhs) ≡ mp_internal_sym) {
          ▷ Assign the current expression to an internal variable ◁
        if ((mp→cur_exp.type ≡ mp_known ∨ mp→cur_exp.type ≡
              mp_string_type) ∧ (internal_type(mp_sym_info(lhs)) ≡ mp→cur_exp.type))
          {
          if (mp_sym_info(lhs) ≡ mp_number_system) {
            forbidden_internal_assignment(mp, lhs);
          }
          else if (mp_sym_info(lhs) ≡ mp_number_precision) {
            if (¬(mp→cur_exp.type ≡ mp_known ∧ (¬number_less(cur_exp_value_number(),
                  precision_min)) ∧ (¬number_greater(cur_exp_value_number(), precision_max)))) {
              bad_internal_assignment_precision(mp, lhs, precision_min, precision_max);
            }
            else {
              set_internal_from_cur_exp(mp_sym_info(lhs)); set_precision();
            }
          }
          else {
            set_internal_from_cur_exp(mp_sym_info(lhs));
          }
        }
        else {
          bad_internal_assignment(mp, lhs);
        }
      }
      else {    ▷ Assign the current expression to the variable lhs ◁
```

mp_node p; ▷ where the left-hand value is stored ◁
mp_node q; ▷ temporary capsule for the right-hand value ◁
$p \leftarrow mp\_find\_variable(mp, lhs)$;
if $(p \neq \Lambda)$ {
$q \leftarrow mp\_stash\_cur\_exp(mp)$; $mp\text{→}cur\_exp.type \leftarrow mp\_und\_type(mp, p)$; $mp\_recycle\_value(mp, p)$;
$mp\_type(p) \leftarrow mp\text{→}cur\_exp.type$; $set\_value\_number(p, zero\_t)$; $mp\_make\_exp\_copy(mp, p)$;
$p \leftarrow mp\_stash\_cur\_exp(mp)$; $mp\_unstash\_cur\_exp(mp, q)$; $mp\_make\_eq(mp, p)$;
}
else {
$bad\_expression\_assignment(mp, lhs)$;
}
}
$mp\_flush\_node\_list(mp, lhs)$;
}
}

1042. And now we get to the nitty-gritty. The *make_eq* procedure is given a pointer to a capsule that is to be equated to the current expression.

⟨ Declare the procedure called *make_eq* 1042 ⟩ ≡
static void *mp_make_eq*(**MP** *mp*, **mp_node** *lhs*);

This code is used in section 1038.

1043. **static void** *announce_bad_equation*(**MP** *mp*, **mp_node** *lhs*)

```
{
  char msg[256];
  const char *hlp[] ← {"I'm␣sorry,␣but␣I␣don't␣know␣how␣to␣make␣such␣things␣equal.",
      "(See␣the␣two␣expressions␣just␣above␣the␣error␣message.)", Λ};
  mp_snprintf(msg, 256, "Equation␣cannot␣be␣performed␣(%s=%s)",
      (mp_type(lhs) ≤ mp_pair_type ? mp_type_string(mp_type(lhs)) : "numeric"),
      (mp→cur_exp.type ≤ mp_pair_type ? mp_type_string(mp→cur_exp.type) : "numeric"));
  mp_disp_err(mp, lhs); mp_disp_err(mp, Λ); mp_back_error(mp, msg, hlp, true); mp_get_x_next(mp);
}
static void exclaim_inconsistent_equation(MP mp)
{
  const char *hlp[] ← {"The␣equation␣I␣just␣read␣contradicts␣what␣was␣said␣before.",
      "But␣don't␣worry;␣continue␣and␣I'll␣just␣ignore␣it.", Λ};
  mp_back_error(mp, "Inconsistent␣equation", hlp, true); mp_get_x_next(mp);
}
static void exclaim_redundant_or_inconsistent_equation(MP mp)
{
  const char *hlp[] ← {"An␣equation␣between␣already-known␣quantities␣can't␣help.",
      "But␣don't␣worry;␣continue␣and␣I'll␣just␣ignore␣it.", Λ};
  mp_back_error(mp, "Redundant␣or␣inconsistent␣equation", hlp, true); mp_get_x_next(mp);
}
static void report_redundant_or_inconsistent_equation(MP mp, mp_node lhs, mp_number v)
{
  if (mp→cur_exp.type ≤ mp_string_type) {
    if (mp→cur_exp.type ≡ mp_string_type) {
      if (mp_str_vs_str(mp, value_str(lhs), cur_exp_str()) ≠ 0) {
        exclaim_inconsistent_equation(mp);
      }
      else {
        exclaim_redundant_equation(mp);
      }
    }
    else if (¬number_equal(v, cur_exp_value_number())) {
      exclaim_inconsistent_equation(mp);
    }
    else {
      exclaim_redundant_equation(mp);
    }
  }
  else {
    exclaim_redundant_or_inconsistent_equation(mp);
  }
}
void mp_make_eq(MP mp, mp_node lhs)
{
  mp_value new_expr;
  mp_variable_type t;    ▷ type of the left-hand side ◁
  mp_number v;    ▷ value of the left-hand side ◁
  memset(&new_expr, 0, sizeof(mp_value)); new_number(v);
```

```
RESTART: t ← mp_type(lhs);
  if (t ≤ mp_pair_type) number_clone(v, value_number(lhs));
      ▷ For each type t, make an equation or complain if cur_type is incompatible with t ◁
  switch (t) {
  case mp_boolean_type: case mp_string_type: case mp_pen_type: case mp_path_type:
    case mp_picture_type:
    if (mp→cur_exp.type ≡ t + unknown_tag) {
      new_number(new_expr.data.n);
      if (t ≡ mp_boolean_type) {
        number_clone(new_expr.data.n, v);
      }
      else if (t ≡ mp_string_type) {
        new_expr.data.str ← value_str(lhs);
      }
      else if (t ≡ mp_picture_type) {
        new_expr.data.node ← value_node(lhs);
      }
      else {    ▷ pen or path ◁
        new_expr.data.p ← value_knot(lhs);
      }
      mp_nonlinear_eq(mp, new_expr, cur_exp_node( ), false); mp_unstash_cur_exp(mp, cur_exp_node( ));
    }
    else if (mp→cur_exp.type ≡ t) {
      report_redundant_or_inconsistent_equation(mp, lhs, v);
    }
    else {
      announce_bad_equation(mp, lhs);
    }
    break;
  case unknown_types:
    if (mp→cur_exp.type ≡ t − unknown_tag) {
      mp_nonlinear_eq(mp, mp→cur_exp, lhs, true);
    }
    else if (mp→cur_exp.type ≡ t) {
      mp_ring_merge(mp, lhs, cur_exp_node( ));
    }
    else if (mp→cur_exp.type ≡ mp_pair_type) {
      if (t ≡ mp_unknown_path) {
        mp_pair_to_path(mp); goto RESTART;
      }
    }
    else {
      announce_bad_equation(mp, lhs);
    }
    break;
  case mp_transform_type: case mp_color_type: case mp_cmykcolor_type: case mp_pair_type:
    if (mp→cur_exp.type ≡ t) {    ▷ Do multiple equations ◁
      mp_node q ← value_node(cur_exp_node( ));
      mp_node p ← value_node(lhs);
      switch (t) {
      case mp_transform_type: mp_try_eq(mp, yy_part(p), yy_part(q));
        mp_try_eq(mp, yx_part(p), yx_part(q)); mp_try_eq(mp, xy_part(p), xy_part(q));
```

```
        mp_try_eq(mp, xx_part(p), xx_part(q)); mp_try_eq(mp, ty_part(p), ty_part(q));
        mp_try_eq(mp, tx_part(p), tx_part(q)); break;
      case mp_color_type: mp_try_eq(mp, blue_part(p), blue_part(q));
        mp_try_eq(mp, green_part(p), green_part(q)); mp_try_eq(mp, red_part(p), red_part(q)); break;
      case mp_cmykcolor_type: mp_try_eq(mp, black_part(p), black_part(q));
        mp_try_eq(mp, yellow_part(p), yellow_part(q));
        mp_try_eq(mp, magenta_part(p), magenta_part(q)); mp_try_eq(mp, cyan_part(p), cyan_part(q));
        break;
      case mp_pair_type: mp_try_eq(mp, y_part(p), y_part(q)); mp_try_eq(mp, x_part(p), x_part(q));
        break;
      default:   ▷ there are no other valid cases, but please the compiler ◁
        break;
      }
    }
    else {
      announce_bad_equation(mp, lhs);
    }
    break;
  case mp_known: case mp_dependent: case mp_proto_dependent: case mp_independent:
    if (mp→cur_exp.type ≥ mp_known) {
      mp_try_eq(mp, lhs, Λ);
    }
    else {
      announce_bad_equation(mp, lhs);
    }
    break;
  case mp_vacuous: announce_bad_equation(mp, lhs); break;
  default:   ▷ there are no other valid cases, but please the compiler ◁
    announce_bad_equation(mp, lhs); break;
  }
  check_arith( ); mp_recycle_value(mp, lhs); free_number(v); mp_free_value_node(mp, lhs);
}
```

1044. The first argument to *try_eq* is the location of a value node in a capsule that will soon be recycled. The second argument is either a location within a pair or transform node pointed to by *cur_exp*, or it is Λ (which means that *cur_exp* itself serves as the second argument). The idea is to leave *cur_exp* unchanged, but to equate the two operands.

⟨ Declarations 10 ⟩ +≡

```
static void mp_try_eq(MP mp, mp_node l, mp_node r);
```

1045. #define equation_threshold_k ((math_data *) mp→math)→equation_threshold_t

```
static void deal_with_redundant_or_inconsistent_equation(MP mp, mp_value_node p, mp_node r)
{
  mp_number absp;
  new_number(absp); number_clone(absp, value_number(p)); number_abs(absp);
  if (number_greater(absp, equation_threshold_k)) {   ▷ off by .001 or more ◁
    char msg[256];
    const char *hlp[] ← {"The␣equation␣I␣just␣read␣contradicts␣what␣was␣said␣before.",
        "But␣don't␣worry;␣continue␣and␣I'll␣just␣ignore␣it.", Λ};
    mp_snprintf(msg, 256, "Inconsistent␣equation␣(off␣by␣%s)", number_tostring(value_number(p)));
    mp_back_error(mp, msg, hlp, true); mp_get_x_next(mp);
  }
  else if (r ≡ Λ) {
    exclaim_redundant_equation(mp);
  }
  free_number(absp); mp_free_dep_node(mp, p);
}
void mp_try_eq(MP mp, mp_node l, mp_node r)
{
  mp_value_node p;   ▷ dependency list for right operand minus left operand ◁
  mp_variable_type t;   ▷ the type of list p ◁
  mp_value_node q;   ▷ the constant term of p is here ◁
  mp_value_node pp;   ▷ dependency list for right operand ◁
  mp_variable_type tt;   ▷ the type of list pp ◁
  boolean copied;   ▷ have we copied a list that ought to be recycled? ◁   ▷ Remove the left operand
      from its container, negate it, and put it into dependency list p with constant term q ◁
  t ← mp_type(l);
  if (t ≡ mp_known) {
    mp_number arg1;
    new_number(arg1); number_clone(arg1, value_number(l)); number_negate(arg1);
    t ← mp_dependent; p ← mp_const_dependency(mp, arg1); q ← p; free_number(arg1);
  }
  else if (t ≡ mp_independent) {
    t ← mp_dependent; p ← mp_single_dependency(mp, l); number_negate(dep_value(p));
    q ← mp→dep_final;
  }
  else {
    mp_value_node ll ← (mp_value_node) l;
    p ← (mp_value_node) dep_list(ll); q ← p;
    while (1) {
      number_negate(dep_value(q));
      if (dep_info(q) ≡ Λ) break;
      q ← (mp_value_node) mp_link(q);
    }
    mp_link(prev_dep(ll)) ← mp_link(q); set_prev_dep((mp_value_node) mp_link(q), prev_dep(ll));
    mp_type(ll) ← mp_known;
  }   ▷ Add the right operand to list p ◁
  if (r ≡ Λ) {
    if (mp→cur_exp.type ≡ mp_known) {
      number_add(value_number(q), cur_exp_value_number()); goto DONE1;
```

```
      }
      else {
        tt ← mp→cur_exp.type;
        if (tt ≡ mp_independent) pp ← mp_single_dependency(mp, cur_exp_node());
        else pp ← (mp_value_node) dep_list((mp_value_node) cur_exp_node());
      }
    }
    else {
      if (mp_type(r) ≡ mp_known) {
        number_add(dep_value(q), value_number(r)); goto DONE1;
      }
      else {
        tt ← mp_type(r);
        if (tt ≡ mp_independent) pp ← mp_single_dependency(mp, r);
        else pp ← (mp_value_node) dep_list((mp_value_node) r);
      }
    }
    if (tt ≠ mp_independent) {
      copied ← false;
    }
    else {
      copied ← true; tt ← mp_dependent;
    }   ▷ Add dependency list pp of type tt to dependency list p of type t ◁
    mp→watch_coefs ← false;
    if (t ≡ tt) {
      p ← mp_p_plus_q(mp, p, pp, (quarterword) t);
    }
    else if (t ≡ mp_proto_dependent) {
      p ← mp_p_plus_fq(mp, p, unity_t, pp, mp_proto_dependent, mp_dependent);
    }
    else {
      mp_number x;
      new_number(x); q ← p;
      while (dep_info(q) ≠ Λ) {
        number_clone(x, dep_value(q)); fraction_to_round_scaled(x); set_dep_value(q, x);
        q ← (mp_value_node) mp_link(q);
      }
      free_number(x); t ← mp_proto_dependent; p ← mp_p_plus_q(mp, p, pp, (quarterword) t);
    }
    mp→watch_coefs ← true;
    if (copied) mp_flush_node_list(mp, (mp_node) pp);
  DONE1:
    if (dep_info(p) ≡ Λ) {
      deal_with_redundant_or_inconsistent_equation(mp, p, r);
    }
    else {
      mp_linear_eq(mp, p, (quarterword) t);
      if (r ≡ Λ ∧ mp→cur_exp.type ≠ mp_known) {
        if (mp_type(cur_exp_node()) ≡ mp_known) {
          mp_node pp ← cur_exp_node();
          set_cur_exp_value_number(value_number(pp)); mp→cur_exp.type ← mp_known;
          mp_free_value_node(mp, pp);
```

```
        }
      }
    }
  }
```

1046. Our next goal is to process type declarations. For this purpose it's convenient to have a procedure that scans a ⟨declared variable⟩ and returns the corresponding token list. After the following procedure has acted, the token after the declared variable will have been scanned, so it will appear in *cur_cmd*, *cur_mod*, and *cur_sym*.

⟨ Declarations 10 ⟩ +≡

```
  static mp_node mp_scan_declared_variable(MP mp);
```

1047. **mp_node** *mp_scan_declared_variable*(**MP** *mp*)

```
  {
    mp_sym x;    ▷ hash address of the variable's root ◁
    mp_node h, t;    ▷ head and tail of the token list to be returned ◁
    mp_get_symbol(mp); x ← cur_sym();
    if (cur_cmd() ≠ mp_tag_token) mp_clear_symbol(mp, x, false);
    h ← mp_get_symbolic_node(mp); set_mp_sym_sym(h, x); t ← h;
    while (1) {
      mp_get_x_next(mp);
      if (cur_sym() ≡ Λ) break;
      if (cur_cmd() ≠ mp_tag_token) {
        if (cur_cmd() ≠ mp_internal_quantity) {
          if (cur_cmd() ≡ mp_left_bracket) {    ▷ Descend past a collective subscript ◁
              ▷ If the subscript isn't collective, we don't accept it as part of the declared variable. ◁
            mp_sym ll ← cur_sym();    ▷ hash address of left bracket ◁
            mp_get_x_next(mp);
            if (cur_cmd() ≡ mp_right_bracket) {
              set_cur_sym(collective_subscript);
            }
            else {
              mp_back_input(mp); set_cur_sym(ll); set_cur_cmd((mp_variable_type) mp_left_bracket);
              break;
            }
          }
          else {
            break;
          }
        }
      }
      mp_link(t) ← mp_get_symbolic_node(mp); t ← mp_link(t); set_mp_sym_sym(t, cur_sym());
      mp_name_type(t) ← cur_sym_mod();
    }
    if ((eq_type(x) % mp_outer_tag) ≠ mp_tag_token) mp_clear_symbol(mp, x, false);
    if (equiv_node(x) ≡ Λ) mp_new_root(mp, x);
    return h;
  }
```

1048. Type declarations are introduced by the following primitive operations.

⟨ Put each of METAPOST's primitives into the hash table 204 ⟩ +≡
```
mp_primitive(mp, "numeric", mp_type_name, mp_numeric_type);
mp_primitive(mp, "string", mp_type_name, mp_string_type);
mp_primitive(mp, "boolean", mp_type_name, mp_boolean_type);
mp_primitive(mp, "path", mp_type_name, mp_path_type);
mp_primitive(mp, "pen", mp_type_name, mp_pen_type);
mp_primitive(mp, "picture", mp_type_name, mp_picture_type);
mp_primitive(mp, "transform", mp_type_name, mp_transform_type);
mp_primitive(mp, "color", mp_type_name, mp_color_type);
mp_primitive(mp, "rgbcolor", mp_type_name, mp_color_type);
mp_primitive(mp, "cmykcolor", mp_type_name, mp_cmykcolor_type);
mp_primitive(mp, "pair", mp_type_name, mp_pair_type);
```

1049. ⟨ Cases of *print_cmd_mod* for symbolic printing of primitives 239 ⟩ +≡
```
case mp_type_name: mp_print_type(mp, (quarterword) m); break;
```

1050. Now we are ready to handle type declarations, assuming that a *type_name* has just been scanned.

⟨ Declare action procedures for use by *do_statement* 1050 ⟩ ≡
```
static void mp_do_type_declaration(MP mp);
```

See also sections 1075, 1082, 1084, 1088, 1090, 1098, 1100, 1104, 1106, 1108, 1112, 1114, 1116, 1121, 1123, 1128, 1130, 1132, 1134, 1141, 1149, 1172, 1174, 1177, 1239, and 1259.

This code is used in section 1035.

1051.
```
static void flush_spurious_symbols_after_declared_variable(MP mp);
void mp_do_type_declaration(MP mp)
{
  integer t;   ▷ the type being declared ◁
  mp_node p;   ▷ token list for a declared variable ◁
  mp_node q;   ▷ value node for the variable ◁
  if (cur_mod() ≥ mp_transform_type) t ← (quarterword) cur_mod();
  else t ← (quarterword)(cur_mod() + unknown_tag);
  do {
    p ← mp_scan_declared_variable(mp);
    mp_flush_variable(mp, equiv_node(mp_sym_sym(p)), mp_link(p), false); q ← mp_find_variable(mp, p);
    if (q ≠ Λ) {
      mp_type(q) ← t; set_value_number(q, zero_t);   ▷ TODO: this was Λ ◁
    }
    else {
      const char *hlp[] ← {"You can't use, e.g., `numeric foo[]' after `vardef foo'.",
          "Proceed, and I'll ignore the illegal redeclaration.", Λ};
      mp_back_error(mp, "Declared variable conflicts with previous vardef", hlp, true);
      mp_get_x_next(mp);
    }
    mp_flush_node_list(mp, p);
    if (cur_cmd() < mp_comma) {
      flush_spurious_symbols_after_declared_variable(mp);
    }
  } while (¬mp_end_of_statement);
}
```

1052. **static void** *flush_spurious_symbols_after_declared_variable*(**MP** *mp*)

```
{
  const char *hlp[] ← {"Variables␣in␣declarations␣must␣consist␣entirely␣of",
      "names␣and␣collective␣subscripts,␣e.g.,␣`x[]a'.",
      "Are␣you␣trying␣to␣use␣a␣reserved␣word␣in␣a␣variable␣name?",
      "I'm␣going␣to␣discard␣the␣junk␣I␣found␣here,",
      "up␣to␣the␣next␣comma␣or␣the␣end␣of␣the␣declaration.", Λ};
  if (cur_cmd() ≡ mp_numeric_token)
    hlp[2] ← "Explicit␣subscripts␣like␣`x15a'␣aren't␣permitted.";
  mp_back_error(mp, "Illegal␣suffix␣of␣declared␣variable␣will␣be␣flushed", hlp, true);
  mp_get_x_next(mp); mp→scanner_status ← flushing;
  do {
    get_t_next(mp); ⟨Decrease the string reference count, if the current token is a string 819⟩;
  } while (cur_cmd() < mp_comma);   ▷ break on either end_of_statement or comma ◁
  mp→scanner_status ← normal;
}
```

1053. METAPOST's *main_control* procedure just calls *do_statement* repeatedly until coming to the end of the user's program. Each execution of *do_statement* concludes with *cur_cmd* ← *semicolon*, *end_group*, or *stop*.

```
static void mp_main_control(MP mp)
{
  do {
    mp_do_statement(mp);
    if (cur_cmd() ≡ mp_end_group) {
      mp_value new_expr;
      const char *hlp[] ← {"I'm␣not␣currently␣working␣on␣a␣`begingroup',",
          "so␣I␣had␣better␣not␣try␣to␣end␣anything.", Λ};
      memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
      mp_error(mp, "Extra␣`endgroup'", hlp, true); mp_flush_cur_exp(mp, new_expr);
    }
  } while (cur_cmd() ≠ mp_stop);
}
int mp_run(MP mp)
{
  if (mp→history < mp_fatal_error_stop) {
    xfree(mp→jump_buf); mp→jump_buf ← malloc(sizeof(jmp_buf));
    if (mp→jump_buf ≡ Λ ∨ setjmp(*(mp→jump_buf)) ≠ 0) return mp→history;
    mp_main_control(mp);   ▷ come to life ◁
    mp_final_cleanup(mp);   ▷ prepare for death ◁
    mp_close_files_and_terminate(mp);
  }
  return mp→history;
}
```

1054. This function allows setting of internals from an external source (like the command line or a controlling application).

It accepts two **char** ∗'s, even for numeric assignments when it calls *atoi* to get an integer from the start of the string.

```
void mp_set_internal(MP mp, char *n, char *v, int isstring)
{
  size_t l ← strlen(n);
  char err[256];
  const char *errid ← Λ;
  if (l > 0) {
    mp_sym p ← mp_id_lookup(mp, n, l, false);
    if (p ≡ Λ) {
      errid ← "variable␣does␣not␣exist";
    }
    else {
      if (eq_type(p) ≡ mp_internal_quantity) {
        if ((internal_type(equiv(p)) ≡ mp_string_type) ∧ (isstring)) {
          set_internal_string(equiv(p), mp_rts(mp, v));
        }
        else if ((internal_type(equiv(p)) ≡ mp_known) ∧ (¬isstring)) {
          int test ← atoi(v);
          if (test > 16383 ∧ mp→math_mode ≡ mp_math_scaled_mode) {
            errid ← "value␣is␣too␣large";
          }
          else if (test < −16383 ∧ mp→math_mode ≡ mp_math_scaled_mode) {
            errid ← "value␣is␣too␣small";
          }
          else {
            set_internal_from_number(equiv(p), unity_t);
            number_multiply_int(internal_value(equiv(p)), test);
          }
        }
        else {
          errid ← "value␣has␣the␣wrong␣type";
        }
      }
      else {
        errid ← "variable␣is␣not␣an␣internal";
      }
    }
  }
  if (errid ≠ Λ) {
    if (isstring) {
      mp_snprintf(err, 256, "%s=\"%s\":␣%s,␣assignment␣ignored.", n, v, errid);
    }
    else {
      mp_snprintf(err, 256, "%s=%d:␣%s,␣assignment␣ignored.", n, atoi(v), errid);
    }
    mp_warn(mp, err);
  }
}
```

1055. ⟨ Exported function headers 22 ⟩ +≡

void *mp_set_internal*(**MP** *mp*, **char** ∗*n*, **char** ∗*v*, **int** *isstring*);

1056. For *mp_execute*, we need to define a structure to store the redirected input and output. This structure holds the five relevant streams: the three informational output streams, the PostScript generation stream, and the input stream. These streams have many things in common, so it makes sense to give them their own structure definition.

fptr is a virtual file pointer
data is the data this stream holds
cur is a cursor pointing into *data*
size is the allocated length of the data stream
used is the actual length of the data stream

There are small differences between input and output: *term_in* never uses *used*, whereas the other four never use *cur*.

The file *luatexdir/tex/texfileio.h* defines *term_in* as *stdin* and *term_out* as *stdout*. Moreover *stdio.h* for MinGW defines *stdin* as (&*_iob*[0]) and *stdout* as (&*_iob*[1]). We must avoid all that.

⟨ Exported types 19 ⟩ +≡

```
#undef term_in
#undef term_out
  typedef struct {
    void *fptr;
    char *data;
    char *cur;
    size_t size;
    size_t used;
  } mp_stream;
  typedef struct {
    mp_stream term_out;
    mp_stream error_out;
    mp_stream log_out;
    mp_stream ship_out;
    mp_stream term_in;
    struct mp_edge_object *edges;
  } mp_run_data;
```

1057. We need a function to clear an output stream, this is called at the beginning of *mp_execute*. We also need one for destroying an output stream, this is called just before a stream is (re)opened.

```
static void mp_reset_stream(mp_stream *str)
{
  xfree(str→data); str→cur ← Λ; str→size ← 0; str→used ← 0;
}
static void mp_free_stream(mp_stream *str)
{
  xfree(str→fptr); mp_reset_stream(str);
}
```

1058. ⟨ Declarations 10 ⟩ +≡

```
static void mp_reset_stream(mp_stream *str);
static void mp_free_stream(mp_stream *str);
```

1059. The global instance contains a pointer instead of the actual structure even though it is essentially static, because that makes it is easier to move the object around.

⟨ Global variables 18 ⟩ +≡
```
mp_run_data run_data;
```

1060. Another type is needed: the indirection will overload some of the file pointer objects in the instance (but not all). For clarity, an indirect object is used that wraps a **FILE** ∗.

⟨ Types in the outer block 37 ⟩ +≡
```
typedef struct File {
  FILE *f;
} File;
```

1061. Here are all of the functions that need to be overloaded for *mp_execute*.

⟨ Declarations 10 ⟩ +≡
```
static void *mplib_open_file(MP mp, const char *fname, const char *fmode, int ftype);
static int mplib_get_char(void *f, mp_run_data *mplib_data);
static void mplib_unget_char(void *f, mp_run_data *mplib_data, int c);
static char *mplib_read_ascii_file(MP mp, void *ff, size_t *size);
static void mplib_write_ascii_file(MP mp, void *ff, const char *s);
static void mplib_read_binary_file(MP mp, void *ff, void **data, size_t *size);
static void mplib_write_binary_file(MP mp, void *ff, void *s, size_t size);
static void mplib_close_file(MP mp, void *ff);
static int mplib_eof_file(MP mp, void *ff);
static void mplib_flush_file(MP mp, void *ff);
static void mplib_shipout_backend(MP mp, void *h);
```

1062. The *xmalloc*(1, 1) calls make sure the stored indirection values are unique.

```
#define reset_stream(a)
        do {
          mp_reset_stream(&(a));
          if (¬ff→f) {
            ff→f ← xmalloc(1, 1); (a).fptr ← ff→f;
          }
        } while (0)

  static void *mplib_open_file(MP mp, const char *fname, const char *fmode, int ftype)
  {
    File *ff ← xmalloc(1, sizeof(File));
    mp_run_data *run ← mp_rundata(mp);
    ff→f ← Λ;
    if (ftype ≡ mp_filetype_terminal) {
      if (fmode[0] ≡ 'r') {
        if (¬ff→f) {
          ff→f ← xmalloc(1, 1); run→term_in.fptr ← ff→f;
        }
      }
      else {
        reset_stream(run→term_out);
      }
    }
    else if (ftype ≡ mp_filetype_error) {
      reset_stream(run→error_out);
    }
    else if (ftype ≡ mp_filetype_log) {
      reset_stream(run→log_out);
    }
    else if (ftype ≡ mp_filetype_postscript) {
      mp_free_stream(&(run→ship_out)); ff→f ← xmalloc(1, 1); run→ship_out.fptr ← ff→f;
    }
    else if (ftype ≡ mp_filetype_bitmap) {
      mp_free_stream(&(run→ship_out)); ff→f ← xmalloc(1, 1); run→ship_out.fptr ← ff→f;
    }
    else {
      char realmode[3];
      char *f ← (mp→find_file)(mp, fname, fmode, ftype);
      if (f ≡ Λ) return Λ;
      realmode[0] ← *fmode; realmode[1] ← 'b'; realmode[2] ← 0; ff→f ← fopen(f, realmode); free(f);
      if ((fmode[0] ≡ 'r') ∧ (ff→f ≡ Λ)) {
        free(ff); return Λ;
      }
    }
    return ff;
  }

  static int mplib_get_char(void *f, mp_run_data *run)
  {
    int c;
    if (f ≡ run→term_in.fptr ∧ run→term_in.data ≠ Λ) {
      if (run→term_in.size ≡ 0) {
```

```
      if (run→term_in.cur ≠ Λ) {
        run→term_in.cur ← Λ;
      }
      else {
        xfree(run→term_in.data);
      }
      c ← EOF;
    }
    else {
      run→term_in.size −−; c ← ∗(run→term_in.cur)++;
    }
  }
  else {
    c ← fgetc(f);
  }
  return c;
}
static void mplib_unget_char(void ∗f, mp_run_data ∗run, int c)
{
  if (f ≡ run→term_in.fptr ∧ run→term_in.cur ≠ Λ) {
    run→term_in.size ++; run→term_in.cur −−;
  }
  else {
    ungetc(c, f);
  }
}
static char ∗mplib_read_ascii_file(MP mp, void ∗ff, size_t ∗size)
{
  char ∗s ← Λ;
  if (ff ≠ Λ) {
    int c;
    size_t len ← 0, lim ← 128;
    mp_run_data ∗run ← mp_rundata(mp);
    FILE ∗f ← ((File ∗) ff)→f;
    if (f ≡ Λ) return Λ;
    ∗size ← 0; c ← mplib_get_char(f, run);
    if (c ≡ EOF) return Λ;
    s ← malloc(lim);
    if (s ≡ Λ) return Λ;
    while (c ≠ EOF ∧ c ≠ '\n' ∧ c ≠ '\r') {
      if (len ≥ (lim − 1)) {
        s ← xrealloc(s, (lim + (lim ≫ 2)), 1);
        if (s ≡ Λ) return Λ;
        lim += (lim ≫ 2);
      }
      s[len ++] ← (char) c; c ← mplib_get_char(f, run);
    }
    if (c ≡ '\r') {
      c ← mplib_get_char(f, run);
      if (c ≠ EOF ∧ c ≠ '\n') mplib_unget_char(f, run, c);
    }
```

```
    s[len] ← 0; *size ← len;
  }
  return s;
}
static void mp_append_string(MP mp, mp_stream *a, const char *b)
{
  size_t l ← strlen(b) + 1;   ▷ don't forget the trailing '\0' ◁
  if ((a→used + l) ≥ a→size) {
    a→size += 256 + (a→size)/5 + l; a→data ← xrealloc(a→data, a→size, 1);
  }
  memcpy(a→data + a→used, b, l); a→used += (l − 1);
}
static void mp_append_data(MP mp, mp_stream *a, void *b, size_t l)
{
  if ((a→used + l) ≥ a→size) {
    a→size += 256 + (a→size)/5 + l; a→data ← xrealloc(a→data, a→size, 1);
  }
  memcpy(a→data + a→used, b, l); a→used += l;
}
static void mplib_write_ascii_file(MP mp, void *ff, const char *s)
{
  if (ff ≠ Λ) {
    void *f ← ((File *) ff)→f;
    mp_run_data *run ← mp_rundata(mp);
    if (f ≠ Λ) {
      if (f ≡ run→term_out.fptr) {
        mp_append_string(mp, &(run→term_out), s);
      }
      else if (f ≡ run→error_out.fptr) {
        mp_append_string(mp, &(run→error_out), s);
      }
      else if (f ≡ run→log_out.fptr) {
        mp_append_string(mp, &(run→log_out), s);
      }
      else if (f ≡ run→ship_out.fptr) {
        mp_append_string(mp, &(run→ship_out), s);
      }
      else {
        fprintf((FILE *) f, "%s", s);
      }
    }
  }
}
static void mplib_read_binary_file(MP mp, void *ff, void **data, size_t *size)
{
  (void) mp;
  if (ff ≠ Λ) {
    size_t len ← 0;
    FILE *f ← ((File *) ff)→f;
    if (f ≠ Λ) len ← fread(*data, 1, *size, f);
```

```
    *size ← len;
  }
}
static void mplib_write_binary_file(MP mp, void *ff, void *s, size_t size)
{
  (void) mp;
  if (ff ≠ Λ) {
    void *f ← ((File *) ff)→f;
    mp_run_data *run ← mp_rundata(mp);
    if (f ≠ Λ) {
      if (f ≡ run→ship_out.fptr) {
        mp_append_data(mp, &(run→ship_out), s, size);
      }
      else {
        (void) fwrite(s, size, 1, f);
      }
    }
  }
}
static void mplib_close_file(MP mp, void *ff)
{
  if (ff ≠ Λ) {
    mp_run_data *run ← mp_rundata(mp);
    void *f ← ((File *) ff)→f;
    if (f ≠ Λ) {
      if (f ≠ run→term_out.fptr ∧ f ≠ run→error_out.fptr ∧ f ≠ run→log_out.fptr ∧ f ≠
            run→ship_out.fptr ∧ f ≠ run→term_in.fptr) {
        fclose(f);
      }
    }
    free(ff);
  }
}
static int mplib_eof_file(MP mp, void *ff)
{
  if (ff ≠ Λ) {
    mp_run_data *run ← mp_rundata(mp);
    FILE *f ← ((File *) ff)→f;
    if (f ≡ Λ) return 1;
    if (f ≡ run→term_in.fptr ∧ run→term_in.data ≠ Λ) {
      return (run→term_in.size ≡ 0);
    }
    return feof(f);
  }
  return 1;
}
static void mplib_flush_file(MP mp, void *ff)
{
  (void) mp; (void) ff; return;
}
```

```
static void mplib_shipout_backend(MP mp, void *voidh)
{
  mp_edge_header_node h ← (mp_edge_header_node) voidh;
  mp_edge_object *hh ← mp_gr_export(mp, h);
  if (hh) {
    mp_run_data *run ← mp_rundata(mp);
    if (run→edges ≡ Λ) {
      run→edges ← hh;
    }
    else {
      mp_edge_object *p ← run→edges;
      while (p→next ≠ Λ) {
        p ← p→next;
      }
      p→next ← hh;
    }
  }
}
```

1063. This is where we fill them all in.

⟨ Prepare function pointers for non-interactive use 1063 ⟩ ≡

```
{
  mp→open_file ← mplib_open_file; mp→close_file ← mplib_close_file; mp→eof_file ← mplib_eof_file;
  mp→flush_file ← mplib_flush_file; mp→write_ascii_file ← mplib_write_ascii_file;
  mp→read_ascii_file ← mplib_read_ascii_file; mp→write_binary_file ← mplib_write_binary_file;
  mp→read_binary_file ← mplib_read_binary_file; mp→shipout_backend ← mplib_shipout_backend;
}
```

This code is used in section 20.

1064. Perhaps this is the most important API function in the library.

⟨ Exported function headers 22 ⟩ +≡

```
extern mp_run_data *mp_rundata(MP mp);
```

1065.

```
mp_run_data *mp_rundata(MP mp)
{
  return &(mp→run_data);
}
```

1066. ⟨ Dealloc variables 31 ⟩ +≡

```
mp_free_stream(&(mp→run_data.term_in)); mp_free_stream(&(mp→run_data.term_out));
mp_free_stream(&(mp→run_data.log_out)); mp_free_stream(&(mp→run_data.error_out));
mp_free_stream(&(mp→run_data.ship_out));
```

1067. ⟨ Finish non-interactive use 1067 ⟩ ≡

```
{
  xfree(mp→term_out); xfree(mp→term_in); xfree(mp→err_out);
}
```

This code is used in section 16.

1068. ⟨ Start non-interactive work 1068 ⟩ ≡
⟨ Initialize the output routines 87 ⟩;
mp→input_ptr ← 0; *mp→max_in_stack* ← *file_bottom*; *mp→in_open* ← *file_bottom*; *mp→open_parens* ← 0;
mp→max_buf_stack ← 0; *mp→param_ptr* ← 0; *mp→max_param_stack* ← 0; *start* ← *loc* ← 0;
iindex ← *file_bottom*; *nloc* ← *nstart* ← Λ; *mp→first* ← 0; *line* ← 0; *name* ← *is_term*;
mp→mpx_name[*file_bottom*] ← *absent*; *mp→force_eof* ← *false*; *t_open_in*( );
mp→scanner_status ← *normal*;
if (¬*mp→ini_version*) {
  if (¬*mp_load_preload_file*(*mp*)) {
    mp→history ← *mp_fatal_error_stop*; **return** *mp→history*;
  }
}
mp_fix_date_and_time(*mp*);
if (*mp→random_seed* ≡ 0)
  mp→random_seed ← (*number_to_scaled*(*internal_value*(*mp_time*))/*number_to_scaled*(*unity_t*)) +
      number_to_scaled(*internal_value*(*mp_day*));
init_randoms(*mp→random_seed*); *initialize_print_selector*( ); *mp_open_log_file*(*mp*); *mp_set_job_id*(*mp*);
mp_init_map_file(*mp*, *mp→troff_mode*); *mp→history* ← *mp_spotless*; ▷ ready to go! ◁
if (*mp→troff_mode*) {
  number_clone(*internal_value*(*mp_gtroffmode*), *unity_t*);
  number_clone(*internal_value*(*mp_prologues*), *unity_t*);
}
⟨ Fix up *mp→internal*[*mp_job_name*] 872 ⟩;
if (*mp→start_sym* ≠ Λ) { ▷ insert the '**everyjob**' symbol ◁
  set_cur_sym(*mp→start_sym*); *mp_back_input*(*mp*);
}

This code is used in section 1069.

1069. **int** *mp_execute*(**MP** *mp*, **char** $*s$, **size_t** *l*)

```
{
  mp_reset_stream(&(mp→run_data.term_out)); mp_reset_stream(&(mp→run_data.log_out));
  mp_reset_stream(&(mp→run_data.error_out)); mp_reset_stream(&(mp→run_data.ship_out));
  if (mp→finished) {
    return mp→history;
  }
  else if (¬mp→noninteractive) {
    mp→history ← mp_fatal_error_stop; return mp→history;
  }
  if (mp→history < mp_fatal_error_stop) {
    xfree(mp→jump_buf); mp→jump_buf ← malloc(sizeof(jmp_buf));
    if (mp→jump_buf ≡ Λ ∨ setjmp(*(mp→jump_buf)) ≠ 0) {
      return mp→history;
    }
    if (s ≡ Λ) {    ▷ this signals EOF ◁
      mp_final_cleanup(mp);    ▷ prepare for death ◁
      mp_close_files_and_terminate(mp); return mp→history;
    }
    mp→tally ← 0; mp→term_offset ← 0; mp→file_offset ← 0;    ▷ Perhaps some sort of warning here
        when data is not * yet exhausted would be nice ... this happens after errors ◁
    if (mp→run_data.term_in.data) xfree(mp→run_data.term_in.data);
    mp→run_data.term_in.data ← xstrdup(s); mp→run_data.term_in.cur ← mp→run_data.term_in.data;
    mp→run_data.term_in.size ← l;
    if (mp→run_state ≡ 0) {
      mp→selector ← term_only; ⟨Start non-interactive work 1068⟩;
    }
    mp→run_state ← 1; (void) mp_input_ln(mp, mp→term_in); mp_firm_up_the_line(mp);
    mp→buffer[limit] ← xord('%'); mp→first ← (size_t)(limit + 1); loc ← start;
    do {
      mp_do_statement(mp);
    } while (cur_cmd() ≠ mp_stop);
    mp_final_cleanup(mp); mp_close_files_and_terminate(mp);
  }
  return mp→history;
}
```

1070. This function cleans up

```
int mp_finish(MP mp)
{
  int history ← 0;
  if (mp→finished ∨ mp→history ≥ mp_fatal_error_stop) {
    history ← mp→history; mp_free(mp); return history;
  }
  xfree(mp→jump_buf); mp→jump_buf ← malloc(sizeof(jmp_buf));
  if (mp→jump_buf ≡ Λ ∨ setjmp(∗(mp→jump_buf)) ≠ 0) {
    history ← mp→history;
  }
  else {
    history ← mp→history; mp_final_cleanup(mp);    ▷ prepare for death ◁
  }
  mp_close_files_and_terminate(mp); mp_free(mp); return history;
}
```

1071. People may want to know the library version

```
char ∗mp_metapost_version(void)
{
  return mp_strdup(metapost_version);
}
void mp_show_library_versions(void)
{
  fprintf(stdout, "Compiled␣with␣cairo␣%s;␣using␣%s\n", COMPILED_CAIRO_VERSION_STRING,
      cairo_version_string()); fprintf(stdout, "Compiled␣with␣pixman␣%s;␣using␣%s\n",
      COMPILED_PIXMAN_VERSION_STRING, pixman_version_string());
  fprintf(stdout, "Compiled␣with␣libpng␣%s;␣using␣%s\n", PNG_LIBPNG_VER_STRING, png_libpng_ver);
  fprintf(stdout, "Compiled␣with␣zlib␣%s;␣using␣%s\n", ZLIB_VERSION, zlibVersion());
  fprintf(stdout, "Compiled␣with␣mpfr␣%s;␣using␣%s\n", COMPILED_MPFR_VERSION_STRING,
      mpfr_get_version()); fprintf(stdout, "Compiled␣with␣mpfi␣%s;␣using␣%s\n",
      COMPILED_MPFI_VERSION_STRING, mpfi_get_version());
  fprintf(stdout, "Compiled␣with␣gmp␣%d.%d.%d;␣using␣%s\n\n", COMPILED__GNU_MP_VERSION,
      COMPILED__GNU_MP_VERSION_MINOR, COMPILED__GNU_MP_VERSION_PATCHLEVEL,
      COMPILED_gmp_version);
}
```

1072. ⟨ Exported function headers 22 ⟩ +≡

```
int mp_run(MP mp);
int mp_execute(MP mp, char ∗s, size_t l);
int mp_finish(MP mp);
char ∗mp_metapost_version(void);
void mp_show_library_versions(void);
```

1073. ⟨ Put each of METAPOST's primitives into the hash table 204 ⟩ +≡

```
mp_primitive(mp, "end", mp_stop, 0); mp_primitive(mp, "dump", mp_stop, 1);
mp→frozen_dump ← mp_frozen_primitive(mp, "dump", mp_stop, 1);
```

1074. ⟨ Cases of *print_cmd_mod* for symbolic printing of primitives 239 ⟩ +≡

case *mp_stop*:
  if $(cur\_mod() \equiv 0)$ *mp_print*(*mp*, "end");
  else *mp_print*(*mp*, "dump");
  break;

1075. Commands. Let's turn now to statements that are classified as "commands" because of their imperative nature. We'll begin with simple ones, so that it will be clear how to hook command processing into the *do_statement* routine; then we'll tackle the tougher commands.

Here's one of the simplest:

⟨ Declare action procedures for use by *do_statement* 1050 ⟩ +≡
```
static void mp_do_random_seed(MP mp);
```

1076. **void** *mp_do_random_seed*(**MP** *mp*)
```
{
  mp_value new_expr;
  memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n); mp_get_x_next(mp);
  if (cur_cmd() ≠ mp_assignment) {
    const char *hlp[] ← {"Always␣say␣‘randomseed:=<numeric␣expression>’.", Λ};
    mp_back_error(mp, "Missing␣‘:=’␣has␣been␣inserted", hlp, true);
  }
  mp_get_x_next(mp); mp_scan_expression(mp);
  if (mp→cur_exp.type ≠ mp_known) {
    const char *hlp[] ← {"Your␣expression␣was␣too␣random␣for␣me␣to␣handle,",
        "so␣I␣won’t␣change␣the␣random␣seed␣just␣now.", Λ};
    mp_disp_err(mp, Λ); mp_back_error(mp, "Unknown␣value␣will␣be␣ignored", hlp, true);
    mp_get_x_next(mp); mp_flush_cur_exp(mp, new_expr);
  }
  else ⟨ Initialize the random seed to cur_exp 1077 ⟩
}
```

1077. ⟨ Initialize the random seed to *cur_exp* 1077 ⟩ ≡
```
{
  init_randoms(number_to_scaled(cur_exp_value_number()));
  if (mp→selector ≥ log_only ∧ mp→selector < write_file) {
    mp→old_setting ← mp→selector; mp→selector ← log_only; mp_print_nl(mp, "{randomseed:=");
    print_number(cur_exp_value_number()); mp_print_char(mp, xord('}')); mp_print_nl(mp, "");
    mp→selector ← mp→old_setting;
  }
}
```
This code is used in section 1076.

1078. ⟨ Put each of METAPOST's primitives into the hash table 204 ⟩ +≡
```
mp_primitive(mp, "batchmode", mp_mode_command, mp_batch_mode);
mp_primitive(mp, "nonstopmode", mp_mode_command, mp_nonstop_mode);
mp_primitive(mp, "scrollmode", mp_mode_command, mp_scroll_mode);
mp_primitive(mp, "errorstopmode", mp_mode_command, mp_error_stop_mode);
```

1079. ⟨ Cases of *print_cmd_mod* for symbolic printing of primitives 239 ⟩ +≡
```
case mp_mode_command:
  switch (m) {
  case mp_batch_mode: mp_print(mp, "batchmode"); break;
  case mp_nonstop_mode: mp_print(mp, "nonstopmode"); break;
  case mp_scroll_mode: mp_print(mp, "scrollmode"); break;
  default: mp_print(mp, "errorstopmode"); break;
  }
  break;
```

1080. The '**inner**' and '**outer**' commands are only slightly harder.

⟨ Put each of METAPOST's primitives into the hash table 204 ⟩ +≡
```
mp_primitive(mp, "inner", mp_protection_command, 0);
mp_primitive(mp, "outer", mp_protection_command, 1);
```

1081. ⟨ Cases of *print_cmd_mod* for symbolic printing of primitives 239 ⟩ +≡
```
case mp_protection_command:
  if (m ≡ 0) mp_print(mp, "inner");
  else mp_print(mp, "outer");
  break;
```

1082. And here's another simple one (somewhat different in flavor):

⟨ Declare action procedures for use by *do_statement* 1050 ⟩ +≡
```
static void mp_do_protection(MP mp);
```

1083.
```
void mp_do_protection(MP mp)
{
  int m;    ▷ 0 to unprotect, 1 to protect ◁
  halfword t;    ▷ the eq_type before we change it ◁
  m ← cur_mod();
  do {
    mp_get_symbol(mp); t ← eq_type(cur_sym());
    if (m ≡ 0) {
      if (t ≥ mp_outer_tag) set_eq_type(cur_sym(), (t − mp_outer_tag));
    }
    else if (t < mp_outer_tag) {
      set_eq_type(cur_sym(), (t + mp_outer_tag));
    }
    mp_get_x_next(mp);
  } while (cur_cmd() ≡ mp_comma);
}
```

1084. METAPOST never defines the tokens '(' and ')' to be primitives, but plain METAPOST begins with the declaration '**delimiters** ()'. Such a declaration assigns the command code *left_delimiter* to '(' and *right_delimiter* to ')'; the *equiv* of each delimiter is the hash address of its mate.

⟨ Declare action procedures for use by *do_statement* 1050 ⟩ +≡
```
static void mp_def_delims(MP mp);
```

1085.
```
void mp_def_delims(MP mp)
{
  mp_sym l_delim, r_delim;    ▷ the new delimiter pair ◁
  mp_get_clear_symbol(mp); l_delim ← cur_sym(); mp_get_clear_symbol(mp); r_delim ← cur_sym();
  set_eq_type(l_delim, mp_left_delimiter); set_equiv_sym(l_delim, r_delim);
  set_eq_type(r_delim, mp_right_delimiter); set_equiv_sym(r_delim, l_delim); mp_get_x_next(mp);
}
```

1086. Here is a procedure that is called when METAPOST has reached a point where some right delimiter is mandatory.

⟨ Declarations 10 ⟩ +≡
```
static void mp_check_delimiter(MP mp, mp_sym l_delim, mp_sym r_delim);
```

1087. **void** *mp_check_delimiter*(**MP** *mp*, **mp_sym** *l_delim*, **mp_sym** *r_delim*)

```
{
  if (cur_cmd() ≡ mp_right_delimiter)
    if (equiv_sym(cur_sym()) ≡ l_delim) return;
  if (cur_sym() ≠ r_delim) {
    char msg[256];
    const char *hlp[] ← {"I␣found␣no␣right␣delimiter␣to␣match␣a␣left␣one.␣So␣I've",
        "put␣one␣in,␣behind␣the␣scenes;␣this␣may␣fix␣the␣problem.", Λ};
    mp_snprintf(msg, 256, "Missing␣`%s'␣has␣been␣inserted", mp_str(mp, text(r_delim)));
    mp_back_error(mp, msg, hlp, true);
  }
  else {
    char msg[256];
    const char *hlp[] ← {"Strange:␣This␣token␣has␣lost␣its␣former␣meaning!",
        "I'll␣read␣it␣as␣a␣right␣delimiter␣this␣time;",
        "but␣watch␣out,␣I'll␣probably␣miss␣it␣later.", Λ};
    mp_snprintf(msg, 256, "The␣token␣`%s'␣is␣no␣longer␣a␣right␣delimiter", mp_str(mp,
        text(r_delim))); mp_error(mp, msg, hlp, true);
  }
}
```

1088. The next two commands save or change the values associated with tokens.

⟨ Declare action procedures for use by *do_statement* 1050 ⟩ +≡
  static void *mp_do_statement*(**MP** *mp*);
  static void *mp_do_interim*(**MP** *mp*);

1089. **void** *mp_do_interim*(**MP** *mp*)

```
{
  mp_get_x_next(mp);
  if (cur_cmd() ≠ mp_internal_quantity) {
    char msg[256];
    const char *hlp[] ← {"Something␣like␣`tracingonline'␣should␣follow␣`interim'.", Λ};
    mp_snprintf(msg, 256, "The␣token␣`%s'␣isn't␣an␣internal␣quantity",
        (cur_sym() ≡ Λ ? "(%CAPSULE)" : mp_str(mp, text(cur_sym()))));
    mp_back_error(mp, msg, hlp, true);
  }
  else {
    mp_save_internal(mp, cur_mod()); mp_back_input(mp);
  }
  mp_do_statement(mp);
}
```

1090. The following procedure is careful not to undefine the left-hand symbol too soon, lest commands like '`let x=x`' have a surprising effect.

⟨ Declare action procedures for use by *do_statement* 1050 ⟩ +≡
  static void *mp_do_let*(**MP** *mp*);

1091. **void** *mp_do_let*(**MP** *mp*)

```
{
  mp_sym l;    ▷ hash location of the left-hand symbol ◁
  mp_get_symbol(mp); l ← cur_sym(); mp_get_x_next(mp);
  if (cur_cmd() ≠ mp_equals ∧ cur_cmd() ≠ mp_assignment) {
    const char *hlp[] ← {"You should have said `let symbol = something'.",
        "But don't worry; I'll pretend that an equals sign",
        "was present. The next token I read will be `something'.", Λ};
    mp_back_error(mp, "Missing `=' has been inserted", hlp, true);
  }
  mp_get_symbol(mp);
  switch (cur_cmd()) {
  case mp_defined_macro: case mp_secondary_primary_macro: case mp_tertiary_secondary_macro:
    case mp_expression_tertiary_macro: add_mac_ref(cur_mod_node()); break;
  default: break;
  }
  mp_clear_symbol(mp, l, false); set_eq_type(l, cur_cmd());
  if (cur_cmd() ≡ mp_tag_token) set_equiv(l, 0);    ▷ TODO: this was Λ ◁
  else if (cur_cmd() ≡ mp_defined_macro ∨ cur_cmd() ≡ mp_secondary_primary_macro ∨ cur_cmd() ≡
        mp_tertiary_secondary_macro ∨ cur_cmd() ≡ mp_expression_tertiary_macro)
    set_equiv_node(l, cur_mod_node());
  else if (cur_cmd() ≡ mp_left_delimiter ∨ cur_cmd() ≡ mp_right_delimiter)
    set_equiv_sym(l, equiv_sym(cur_sym()));
  else set_equiv(l, cur_mod());
  mp_get_x_next(mp);
}
```

1092. ⟨Declarations 10⟩ +≡

```
static void mp_do_new_internal(MP mp);
```

1093. ⟨Internal library declarations 14⟩ +≡

```
void mp_grow_internals(MP mp, int l);
```

1094.

```
void mp_grow_internals(MP mp, int l)
{
  mp_internal *internal;
  int k;
  if (l > max_halfword) {
    mp_confusion(mp, "out␣of␣memory␣space");   ▷ can't be reached ◁
  }
  internal ← xmalloc((l + 1), sizeof(mp_internal));
  for (k ← 0; k ≤ l; k++) {
    if (k ≤ mp→max_internal) {
      memcpy(internal + k, mp→internal + k, sizeof(mp_internal));
    }
    else {
      memset(internal + k, 0, sizeof(mp_internal));
      new_number(((mp_internal *)(internal + k))→v.data.n);
    }
  }
  xfree(mp→internal); mp→internal ← internal; mp→max_internal ← l;
}

void mp_do_new_internal(MP mp)
{
  int the_type ← mp_known;
  mp_get_x_next(mp);
  if (cur_cmd() ≡ mp_type_name ∧ cur_mod() ≡ mp_string_type) {
    the_type ← mp_string_type;
  }
  else {
    if (¬(cur_cmd() ≡ mp_type_name ∧ cur_mod() ≡ mp_numeric_type)) {
      mp_back_input(mp);
    }
  }
  do {
    if (mp→int_ptr ≡ mp→max_internal) {
      mp_grow_internals(mp, (mp→max_internal + (mp→max_internal/4)));
    }
    mp_get_clear_symbol(mp); incr(mp→int_ptr); set_eq_type(cur_sym(), mp_internal_quantity);
    set_equiv(cur_sym(), mp→int_ptr);
    if (internal_name(mp→int_ptr) ≠ Λ) xfree(internal_name(mp→int_ptr));
    set_internal_name(mp→int_ptr, mp_xstrdup(mp, mp_str(mp, text(cur_sym()))));
    if (the_type ≡ mp_string_type) {
      set_internal_string(mp→int_ptr, mp_rts(mp, ""));
    }
    else {
      set_number_to_zero(internal_value(mp→int_ptr));
    }
    set_internal_type(mp→int_ptr, the_type); mp_get_x_next(mp);
  } while (cur_cmd() ≡ mp_comma);
}
```

1095. ⟨ Dealloc variables 31 ⟩ +≡

for ($k \leftarrow 0$; $k \le mp\rightarrow max\_internal$; k++) {
  free_number(*mp*→*internal*[*k*].*v*.*data*.*n*); *xfree*(*internal_name*(*k*));
}
xfree(*mp*→*internal*);

1096. The various '**show**' commands are distinguished by modifier fields in the usual way.

#define *show_token_code* 0 ▷ show the meaning of a single token ◁
#define *show_stats_code* 1 ▷ show current memory and string usage ◁
#define *show_code* 2 ▷ show a list of expressions ◁
#define *show_var_code* 3 ▷ show a variable and its descendants ◁
#define *show_dependencies_code* 4 ▷ show dependent variables in terms of independents ◁

⟨ Put each of METAPOST's primitives into the hash table 204 ⟩ +≡

mp_primitive(*mp*, "showtoken", *mp_show_command*, *show_token_code*);
mp_primitive(*mp*, "showstats", *mp_show_command*, *show_stats_code*);
mp_primitive(*mp*, "show", *mp_show_command*, *show_code*);
mp_primitive(*mp*, "showvariable", *mp_show_command*, *show_var_code*);
mp_primitive(*mp*, "showdependencies", *mp_show_command*, *show_dependencies_code*);

1097. ⟨ Cases of *print_cmd_mod* for symbolic printing of primitives 239 ⟩ +≡

case *mp_show_command*:
  switch (*m*) {
  case *show_token_code*: *mp_print*(*mp*, "showtoken"); **break**;
  case *show_stats_code*: *mp_print*(*mp*, "showstats"); **break**;
  case *show_code*: *mp_print*(*mp*, "show"); **break**;
  case *show_var_code*: *mp_print*(*mp*, "showvariable"); **break**;
  default: *mp_print*(*mp*, "showdependencies"); **break**;
  }
  break;

1098. The value of *cur_mod* controls the *verbosity* in the *print_exp* routine: if it's *show_code*, complicated structures are abbreviated, otherwise they aren't.

⟨ Declare action procedures for use by *do_statement* 1050 ⟩ +≡

static void *mp_do_show*(**MP** *mp*);

1099. **void** *mp_do_show*(**MP** *mp*)

{
  mp_value *new_expr*;
  do {
    memset(&*new_expr*, 0, **sizeof**(**mp_value**)); *new_number*(*new_expr*.*data*.*n*); *mp_get_x_next*(*mp*);
    mp_scan_expression(*mp*); *mp_print_nl*(*mp*, ">>␣"); *mp_print_exp*(*mp*, Λ, 2);
    mp_flush_cur_exp(*mp*, *new_expr*);
  } **while** (*cur_cmd*() ≡ *mp_comma*);
}

1100. ⟨ Declare action procedures for use by *do_statement* 1050 ⟩ +≡

static void *mp_disp_token*(**MP** *mp*);

1101. **void** *mp_disp_token*(**MP** *mp*)

```
{
  mp_print_nl(mp, ">␣");
  if (cur_sym() ≡ Λ) ⟨Show a numeric or string or capsule token 1102⟩
  else {
    mp_print_text(cur_sym()); mp_print_char(mp, xord('='));
    if (eq_type(cur_sym()) ≥ mp_outer_tag) mp_print(mp, "(outer)␣");
    mp_print_cmd_mod(mp, cur_cmd(), cur_mod());
    if (cur_cmd() ≡ mp_defined_macro) {
      mp_print_ln(mp); mp_show_macro(mp, cur_mod_node(), Λ, 100000);
    }    ▷ this avoids recursion between show_macro and print_cmd_mod ◁
  }
}
```

1102. ⟨Show a numeric or string or capsule token 1102⟩ ≡

```
{
  if (cur_cmd() ≡ mp_numeric_token) {
    print_number(cur_mod_number());
  }
  else if (cur_cmd() ≡ mp_capsule_token) {
    mp_print_capsule(mp, cur_mod_node());
  }
  else {
    mp_print_char(mp, xord('"')); mp_print_str(mp, cur_mod_str()); mp_print_char(mp, xord('"'));
    delete_str_ref(cur_mod_str());
  }
}
```

This code is used in section 1101.

1103. The following cases of *print_cmd_mod* might arise in connection with *disp_token*, although they don't necessarily correspond to primitive tokens.

⟨ Cases of *print_cmd_mod* for symbolic printing of primitives 239 ⟩ +≡

```
case mp_left_delimiter: case mp_right_delimiter:
  if (c ≡ mp_left_delimiter) mp_print(mp, "left");
  else mp_print(mp, "right");
#if 0
  mp_print(mp, "␣delimiter␣that␣matches␣"); mp_print_text(m);
#else
  mp_print(mp, "␣delimiter");
#endif
  break;
case mp_tag_token:
  if (m ≡ 0)    ▷ TODO: this was Λ ◁
    mp_print(mp, "tag");
  else mp_print(mp, "variable");
  break;
case mp_defined_macro: mp_print(mp, "macro:"); break;
case mp_secondary_primary_macro: case mp_tertiary_secondary_macro:
  case mp_expression_tertiary_macro: mp_print_cmd_mod(mp, mp_macro_def, c);
  mp_print(mp, "'d␣macro:"); mp_print_ln(mp);
  mp_show_token_list(mp, mp_link(mp_link(cur_mod_node())), 0, 1000, 0); break;
case mp_repeat_loop: mp_print(mp, "[repeat␣the␣loop]"); break;
case mp_internal_quantity: mp_print(mp, internal_name(m)); break;
```

1104. ⟨ Declare action procedures for use by *do_statement* 1050 ⟩ +≡

```
  static void mp_do_show_token(MP mp);
```

1105.

```
void mp_do_show_token(MP mp)
  {
    do {
      get_t_next(mp); mp_disp_token(mp); mp_get_x_next(mp);
    } while (cur_cmd() ≡ mp_comma);
  }
```

1106. ⟨ Declare action procedures for use by *do_statement* 1050 ⟩ +≡

```
  static void mp_do_show_stats(MP mp);
```

1107.

```
void mp_do_show_stats(MP mp)
  {
    mp_print_nl(mp, "Memory␣usage␣"); mp_print_int(mp, (integer) mp→var_used); mp_print_ln(mp);
    mp_print_nl(mp, "String␣usage␣"); mp_print_int(mp, (int) mp→strs_in_use);
    mp_print_char(mp, xord('&')); mp_print_int(mp, (int) mp→pool_in_use); mp_print_ln(mp);
    mp_get_x_next(mp);
  }
```

1108. Here's a recursive procedure that gives an abbreviated account of a variable, for use by *do_show_var*.

⟨ Declare action procedures for use by *do_statement* 1050 ⟩ +≡

```
  static void mp_disp_var(MP mp, mp_node p);
```

1109. **void** *mp_disp_var*(**MP** *mp*, **mp_node** *p*)

```
{
  mp_node q;   ▷ traverses attributes and subscripts ◁
  int n;   ▷ amount of macro text to show ◁
  if (mp_type(p) ≡ mp_structured) ⟨Descend the structure 1110⟩
  else if (mp_type(p) ≥ mp_unsuffixed_macro) ⟨Display a variable macro 1111⟩
  else if (mp_type(p) ≠ mp_undefined) {
    mp_print_nl(mp, ""); mp_print_variable_name(mp, p); mp_print_char(mp, xord('='));
    mp_print_exp(mp, p, 0);
  }
}
```

1110. ⟨Descend the structure 1110⟩ ≡

```
{
  q ← attr_head(p);
  do {
    mp_disp_var(mp, q); q ← mp_link(q);
  } while (q ≠ mp→end_attr);
  q ← subscr_head(p);
  while (mp_name_type(q) ≡ mp_subscr) {
    mp_disp_var(mp, q); q ← mp_link(q);
  }
}
```

This code is used in section 1109.

1111. ⟨Display a variable macro 1111⟩ ≡

```
{
  mp_print_nl(mp, ""); mp_print_variable_name(mp, p);
  if (mp_type(p) > mp_unsuffixed_macro) mp_print(mp, "@#");   ▷ suffixed_macro ◁
  mp_print(mp, "=macro:");
  if ((int) mp→file_offset ≥ mp→max_print_line − 20) n ← 5;
  else n ← mp→max_print_line − (int) mp→file_offset − 15;
  mp_show_macro(mp, value_node(p), Λ, n);
}
```

This code is used in section 1109.

1112. ⟨Declare action procedures for use by *do_statement* 1050⟩ +≡

```
static void mp_do_show_var(MP mp);
```

1113. **void** *mp_do_show_var*(**MP** *mp*)

```
{
  do {
    get_t_next(mp);
    if (cur_sym() ≠ Λ)
      if (cur_sym_mod() ≡ 0)
        if (cur_cmd() ≡ mp_tag_token)
          if (cur_mod() ≠ 0 ∨ cur_mod_node() ≠ Λ) {
            mp_disp_var(mp, cur_mod_node()); goto DONE;
          }
    mp_disp_token(mp);
  DONE: mp_get_x_next(mp);
  } while (cur_cmd() ≡ mp_comma);
}
```

1114. ⟨ Declare action procedures for use by *do_statement* 1050 ⟩ +≡

```
static void mp_do_show_dependencies(MP mp);
```

1115. **void** *mp_do_show_dependencies*(**MP** *mp*)

```
{
  mp_value_node p;    ▷ link that runs through all dependencies ◁
  p ← (mp_value_node) mp_link(mp→dep_head);
  while (p ≠ mp→dep_head) {
    if (mp_interesting(mp, (mp_node) p)) {
      mp_print_nl(mp, ""); mp_print_variable_name(mp, (mp_node) p);
      if (mp_type(p) ≡ mp_dependent) mp_print_char(mp, xord('='));
      else mp_print(mp, "␣=␣");    ▷ extra spaces imply proto-dependency ◁
      mp_print_dependency(mp, (mp_value_node) dep_list(p), mp_type(p));
    }
    p ← (mp_value_node) dep_list(p);
    while (dep_info(p) ≠ Λ) p ← (mp_value_node) mp_link(p);
    p ← (mp_value_node) mp_link(p);
  }
  mp_get_x_next(mp);
}
```

1116. Finally we are ready for the procedure that governs all of the show commands.

⟨ Declare action procedures for use by *do_statement* 1050 ⟩ +≡

```
static void mp_do_show_whatever(MP mp);
```

1117.

```
void mp_do_show_whatever(MP mp)
{
  if (mp→interaction ≡ mp_error_stop_mode) wake_up_terminal();
  switch (cur_mod()) {
  case show_token_code: mp_do_show_token(mp); break;
  case show_stats_code: mp_do_show_stats(mp); break;
  case show_code: mp_do_show(mp); break;
  case show_var_code: mp_do_show_var(mp); break;
  case show_dependencies_code: mp_do_show_dependencies(mp); break;
  }    ▷ there are no other cases ◁
  if (number_positive(internal_value(mp_showstopping))) {
    const char *hlp[] ← {"This␣isn't␣an␣error␣message;␣I'm␣just␣showing␣something.", Λ};
    if (mp→interaction < mp_error_stop_mode) {
      hlp[0] ← Λ; decr(mp→error_count);
    }
    if (cur_cmd() ≡ mp_semicolon) {
      mp_error(mp, "OK", hlp, true);
    }
    else {
      mp_back_error(mp, "OK", hlp, true); mp_get_x_next(mp);
    }
  }
}
```

1118. The '**addto**' command needs the following additional primitives:

```
#define double_path_code 0    ▷ command modifier for 'doublepath' ◁
#define contour_code 1    ▷ command modifier for 'contour' ◁
#define also_code 2    ▷ command modifier for 'also' ◁
```

1119. Pre- and postscripts need two new identifiers:

```
#define with_mp_pre_script 11
#define with_mp_post_script 13
```

⟨ Put each of METAPOST's primitives into the hash table 204 ⟩ +≡

```
  mp_primitive(mp, "doublepath", mp_thing_to_add, double_path_code);
  mp_primitive(mp, "contour", mp_thing_to_add, contour_code);
  mp_primitive(mp, "also", mp_thing_to_add, also_code);
  mp_primitive(mp, "withpen", mp_with_option, mp_pen_type);
  mp_primitive(mp, "dashed", mp_with_option, mp_picture_type);
  mp_primitive(mp, "withprescript", mp_with_option, with_mp_pre_script);
  mp_primitive(mp, "withpostscript", mp_with_option, with_mp_post_script);
  mp_primitive(mp, "withoutcolor", mp_with_option, mp_no_model);
  mp_primitive(mp, "withgreyscale", mp_with_option, mp_grey_model);
  mp_primitive(mp, "withcolor", mp_with_option, mp_uninitialized_model);
    ▷ withrgbcolor is an alias for withcolor ◁
  mp_primitive(mp, "withrgbcolor", mp_with_option, mp_rgb_model);
  mp_primitive(mp, "withcmykcolor", mp_with_option, mp_cmyk_model);
```

1120. ⟨ Cases of *print_cmd_mod* for symbolic printing of primitives 239 ⟩ +≡
case *mp_thing_to_add*:
  if ($m \equiv$ *contour_code*) *mp_print*(*mp*, "contour");
  else if ($m \equiv$ *double_path_code*) *mp_print*(*mp*, "doublepath");
  else *mp_print*(*mp*, "also");
  break;
case *mp_with_option*:
  if ($m \equiv$ *mp_pen_type*) *mp_print*(*mp*, "withpen");
  else if ($m \equiv$ *with_mp_pre_script*) *mp_print*(*mp*, "withprescript");
  else if ($m \equiv$ *with_mp_post_script*) *mp_print*(*mp*, "withpostscript");
  else if ($m \equiv$ *mp_no_model*) *mp_print*(*mp*, "withoutcolor");
  else if ($m \equiv$ *mp_rgb_model*) *mp_print*(*mp*, "withrgbcolor");
  else if ($m \equiv$ *mp_uninitialized_model*) *mp_print*(*mp*, "withcolor");
  else if ($m \equiv$ *mp_cmyk_model*) *mp_print*(*mp*, "withcmykcolor");
  else if ($m \equiv$ *mp_grey_model*) *mp_print*(*mp*, "withgreyscale");
  else *mp_print*(*mp*, "dashed");
  break;

1121. The *scan_with_list* procedure parses a ⟨with list⟩ and updates the list of graphical objects starting at *p*. Each ⟨with clause⟩ updates all graphical objects whose *type* is compatible. Other objects are ignored.

⟨ Declare action procedures for use by *do_statement* 1050 ⟩ +≡
  static void *mp_scan_with_list*(**MP** *mp*, **mp_node** *p*);

1122. Forcing the color to be between 0 and *unity* here guarantees that no picture will ever contain a color outside the legal range for PostScript graphics.

```
#define make_cp_a_colored_object()
        do {
          cp ← p;
          while (cp ≠ Λ) {
            if (has_color(cp)) break;
            cp ← mp_link(cp);
          }
        } while (0)
#define clear_color(A)
        do {
          set_number_to_zero(((mp_stroked_node)(A))→cyan);
          set_number_to_zero(((mp_stroked_node)(A))→magenta);
          set_number_to_zero(((mp_stroked_node)(A))→yellow);
          set_number_to_zero(((mp_stroked_node)(A))→black);
          mp_color_model((A)) ← mp_uninitialized_model;
        } while (0)
#define set_color_val(A, B)
        do {
          number_clone(A, (B));
          if (number_negative(A)) set_number_to_zero(A);
          if (number_greater(A, unity_t)) set_number_to_unity(A);
        } while (0)

  static int is_invalid_with_list(MP mp, mp_variable_type t)
  {
    return ((t ≡ with_mp_pre_script) ∧ (mp→cur_exp.type ≠ mp_string_type)) ∨
        ((t ≡ with_mp_post_script) ∧ (mp→cur_exp.type ≠ mp_string_type)) ∨
        ((t ≡ (mp_variable_type) mp_uninitialized_model) ∧ ((mp→cur_exp.type ≠ mp_cmykcolor_type)
        ∧ (mp→cur_exp.type ≠ mp_color_type) ∧ (mp→cur_exp.type ≠ mp_known)
        ∧ (mp→cur_exp.type ≠ mp_boolean_type))) ∨ ((t ≡ (mp_variable_type) mp_cmyk_model)
        ∧ (mp→cur_exp.type ≠ mp_cmykcolor_type)) ∨ ((t ≡ (mp_variable_type) mp_rgb_model)
        ∧ (mp→cur_exp.type ≠ mp_color_type)) ∨ ((t ≡ (mp_variable_type) mp_grey_model)
        ∧ (mp→cur_exp.type ≠ mp_known)) ∨ ((t ≡ (mp_variable_type) mp_pen_type)
        ∧ (mp→cur_exp.type ≠ t)) ∨ ((t ≡ (mp_variable_type) mp_picture_type) ∧ (mp→cur_exp.type ≠ t));
  }

  static void complain_invalid_with_list(MP mp, mp_variable_type t)
  {     ▷ Complain about improper type ◁
    mp_value new_expr;
    const char *hlp[] ← {"Next␣time␣say␣`withpen␣<known␣pen␣expression>';",
        "I'll␣ignore␣the␣bad␣`with'␣clause␣and␣look␣for␣another.", Λ};
    memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n); mp_disp_err(mp, Λ);
    if (t ≡ with_mp_pre_script)
      hlp[0] ← "Next␣time␣say␣`withprescript␣<known␣string␣expression>';";
    else if (t ≡ with_mp_post_script)
      hlp[0] ← "Next␣time␣say␣`withpostscript␣<known␣string␣expression>';";
    else if (t ≡ mp_picture_type) hlp[0] ← "Next␣time␣say␣`dashed␣<known␣picture␣expression>';";
    else if (t ≡ (mp_variable_type) mp_uninitialized_model)
      hlp[0] ← "Next␣time␣say␣`withcolor␣<known␣color␣expression>';";
    else if (t ≡ (mp_variable_type) mp_rgb_model)
      hlp[0] ← "Next␣time␣say␣`withrgbcolor␣<known␣color␣expression>';";
```

```
    else if (t ≡ (mp_variable_type) mp_cmyk_model)
      hlp[0] ← "Next␣time␣say␣‘withcmykcolor␣<known␣cmykcolor␣expression>’;";
    else if (t ≡ (mp_variable_type) mp_grey_model)
      hlp[0] ← "Next␣time␣say␣‘withgreyscale␣<known␣numeric␣expression>’;";
    mp_back_error(mp, "Improper␣type", hlp, true); mp_get_x_next(mp);
    mp_flush_cur_exp(mp, new_expr);
  }
  void mp_scan_with_list(MP mp, mp_node p)
  {
    mp_variable_type t;   ▷ cur_mod of the with_option (should match cur_type) ◁
    mp_node q;   ▷ for list manipulation ◁
    mp_node cp, pp, dp, ap, bp;   ▷ objects being updated; void initially; Λ to suppress update ◁
    cp ← MP_VOID; pp ← MP_VOID; dp ← MP_VOID; ap ← MP_VOID; bp ← MP_VOID;
    while (cur_cmd() ≡ mp_with_option) {
        ▷ TODO: this is not very nice: the color models have their own enumeration ◁
      t ← (mp_variable_type) cur_mod(); mp_get_x_next(mp);
      if (t ≠ (mp_variable_type) mp_no_model) mp_scan_expression(mp);
      if (is_invalid_with_list(mp, t)) {
        complain_invalid_with_list(mp, t); continue;
      }
      if (t ≡ (mp_variable_type) mp_uninitialized_model) {
        mp_value new_expr;
        memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
        if (cp ≡ MP_VOID) make_cp_a_colored_object();
        if (cp ≠ Λ) {   ▷ Transfer a color from the current expression to object cp ◁
          if (mp→cur_exp.type ≡ mp_color_type) {
              ▷ Transfer a rgbcolor from the current expression to object cp ◁
            mp_stroked_node cp0 ← (mp_stroked_node) cp;
            q ← value_node(cur_exp_node()); clear_color(cp0); mp_color_model(cp) ← mp_rgb_model;
            set_color_val(cp0→red, value_number(red_part(q)));
            set_color_val(cp0→green, value_number(green_part(q)));
            set_color_val(cp0→blue, value_number(blue_part(q)));
          }
          else if (mp→cur_exp.type ≡ mp_cmykcolor_type) {
              ▷ Transfer a cmykcolor from the current expression to object cp ◁
            mp_stroked_node cp0 ← (mp_stroked_node) cp;
            q ← value_node(cur_exp_node()); set_color_val(cp0→cyan, value_number(cyan_part(q)));
            set_color_val(cp0→magenta, value_number(magenta_part(q)));
            set_color_val(cp0→yellow, value_number(yellow_part(q)));
            set_color_val(cp0→black, value_number(black_part(q)));
            mp_color_model(cp) ← mp_cmyk_model;
          }
          else if (mp→cur_exp.type ≡ mp_known) {
              ▷ Transfer a greyscale from the current expression to object cp ◁
            mp_number qq;
            mp_stroked_node cp0 ← (mp_stroked_node) cp;
            new_number(qq); number_clone(qq, cur_exp_value_number()); clear_color(cp);
            mp_color_model(cp) ← mp_grey_model; set_color_val(cp0→grey, qq); free_number(qq);
          }
          else if (cur_exp_value_boolean() ≡ mp_false_code) {
              ▷ Transfer a noncolor from the current expression to object cp ◁
```

```
        clear_color(cp); mp_color_model(cp) ← mp_no_model;
      }
      else if (cur_exp_value_boolean() ≡ mp_true_code) {
          ▷ Transfer no color from the current expression to object cp ◁
        clear_color(cp); mp_color_model(cp) ← mp_uninitialized_model;
      }
    }
    mp_flush_cur_exp(mp, new_expr);
  }
  else if (t ≡ (mp_variable_type) mp_rgb_model) {
    mp_value new_expr;
    memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
    if (cp ≡ MP_VOID) make_cp_a_colored_object();
    if (cp ≠ Λ) {    ▷ Transfer a rgbcolor from the current expression to object cp ◁
      mp_stroked_node cp0 ← (mp_stroked_node) cp;
      q ← value_node(cur_exp_node()); clear_color(cp0); mp_color_model(cp) ← mp_rgb_model;
      set_color_val(cp0→red, value_number(red_part(q)));
      set_color_val(cp0→green, value_number(green_part(q)));
      set_color_val(cp0→blue, value_number(blue_part(q)));
    }
    mp_flush_cur_exp(mp, new_expr);
  }
  else if (t ≡ (mp_variable_type) mp_cmyk_model) {
    mp_value new_expr;
    memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
    if (cp ≡ MP_VOID) make_cp_a_colored_object();
    if (cp ≠ Λ) {    ▷ Transfer a cmykcolor from the current expression to object cp ◁
      mp_stroked_node cp0 ← (mp_stroked_node) cp;
      q ← value_node(cur_exp_node()); set_color_val(cp0→cyan, value_number(cyan_part(q)));
      set_color_val(cp0→magenta, value_number(magenta_part(q)));
      set_color_val(cp0→yellow, value_number(yellow_part(q)));
      set_color_val(cp0→black, value_number(black_part(q)));
      mp_color_model(cp) ← mp_cmyk_model;
    }
    mp_flush_cur_exp(mp, new_expr);
  }
  else if (t ≡ (mp_variable_type) mp_grey_model) {
    mp_value new_expr;
    memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
    if (cp ≡ MP_VOID) make_cp_a_colored_object();
    if (cp ≠ Λ) {    ▷ Transfer a greyscale from the current expression to object cp ◁
      mp_number qq;
      mp_stroked_node cp0 ← (mp_stroked_node) cp;
      new_number(qq); number_clone(qq, cur_exp_value_number()); clear_color(cp);
      mp_color_model(cp) ← mp_grey_model; set_color_val(cp0→grey, qq); free_number(qq);
    }
    mp_flush_cur_exp(mp, new_expr);
  }
  else if (t ≡ (mp_variable_type) mp_no_model) {
    if (cp ≡ MP_VOID) make_cp_a_colored_object();
    if (cp ≠ Λ) {    ▷ Transfer a noncolor from the current expression to object cp ◁
```

```
        clear_color(cp); mp_color_model(cp) ← mp_no_model;
      }
    }
    else if (t ≡ mp_pen_type) {
      if (pp ≡ MP_VOID) {    ▷ Make pp an object in list p that needs a pen ◁
        pp ← p;
        while (pp ≠ Λ) {
          if (has_pen(pp)) break;
          pp ← mp_link(pp);
        }
      }
      if (pp ≠ Λ) {
        switch (mp_type(pp)) {
        case mp_fill_node_type:
          if (mp_pen_p((mp_fill_node) pp) ≠ Λ)
            mp_toss_knot_list(mp, mp_pen_p((mp_fill_node) pp));
          mp_pen_p((mp_fill_node) pp) ← cur_exp_knot(); break;
        case mp_stroked_node_type:
          if (mp_pen_p((mp_stroked_node) pp) ≠ Λ)
            mp_toss_knot_list(mp, mp_pen_p((mp_stroked_node) pp));
          mp_pen_p((mp_stroked_node) pp) ← cur_exp_knot(); break;
        default: assert(0); break;
        }
        mp→cur_exp.type ← mp_vacuous;
      }
    }
    else if (t ≡ with_mp_pre_script) {
      if (cur_exp_str()→len) {
        if (ap ≡ MP_VOID) ap ← p;
        while ((ap ≠ Λ) ∧ (¬has_color(ap))) ap ← mp_link(ap);
        if (ap ≠ Λ) {
          if (mp_pre_script(ap) ≠ Λ) {    ▷ build a new,combined string ◁
            unsigned old_setting;    ▷ saved selector setting ◁
            mp_string s;    ▷ for string cleanup after combining ◁

            s ← mp_pre_script(ap); old_setting ← mp→selector; mp→selector ← new_string;
            str_room(mp_pre_script(ap)→len + cur_exp_str()→len + 2); mp_print_str(mp, cur_exp_str());
            append_char(13);    ▷ a forced PostScript newline ◁
            mp_print_str(mp, mp_pre_script(ap)); mp_pre_script(ap) ← mp_make_string(mp);
            delete_str_ref(s); mp→selector ← old_setting;
          }
          else {
            mp_pre_script(ap) ← cur_exp_str();
          }
          add_str_ref(mp_pre_script(ap)); mp→cur_exp.type ← mp_vacuous;
        }
      }
    }
    else if (t ≡ with_mp_post_script) {
      if (cur_exp_str()→len) {
        if (bp ≡ MP_VOID) bp ← p;
        while ((bp ≠ Λ) ∧ (¬has_color(bp))) bp ← mp_link(bp);
        if (bp ≠ Λ) {
```

```
          if (mp_post_script(bp) ≠ Λ) {
            unsigned old_setting;    ▷ saved selector setting ◁
            mp_string s;    ▷ for string cleanup after combining ◁
            s ← mp_post_script(bp); old_setting ← mp→selector; mp→selector ← new_string;
            str_room(mp_post_script(bp)→len + cur_exp_str()→len + 2);
            mp_print_str(mp, mp_post_script(bp)); append_char(13);    ▷ a forced PostScript newline ◁
            mp_print_str(mp, cur_exp_str()); mp_post_script(bp) ← mp_make_string(mp);
            delete_str_ref(s); mp→selector ← old_setting;
          }
          else {
            mp_post_script(bp) ← cur_exp_str();
          }
          add_str_ref(mp_post_script(bp)); mp→cur_exp.type ← mp_vacuous;
        }
      }
    }
    else {
      if (dp ≡ MP_VOID) {    ▷ Make dp a stroked node in list p ◁
        dp ← p;
        while (dp ≠ Λ) {
          if (mp_type(dp) ≡ mp_stroked_node_type) break;
          dp ← mp_link(dp);
        }
      }
      if (dp ≠ Λ) {
        if (mp_dash_p(dp) ≠ Λ) delete_edge_ref(mp_dash_p(dp));
        mp_dash_p(dp) ← (mp_node) mp_make_dashes(mp, (mp_edge_header_node) cur_exp_node());
        set_number_to_unity(((mp_stroked_node) dp)→dash_scale); mp→cur_exp.type ← mp_vacuous;
      }
    }
  }    ▷ Copy the information from objects cp, pp, and dp into the rest of the list ◁
  if (cp > MP_VOID) {    ▷ Copy cp's color into the colored objects linked to cp ◁
    q ← mp_link(cp);
    while (q ≠ Λ) {
      if (has_color(q)) {
        mp_stroked_node q0 ← (mp_stroked_node) q;
        mp_stroked_node cp0 ← (mp_stroked_node) cp;
        number_clone(q0→red, cp0→red); number_clone(q0→green, cp0→green);
        number_clone(q0→blue, cp0→blue); number_clone(q0→black, cp0→black);
        mp_color_model(q) ← mp_color_model(cp);
      }
      q ← mp_link(q);
    }
  }
  if (pp > MP_VOID) {    ▷ Copy mp_pen_p(pp) into stroked and filled nodes linked to pp ◁
    q ← mp_link(pp);
    while (q ≠ Λ) {
      if (has_pen(q)) {
        switch (mp_type(q)) {
        case mp_fill_node_type:
          if (mp_pen_p((mp_fill_node) q) ≠ Λ) mp_toss_knot_list(mp, mp_pen_p((mp_fill_node) q));
          mp_pen_p((mp_fill_node) q) ← copy_pen(mp_pen_p((mp_fill_node) pp)); break;
```

case *mp_stroked_node_type*:
 if (*mp_pen_p*((**mp_stroked_node**) *q*) $\neq \Lambda$)
  mp_toss_knot_list(*mp*, *mp_pen_p*((**mp_stroked_node**) *q*));
 mp_pen_p((**mp_stroked_node**) *q*) ← *copy_pen*(*mp_pen_p*((**mp_stroked_node**) *pp*)); **break**;
default: *assert*(0); **break**;
}
}
q ← *mp_link*(q);
}
}
if (*dp* > `MP_VOID`) { ▷ Make stroked nodes linked to *dp* refer to *mp_dash_p*(*dp*) ◁
 q ← *mp_link*(*dp*);
 while ($q \neq \Lambda$) {
  if (*mp_type*(q) ≡ *mp_stroked_node_type*) {
   if (*mp_dash_p*(q) $\neq \Lambda$) *delete_edge_ref*(*mp_dash_p*(q));
   mp_dash_p(q) ← *mp_dash_p*(*dp*); *set_number_to_unity*(((**mp_stroked_node**) q)→*dash_scale*);
   if (*mp_dash_p*(q) $\neq \Lambda$) *add_edge_ref*(*mp_dash_p*(q));
  }
  q ← *mp_link*(q);
 }
}
}

1123. One of the things we need to do when we've parsed an **addto** or similar command is find the header of a supposed **picture** variable, given a token list for that variable. Since the edge structure is about to be updated, we use *private_edges* to make sure that this is possible.

⟨ Declare action procedures for use by *do_statement* 1050 ⟩ +≡
 static mp_edge_header_node *mp_find_edges_var*(**MP** *mp*, **mp_node** t);

1124. **mp_edge_header_node** *mp_find_edges_var*(**MP** *mp*, **mp_node** *t*)

```
{
  mp_node p;
  mp_edge_header_node cur_edges;    ▷ the return value ◁
  p ← mp_find_variable(mp, t);  cur_edges ← Λ;
  if (p ≡ Λ) {
    const char *hlp[] ← {"It␣seems␣you␣did␣a␣nasty␣thing---probably␣by␣accident,",
        "but␣nevertheless␣you␣nearly␣hornswoggled␣me...",
        "While␣I␣was␣evaluating␣the␣right-hand␣side␣of␣this",
        "command,␣something␣happened,␣and␣the␣left-hand␣side",
        "is␣no␣longer␣a␣variable!␣So␣I␣won't␣change␣anything.", Λ};
    char *msg ← mp_obliterated(mp, t);
    mp_back_error(mp, msg, hlp, true);  free(msg);  mp_get_x_next(mp);
  }
  else if (mp_type(p) ≠ mp_picture_type) {
    char msg[256];
    mp_string sname;
    int old_setting ← mp→selector;
    const char *hlp[] ← {"I␣was␣looking␣for␣a␣\"known\"␣picture␣variable.",
        "So␣I'll␣not␣change␣anything␣just␣now.", Λ};
    mp→selector ← new_string;  mp_show_token_list(mp, t, Λ, 1000, 0);  sname ← mp_make_string(mp);
    mp→selector ← old_setting;  mp_snprintf(msg, 256, "Variable␣%s␣is␣the␣wrong␣type(%s)",
        mp_str(mp, sname), mp_type_string(mp_type(p)));  delete_str_ref(sname);
    mp_back_error(mp, msg, hlp, true);  mp_get_x_next(mp);
  }
  else {
    set_value_node(p, (mp_node) mp_private_edges(mp, (mp_edge_header_node) value_node(p)));
    cur_edges ← (mp_edge_header_node) value_node(p);
  }
  mp_flush_node_list(mp, t);  return cur_edges;
}
```

1125. ⟨Put each of METAPOST's primitives into the hash table 204⟩ +≡

```
mp_primitive(mp, "clip", mp_bounds_command, mp_start_clip_node_type);
mp_primitive(mp, "setbounds", mp_bounds_command, mp_start_bounds_node_type);
```

1126. ⟨Cases of *print_cmd_mod* for symbolic printing of primitives 239⟩ +≡

```
case mp_bounds_command:
  if (m ≡ mp_start_clip_node_type) mp_print(mp, "clip");
  else mp_print(mp, "setbounds");
  break;
```

1127. The following function parses the beginning of an **addto** or **clip** command: it expects a variable name followed by a token with *cur_cmd* ← *sep* and then an expression. The function returns the token list for the variable and stores the command modifier for the separator token in the global variable *last_add_type*. We must be careful because this variable might get overwritten any time we call *get_x_next*.

⟨Global variables 18⟩ +≡

```
  quarterword last_add_type;    ▷ command modifier that identifies the last addto command ◁
```

1128. ⟨Declare action procedures for use by *do_statement* 1050⟩ +≡

```
  static mp_node mp_start_draw_cmd(MP mp, quarterword sep);
```

1129. **mp_node** *mp_start_draw_cmd*(**MP** *mp*, **quarterword** *sep*)

```
{
  mp_node lhv;    ▷ variable to add to left ◁
  quarterword add_type ← 0;    ▷ value to be returned in last_add_type ◁
  lhv ← Λ; mp_get_x_next(mp); mp→var_flag ← sep; mp_scan_primary(mp);
  if (mp→cur_exp.type ≠ mp_token_list) {    ▷ Abandon edges command because there's no variable ◁
    mp_value new_expr;
    const char *hlp[] ← {"At␣this␣point␣I␣needed␣to␣see␣the␣name␣of␣a␣picture␣variable.",
        "(Or␣perhaps␣you␣have␣indeed␣presented␣me␣with␣one;␣I␣might",
        "have␣missed␣it,␣if␣it␣wasn't␣followed␣by␣the␣proper␣token.)",
        "So␣I'll␣not␣change␣anything␣just␣now.", Λ};
    memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n); mp_disp_err(mp, Λ);
    set_number_to_zero(new_expr.data.n); mp_back_error(mp, "Not␣a␣suitable␣variable", hlp, true);
    mp_get_x_next(mp); mp_flush_cur_exp(mp, new_expr);
  }
  else {
    lhv ← cur_exp_node(); add_type ← (quarterword) cur_mod(); mp→cur_exp.type ← mp_vacuous;
    mp_get_x_next(mp); mp_scan_expression(mp);
  }
  mp→last_add_type ← add_type; return lhv;
}
```

1130. Here is an example of how to use *mp_start_draw_cmd*.

⟨ Declare action procedures for use by *do_statement* 1050 ⟩ +≡

```
  static void mp_do_bounds(MP mp);
```

1131. **void** *mp_do_bounds*(**MP** *mp*)

```
{
  mp_node lhv;   ▷ variable on left, the corresponding edge structure ◁
  mp_edge_header_node lhe;
  mp_node p;   ▷ for list manipulation ◁
  integer m;   ▷ initial value of cur_mod ◁
  m ← cur_mod(); lhv ← mp_start_draw_cmd(mp, mp_to_token);
  if (lhv ≠ Λ) {
    mp_value new_expr;
    memset(&new_expr, 0, sizeof(mp_value)); lhe ← mp_find_edges_var(mp, lhv);
    if (lhe ≡ Λ) {
      new_number(new_expr.data.n); set_number_to_zero(new_expr.data.n);
      mp_flush_cur_exp(mp, new_expr);
    }
    else if (mp→cur_exp.type ≠ mp_path_type) {
      const char *hlp[] ← {"This␣expression␣should␣have␣specified␣a␣known␣path.",
          "So␣I'll␣not␣change␣anything␣just␣now.", Λ};
      mp_disp_err(mp, Λ); new_number(new_expr.data.n); set_number_to_zero(new_expr.data.n);
      mp_back_error(mp, "Improper␣`clip'", hlp, true); mp_get_x_next(mp);
      mp_flush_cur_exp(mp, new_expr);
    }
    else if (mp_left_type(cur_exp_knot()) ≡ mp_endpoint) {   ▷ Complain about a non-cycle ◁
      const char *hlp[] ← {"That␣contour␣should␣have␣ended␣with␣`..cycle'␣or␣`&cycle'.",
          "So␣I'll␣not␣change␣anything␣just␣now.", Λ};
      mp_back_error(mp, "Not␣a␣cycle", hlp, true); mp_get_x_next(mp);
    }
    else {   ▷ Make cur_exp into a setbounds or clipping path and add it to lhe ◁
      p ← mp_new_bounds_node(mp, cur_exp_knot(), (quarterword) m);
      mp_link(p) ← mp_link(edge_list(lhe)); mp_link(edge_list(lhe)) ← p;
      if (obj_tail(lhe) ≡ edge_list(lhe)) obj_tail(lhe) ← p;
      if (m ≡ mp_start_clip_node_type) {
        p ← mp_new_bounds_node(mp, Λ, mp_stop_clip_node_type);
      }
      else if (m ≡ mp_start_bounds_node_type) {
        p ← mp_new_bounds_node(mp, Λ, mp_stop_bounds_node_type);
      }
      mp_link(obj_tail(lhe)) ← p; obj_tail(lhe) ← p; mp_init_bbox(mp, lhe);
    }
  }
}
```

1132. The *do_add_to* procedure is a little like *do_clip* but there are a lot more cases to deal with.

⟨ Declare action procedures for use by *do_statement* 1050 ⟩ +≡
  static void *mp_do_add_to*(**MP** *mp*);

1133. **void** *mp_do_add_to*(**MP** *mp*)

```
{
  mp_node lhv;
  mp_edge_header_node lhe;   ▷ variable on left, the corresponding edge structure ◁
  mp_node p;   ▷ the graphical object or list for scan_with_list to update ◁
  mp_edge_header_node e;   ▷ an edge structure to be merged ◁
  quarterword add_type;   ▷ also_code, contour_code, or double_path_code ◁
  lhv ← mp_start_draw_cmd(mp, mp_thing_to_add); add_type ← mp→last_add_type;
  if (lhv ≠ Λ) {
    if (add_type ≡ also_code) {   ▷ Make sure the current expression is a suitable picture and set e and p
          appropriately ◁   ▷ Setting p: ← Λ causes the ⟨with list⟩ to be ignored; setting e: ← Λ prevents
          anything from being added to lhe. ◁
      p ← Λ; e ← Λ;
      if (mp→cur_exp.type ≠ mp_picture_type) {
        mp_value new_expr;
        const char *hlp[] ← {"This␣expression␣should␣have␣specified␣a␣known␣picture.",
            "So␣I'll␣not␣change␣anything␣just␣now.", Λ};
        memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
        mp_disp_err(mp, Λ); set_number_to_zero(new_expr.data.n);
        mp_back_error(mp, "Improper␣`addto'", hlp, true); mp_get_x_next(mp);
        mp_flush_cur_exp(mp, new_expr);
      }
      else {
        e ← mp_private_edges(mp, (mp_edge_header_node) cur_exp_node());
        mp→cur_exp.type ← mp_vacuous; p ← mp_link(edge_list(e));
      }
    }
    else {   ▷ Create a graphical object p based on add_type and the current expression ◁
        ▷ In this case add_type <> also_code so setting p: ← Λ suppresses future attempts to add to the
          edge structure. ◁
      e ← Λ; p ← Λ;
      if (mp→cur_exp.type ≡ mp_pair_type) mp_pair_to_path(mp);
      if (mp→cur_exp.type ≠ mp_path_type) {
        mp_value new_expr;
        const char *hlp[] ← {"This␣expression␣should␣have␣specified␣a␣known␣path.",
            "So␣I'll␣not␣change␣anything␣just␣now.", Λ};
        memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
        mp_disp_err(mp, Λ); set_number_to_zero(new_expr.data.n);
        mp_back_error(mp, "Improper␣`addto'", hlp, true); mp_get_x_next(mp);
        mp_flush_cur_exp(mp, new_expr);
      }
      else if (add_type ≡ contour_code) {
        if (mp_left_type(cur_exp_knot()) ≡ mp_endpoint) {   ▷ Complain about a non-cycle ◁
          const char *hlp[] ← {"That␣contour␣should␣have␣ended␣with␣`..cycle'␣or␣`&cycle'.",
              "So␣I'll␣not␣change␣anything␣just␣now.", Λ};
          mp_back_error(mp, "Not␣a␣cycle", hlp, true); mp_get_x_next(mp);
        }
        else {
          p ← mp_new_fill_node(mp, cur_exp_knot()); mp→cur_exp.type ← mp_vacuous;
        }
      }
```

```
        else {
          p ← mp_new_stroked_node(mp, cur_exp_knot()); mp→cur_exp.type ← mp_vacuous;
        }
      }
      mp_scan_with_list(mp, p);    ▷ Use p, e, and add_type to augment lhv as requested ◁
      lhe ← mp_find_edges_var(mp, lhv);
      if (lhe ≡ Λ) {
        if ((e ≡ Λ) ∧ (p ≠ Λ)) e ← mp_toss_gr_object(mp, p);
        if (e ≠ Λ) delete_edge_ref(e);
      }
      else if (add_type ≡ also_code) {
        if (e ≠ Λ) {    ▷ Merge e into lhe and delete e ◁
          if (mp_link(edge_list(e)) ≠ Λ) {
            mp_link(obj_tail(lhe)) ← mp_link(edge_list(e)); obj_tail(lhe) ← obj_tail(e);
            obj_tail(e) ← edge_list(e); mp_link(edge_list(e)) ← Λ; mp_flush_dash_list(mp, lhe);
          }
          mp_toss_edges(mp, e);
        }
      }
      else if (p ≠ Λ) {
        mp_link(obj_tail(lhe)) ← p; obj_tail(lhe) ← p;
        if (add_type ≡ double_path_code) {
          if (mp_pen_p((mp_stroked_node) p) ≡ Λ) {
            mp_pen_p((mp_stroked_node) p) ← mp_get_pen_circle(mp, zero_t);
          }
        }
      }
    }
  }
}
```

1134. ⟨Declare action procedures for use by *do_statement* 1050⟩ +≡

```
⟨Declare the PostScript output procedures 1264⟩;
static void mp_do_ship_out(MP mp);
```

1135.

```
void mp_do_ship_out(MP mp)
{
  integer c;    ▷ the character code ◁
  mp_value new_expr;
  memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n); mp_get_x_next(mp);
  mp_scan_expression(mp);
  if (mp→cur_exp.type ≠ mp_picture_type) {
    ⟨Complain that it's not a known picture 1136⟩;
  }
  else {
    c ← round_unscaled(internal_value(mp_char_code)) % 256;
    if (c < 0) c ← c + 256;
    ⟨Store the width information for character code c 1169⟩;
    mp_ship_out(mp, cur_exp_node()); set_number_to_zero(new_expr.data.n);
    mp_flush_cur_exp(mp, new_expr);
  }
}
```

1136. ⟨ Complain that it's not a known picture 1136 ⟩ ≡

```
{
  const char *hlp[] ← {"I␣can␣only␣output␣known␣pictures.", Λ};
  mp_disp_err(mp, Λ); set_number_to_zero(new_expr.data.n);
  mp_back_error(mp, "Not␣a␣known␣picture", hlp, true); mp_get_x_next(mp);
  mp_flush_cur_exp(mp, new_expr);
}
```

This code is used in section 1135.

1137. The **everyjob** command simply assigns a nonzero value to the global variable *start_sym*.

⟨ Global variables 18 ⟩ +≡

```
mp_sym start_sym;    ▷ a symbolic token to insert at beginning of job ◁
```

1138. ⟨ Set initial values of key variables 42 ⟩ +≡

```
mp→start_sym ← Λ;
```

1139. Finally, we have only the "message" commands remaining.

```
#define message_code 0
#define err_message_code 1
#define err_help_code 2
#define filename_template_code 3
#define print_with_leading_zeroes(A, B)
        do {
          size_t g ← mp→cur_length;
          size_t f ← (size_t)(B);
          mp_print_int(mp, (A)); g ← mp→cur_length − g;
          if (f > g) {
            mp→cur_length ← mp→cur_length − g;
            while (f > g) {
              mp_print_char(mp, xord('0')); decr(f);
            }
            mp_print_int(mp, (A));
          }
          f ← 0;
        } while (0)
```

⟨ Put each of METAPOST's primitives into the hash table 204 ⟩ +≡

```
mp_primitive(mp, "message", mp_message_command, message_code);
mp_primitive(mp, "errmessage", mp_message_command, err_message_code);
mp_primitive(mp, "errhelp", mp_message_command, err_help_code);
mp_primitive(mp, "filenametemplate", mp_message_command, filename_template_code);
```

1140. ⟨ Cases of *print_cmd_mod* for symbolic printing of primitives 239 ⟩ +≡

```
case mp_message_command:
  if (m < err_message_code) mp_print(mp, "message");
  else if (m ≡ err_message_code) mp_print(mp, "errmessage");
  else if (m ≡ filename_template_code) mp_print(mp, "filenametemplate");
  else mp_print(mp, "errhelp");
  break;
```

1141. ⟨ Declare action procedures for use by *do_statement* 1050 ⟩ +≡
⟨ Declare a procedure called *no_string_err* 1144 ⟩;

```
static void mp_do_message(MP mp);
```

1142.

```
void mp_do_message(MP mp)
{
  int m;    ▷ the type of message ◁
  mp_value new_expr;

  m ← cur_mod(); memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
  mp_get_x_next(mp); mp_scan_expression(mp);
  if (mp→cur_exp.type ≠ mp_string_type)
    mp_no_string_err(mp, "A␣message␣should␣be␣a␣known␣string␣expression.");
  else {
    switch (m) {
    case message_code: mp_print_nl(mp, ""); mp_print_str(mp, cur_exp_str()); break;
    case err_message_code: ⟨ Print string cur_exp as an error message 1148 ⟩;
      break;
    case err_help_code: ⟨ Save string cur_exp as the err_help 1145 ⟩;
      break;
    case filename_template_code: ⟨ Save the filename template 1143 ⟩;
      break;
    }    ▷ there are no other cases ◁
  }
  set_number_to_zero(new_expr.data.n); mp_flush_cur_exp(mp, new_expr);
}
```

1143. ⟨ Save the filename template 1143 ⟩ ≡

```
{
  delete_str_ref(internal_string(mp_output_template));
  if (cur_exp_str()→len ≡ 0) {
    set_internal_string(mp_output_template, mp_rts(mp, "%j.%c"));
  }
  else {
    set_internal_string(mp_output_template, cur_exp_str());
    add_str_ref(internal_string(mp_output_template));
  }
}
```

This code is used in section 1142.

1144. ⟨ Declare a procedure called *no_string_err* 1144 ⟩ ≡

```
static void mp_no_string_err(MP mp, const char *s)
{
  const char *hlp[] ← {s, Λ};

  mp_disp_err(mp, Λ); mp_back_error(mp, "Not␣a␣string", hlp, true); mp_get_x_next(mp);
}
```

This code is used in section 1141.

1145. The global variable *err_help* is zero when the user has most recently given an empty help string, or if none has ever been given.

⟨ Save string *cur_exp* as the *err_help* 1145 ⟩ ≡
```
{
  if (mp→err_help ≠ Λ) delete_str_ref(mp→err_help);
  if (cur_exp_str()→len ≡ 0) mp→err_help ← Λ;
  else {
    mp→err_help ← cur_exp_str(); add_str_ref(mp→err_help);
  }
}
```
This code is used in section 1142.

1146. If **errmessage** occurs often in *mp_scroll_mode*, without user-defined **errhelp**, we don't want to give a long help message each time. So we give a verbose explanation only once.

⟨ Global variables 18 ⟩ +≡
```
boolean long_help_seen;    ▷ has the long \errmessage help been used? ◁
```

1147. ⟨ Set initial values of key variables 42 ⟩ +≡
```
mp→long_help_seen ← false;
```

1148. ⟨ Print string *cur_exp* as an error message 1148 ⟩ ≡
```
{
  char msg[256];
  mp_snprintf(msg, 256, "%s", mp_str(mp, cur_exp_str()));
  if (mp→err_help ≠ Λ) {
    mp→use_err_help ← true; mp_back_error(mp, msg, Λ, true);
  }
  else if (mp→long_help_seen) {
    const char *hlp[] ← {"(That␣was␣another␣‘errmessage’.)", Λ};
    mp_back_error(mp, msg, hlp, true);
  }
  else {
    const char *hlp[] ← {"This␣error␣message␣was␣generated␣by␣an␣‘errmessage’",
        "command,␣so␣I␣can\’t␣give␣any␣explicit␣help.",
        "Pretend␣that␣you’re␣Miss␣Marple:␣Examine␣all␣clues,",
        "and␣deduce␣the␣truth␣by␣inspired␣guesses.", Λ};
    if (mp→interaction < mp_error_stop_mode) mp→long_help_seen ← true;
    mp_back_error(mp, msg, hlp, true);
  }
  mp_get_x_next(mp); mp→use_err_help ← false;
}
```
This code is used in section 1142.

1149. ⟨ Declare action procedures for use by *do_statement* 1050 ⟩ +≡
```
static void mp_do_write(MP mp);
```

1150. **void** *mp_do_write*(**MP** *mp*)

```
{
  mp_string t;    ▷ the line of text to be written ◁
  write_index n, n0;    ▷ for searching wr_fname and wr_file arrays ◁
  unsigned old_setting;    ▷ for saving selector during output ◁
  mp_value new_expr;
  memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n); mp_get_x_next(mp);
  mp_scan_expression(mp);
  if (mp→cur_exp.type ≠ mp_string_type) {
    mp_no_string_err(mp, "The␣text␣to␣be␣written␣should␣be␣a␣known␣string␣expression");
  }
  else if (cur_cmd() ≠ mp_to_token) {
    const char *hlp[] ← {"A␣write␣command␣should␣end␣with␣‘to␣<filename>’", Λ};
    mp_back_error(mp, "Missing␣‘to’␣clause", hlp, true); mp_get_x_next(mp);
  }
  else {
    t ← cur_exp_str(); mp→cur_exp.type ← mp_vacuous; mp_get_x_next(mp); mp_scan_expression(mp);
    if (mp→cur_exp.type ≠ mp_string_type)
      mp_no_string_err(mp, "I␣can\'t␣write␣to␣that␣file␣name.␣␣It␣isn't␣a␣known␣string");
    else {
      ⟨Write t to the file named by cur_exp 1151⟩;
    }    ▷ delete_str_ref(t); ◁    ▷ TODO: is this right? ◁
  }
  set_number_to_zero(new_expr.data.n); mp_flush_cur_exp(mp, new_expr);
}
```

1151. ⟨Write t to the file named by *cur_exp* 1151⟩ ≡

```
{
  ⟨Find n where wr_fname[n] ← cur_exp and call open_write_file if cur_exp must be inserted 1152⟩;
  if (mp_str_vs_str(mp, t, mp→eof_line) ≡ 0) ⟨Record the end of file on wr_file[n] 1153⟩
  else {
    old_setting ← mp→selector; mp→selector ← n + write_file; mp_print_str(mp, t); mp_print_ln(mp);
    mp→selector ← old_setting;
  }
}
```

This code is used in section 1150.

1152. ⟨ Find n where *wr_fname*[n] ← *cur_exp* and call *open_write_file* if *cur_exp* must be inserted 1152 ⟩ ≡

```
{
  char *fn ← mp_str(mp, cur_exp_str());
  n ← mp→write_files;  n0 ← mp→write_files;
  while (mp_xstrcmp(fn, mp→wr_fname[n]) ≠ 0) {
    if (n ≡ 0) {    ▷ bottom reached ◁
      if (n0 ≡ mp→write_files) {
        if (mp→write_files < mp→max_write_files) {
          incr(mp→write_files);
        }
        else {
          void **wr_file;
          char **wr_fname;
          write_index l, k;
          l ← mp→max_write_files + (mp→max_write_files/4);
          wr_file ← xmalloc((l + 1), sizeof(void *));  wr_fname ← xmalloc((l + 1), sizeof(char *));
          for (k ← 0; k ≤ l; k++) {
            if (k ≤ mp→max_write_files) {
              wr_file[k] ← mp→wr_file[k];  wr_fname[k] ← mp→wr_fname[k];
            }
            else {
              wr_file[k] ← 0;  wr_fname[k] ← Λ;
            }
          }
          xfree(mp→wr_file);  xfree(mp→wr_fname);  mp→max_write_files ← l;  mp→wr_file ← wr_file;
          mp→wr_fname ← wr_fname;
        }
      }
      n ← n0;  mp_open_write_file(mp, fn, n);
    }
    else {
      decr(n);
      if (mp→wr_fname[n] ≡ Λ) n0 ← n;
    }
  }
}
```

This code is used in section 1151.

1153. ⟨ Record the end of file on *wr_file*[n] 1153 ⟩ ≡

```
{
  (mp→close_file)(mp, mp→wr_file[n]);  xfree(mp→wr_fname[n]);
  if (n ≡ mp→write_files − 1) mp→write_files ← n;
}
```

This code is used in section 1151.

1154. Writing font metric data. TeX gets its knowledge about fonts from font metric files, also called `TFM` files; the '`T`' in '`TFM`' stands for TeX, but other programs know about them too. One of METAPOST's duties is to write `TFM` files so that the user's fonts can readily be applied to typesetting.

The information in a `TFM` file appears in a sequence of 8-bit bytes. Since the number of bytes is always a multiple of 4, we could also regard the file as a sequence of 32-bit words, but METAPOST uses the byte interpretation. The format of `TFM` files was designed by Lyle Ramshaw in 1980. The intent is to convey a lot of different kinds of information in a compact but useful form.

⟨ Global variables 18 ⟩ +≡
  void *$*tfm\_file$*; ▷ the font metric output goes here ◁
  char *$*metric\_file\_name$*; ▷ full name of the font metric file ◁

1155. The first 24 bytes (6 words) of a `TFM` file contain twelve 16-bit integers that give the lengths of the various subsequent portions of the file. These twelve integers are, in order:

$$\begin{aligned}
lf &= \text{length of the entire file, in words;}\\
lh &= \text{length of the header data, in words;}\\
bc &= \text{smallest character code in the font;}\\
ec &= \text{largest character code in the font;}\\
nw &= \text{number of words in the width table;}\\
nh &= \text{number of words in the height table;}\\
nd &= \text{number of words in the depth table;}\\
ni &= \text{number of words in the italic correction table;}\\
nl &= \text{number of words in the lig/kern table;}\\
nk &= \text{number of words in the kern table;}\\
ne &= \text{number of words in the extensible character table;}\\
np &= \text{number of font parameter words.}
\end{aligned}$$

They are all nonnegative and less than 2^{15}. We must have $bc - 1 \le ec \le 255$, $ne \le 256$, and

$$lf \leftarrow 6 + lh + (ec - bc + 1) + nw + nh + nd + ni + nl + nk + ne + np.$$

Note that a font may contain as many as 256 characters (if $bc \leftarrow 0$ and $ec \leftarrow 255$), and as few as 0 characters (if $bc \leftarrow ec + 1$).

Incidentally, when two or more 8-bit bytes are combined to form an integer of 16 or more bits, the most significant bytes appear first in the file. This is called BigEndian order.

1156. The rest of the `TFM` file may be regarded as a sequence of ten data arrays.

The most important data type used here is a *fix_word*, which is a 32-bit representation of a binary fraction. A *fix_word* is a signed quantity, with the two's complement of the entire word used to represent negation. Of the 32 bits in a *fix_word*, exactly 12 are to the left of the binary point; thus, the largest *fix_word* value is $2048 - 2^{-20}$, and the smallest is -2048. We will see below, however, that all but two of the *fix_word* values must lie between -16 and $+16$.

1157. The first data array is a block of header information, which contains general facts about the font. The header must contain at least two words, *header*[0] and *header*[1], whose meaning is explained below. Additional header information of use to other software routines might also be included, and METAPOST will generate it if the `headerbyte` command occurs. For example, 16 more words of header information are in use at the Xerox Palo Alto Research Center; the first ten specify the character coding scheme used (e.g., '`XEROX TEXT`' or '`TEX MATHSY`'), the next five give the font family name (e.g., '`HELVETICA`' or '`CMSY`'), and the last gives the "face byte."

header[0] is a 32-bit check sum that METAPOST will copy into the `GF` output file. This helps ensure consistency between files, since TEX records the check sums from the `TFM`'s it reads, and these should match the check sums on actual fonts that are used. The actual relation between this check sum and the rest of the `TFM` file is not important; the check sum is simply an identification number with the property that incompatible fonts almost always have distinct check sums.

header[1] is a *fix_word* containing the design size of the font, in units of TEX points. This number must be at least 1.0; it is fairly arbitrary, but usually the design size is 10.0 for a "10 point" font, i.e., a font that was designed to look best at a 10-point size, whatever that really means. When a TEX user asks for a font '`at` δ `pt`', the effect is to override the design size and replace it by δ, and to multiply the x and y coordinates of the points in the font image by a factor of δ divided by the design size. *All other dimensions in the* `TFM` *file are fix_word numbers in design-size units.* Thus, for example, the value of *param*[6], which defines the `em` unit, is often the *fix_word* value $2^{20} = 1.0$, since many fonts have a design size equal to one em. The other dimensions must be less than 16 design-size units in absolute value; thus, *header*[1] and *param*[1] are the only *fix_word* entries in the whole `TFM` file whose first byte might be something besides 0 or 255.

1158. Next comes the *char_info* array, which contains one *char_info_word* per character. Each word in this part of the file contains six fields packed into four bytes as follows.

first byte: *width_index* (8 bits)
second byte: *height_index* (4 bits) times 16, plus *depth_index* (4 bits)
third byte: *italic_index* (6 bits) times 4, plus *tag* (2 bits)
fourth byte: *remainder* (8 bits)

The actual width of a character is *width*[*width_index*], in design-size units; this is a device for compressing information, since many characters have the same width. Since it is quite common for many characters to have the same height, depth, or italic correction, the `TFM` format imposes a limit of 16 different heights, 16 different depths, and 64 different italic corrections.

Incidentally, the relation $width[0] = height[0] = depth[0] = italic[0] = 0$ should always hold, so that an index of zero implies a value of zero. The *width_index* should never be zero unless the character does not exist in the font, since a character is valid if and only if it lies between *bc* and *ec* and has a nonzero *width_index*.

1159. The *tag* field in a *char_info_word* has four values that explain how to interpret the *remainder* field.

tag ← 0 (*no_tag*) means that *remainder* is unused.
tag ← 1 (*lig_tag*) means that this character has a ligature/kerning program starting at location *remainder* in the *lig_kern* array.
tag ← 2 (*list_tag*) means that this character is part of a chain of characters of ascending sizes, and not the largest in the chain. The *remainder* field gives the character code of the next larger character.
tag ← 3 (*ext_tag*) means that this character code represents an extensible character, i.e., a character that is built up of smaller pieces so that it can be made arbitrarily large. The pieces are specified in *exten*[*remainder*].

Characters with *tag* ← 2 and *tag* ← 3 are treated as characters with *tag* ← 0 unless they are used in special circumstances in math formulas. For example, TEX's `\sum` operation looks for a *list_tag*, and the `\left` operation looks for both *list_tag* and *ext_tag*.

#**define** *no_tag* 0 ▷ vanilla character ◁
#**define** *lig_tag* 1 ▷ character has a ligature/kerning program ◁
#**define** *list_tag* 2 ▷ character has a successor in a charlist ◁
#**define** *ext_tag* 3 ▷ character is extensible ◁

1160. The *lig_kern* array contains instructions in a simple programming language that explains what to do for special letter pairs. Each word in this array is a *lig_kern_command* of four bytes.

first byte: *skip_byte*, indicates that this is the final program step if the byte is 128 or more, otherwise the next step is obtained by skipping this number of intervening steps.
second byte: *next_char*, "if *next_char* follows the current character, then perform the operation and stop, otherwise continue."
third byte: *op_byte*, indicates a ligature step if less than 128, a kern step otherwise.
fourth byte: *remainder*.

In a kern step, an additional space equal to $kern[256 * (op\_byte - 128) + remainder]$ is inserted between the current character and *next_char*. This amount is often negative, so that the characters are brought closer together by kerning; but it might be positive.

There are eight kinds of ligature steps, having *op_byte* codes $4a+2b+c$ where $0 \le a \le b+c$ and $0 \le b, c \le 1$. The character whose code is *remainder* is inserted between the current character and *next_char*; then the current character is deleted if $b = 0$, and *next_char* is deleted if $c = 0$; then we pass over a characters to reach the next current character (which may have a ligature/kerning program of its own).

If the very first instruction of the *lig_kern* array has $skip\_byte \leftarrow 255$, the *next_char* byte is the so-called right boundary character of this font; the value of *next_char* need not lie between *bc* and *ec*. If the very last instruction of the *lig_kern* array has $skip\_byte \leftarrow 255$, there is a special ligature/kerning program for a left boundary character, beginning at location $256 * op\_byte + remainder$. The interpretation is that TeX puts implicit boundary characters before and after each consecutive string of characters from the same font. These implicit characters do not appear in the output, but they can affect ligatures and kerning.

If the very first instruction of a character's *lig_kern* program has $skip\_byte > 128$, the program actually begins in location $256 * op\_byte + remainder$. This feature allows access to large *lig_kern* arrays, because the first instruction must otherwise appear in a location ≤ 255.

Any instruction with $skip\_byte > 128$ in the *lig_kern* array must satisfy the condition

$$256 * op\_byte + remainder < nl.$$

If such an instruction is encountered during normal program execution, it denotes an unconditional halt; no ligature command is performed.

#define *stop_flag* (128) ▷ value indicating 'STOP' in a lig/kern program ◁
#define *kern_flag* (128) ▷ op code for a kern step ◁
#define *skip_byte*(*A*) *mp*→*lig_kern*[(*A*)].*b0*
#define *next_char*(*A*) *mp*→*lig_kern*[(*A*)].*b1*
#define *op_byte*(*A*) *mp*→*lig_kern*[(*A*)].*b2*
#define *rem_byte*(*A*) *mp*→*lig_kern*[(*A*)].*b3*

1161. Extensible characters are specified by an *extensible_recipe*, which consists of four bytes called *top*, *mid*, *bot*, and *rep* (in this order). These bytes are the character codes of individual pieces used to build up a large symbol. If *top*, *mid*, or *bot* are zero, they are not present in the built-up result. For example, an extensible vertical line is like an extensible bracket, except that the top and bottom pieces are missing.

Let T, M, B, and R denote the respective pieces, or an empty box if the piece isn't present. Then the extensible characters have the form TR^kMR^kB from top to bottom, for some $k \ge 0$, unless M is absent; in the latter case we can have TR^kB for both even and odd values of k. The width of the extensible character is the width of R; and the height-plus-depth is the sum of the individual height-plus-depths of the components used, since the pieces are butted together in a vertical list.

#define *ext_top*(*A*) *mp*→*exten*[(*A*)].*b0* ▷ *top* piece in a recipe ◁
#define *ext_mid*(*A*) *mp*→*exten*[(*A*)].*b1* ▷ *mid* piece in a recipe ◁
#define *ext_bot*(*A*) *mp*→*exten*[(*A*)].*b2* ▷ *bot* piece in a recipe ◁
#define *ext_rep*(*A*) *mp*→*exten*[(*A*)].*b3* ▷ *rep* piece in a recipe ◁

1162. The final portion of a TFM file is the *param* array, which is another sequence of *fix_word* values.

param[1] $\leftarrow$ *slant* is the amount of italic slant, which is used to help position accents. For example, *slant* $\leftarrow$ .25 means that when you go up one unit, you also go .25 units to the right. The *slant* is a pure number; it is the only *fix_word* other than the design size itself that is not scaled by the design size.

param[2] $\leftarrow$ *space* is the normal spacing between words in text. Note that character 040 in the font need not have anything to do with blank spaces.

param[3] $\leftarrow$ *space_stretch* is the amount of glue stretching between words.

param[4] $\leftarrow$ *space_shrink* is the amount of glue shrinking between words.

param[5] $\leftarrow$ *x_height* is the size of one ex in the font; it is also the height of letters for which accents don't have to be raised or lowered.

param[6] $\leftarrow$ *quad* is the size of one em in the font.

param[7] $\leftarrow$ *extra_space* is the amount added to *param*[2] at the ends of sentences.

If fewer than seven parameters are present, TEX sets the missing parameters to zero.

#**define** *slant_code* 1
#**define** *space_code* 2
#**define** *space_stretch_code* 3
#**define** *space_shrink_code* 4
#**define** *x_height_code* 5
#**define** *quad_code* 6
#**define** *extra_space_code* 7

1163. So that is what TFM files hold. One of METAPOST's duties is to output such information, and it does this all at once at the end of a job. In order to prepare for such frenetic activity, it squirrels away the necessary facts in various arrays as information becomes available.

Character dimensions (**charwd**, **charht**, **chardp**, and **charic**) are stored respectively in *tfm_width*, *tfm_height*, *tfm_depth*, and *tfm_ital_corr*. Other information about a character (e.g., about its ligatures or successors) is accessible via the *char_tag* and *char_remainder* arrays. Other information about the font as a whole is kept in additional arrays called *header_byte*, *lig_kern*, *kern*, *exten*, and *param*.

#define *max_tfm_int* 32510
#define *undefined_label* *max_tfm_int* ▷ an undefined local label ◁

⟨ Global variables 18 ⟩ +≡
#define TFM_ITEMS 257
  eight_bits *bc*;
  eight_bits *ec*; ▷ smallest and largest character codes shipped out ◁
  mp_node *tfm_width*[TFM_ITEMS]; ▷ **charwd** values ◁
  mp_node *tfm_height*[TFM_ITEMS]; ▷ **charht** values ◁
  mp_node *tfm_depth*[TFM_ITEMS]; ▷ **chardp** values ◁
  mp_node *tfm_ital_corr*[TFM_ITEMS]; ▷ **charic** values ◁
  boolean *char_exists*[TFM_ITEMS]; ▷ has this code been shipped out? ◁
  int *char_tag*[TFM_ITEMS]; ▷ *remainder* category ◁
  int *char_remainder*[TFM_ITEMS]; ▷ the *remainder* byte ◁
  char **header_byte*; ▷ bytes of the TFM header ◁
  int *header_last*; ▷ last initialized TFM header byte ◁
  int *header_size*; ▷ size of the TFM header ◁
  four_quarters **lig_kern*; ▷ the ligature/kern table ◁
  short *nl*; ▷ the number of ligature/kern steps so far ◁
  mp_number **kern*; ▷ distinct kerning amounts ◁
  short *nk*; ▷ the number of distinct kerns so far ◁
  four_quarters *exten*[TFM_ITEMS]; ▷ extensible character recipes ◁
  short *ne*; ▷ the number of extensible characters so far ◁
  mp_number **param*; ▷ **fontinfo** parameters ◁
  short *np*; ▷ the largest **fontinfo** parameter specified so far ◁
  short *nw*;
  short *nh*;
  short *nd*;
  short *ni*; ▷ sizes of TFM subtables ◁
  short *skip_table*[TFM_ITEMS]; ▷ local label status ◁
  boolean *lk_started*; ▷ has there been a lig/kern step in this command yet? ◁
  integer *bchar*; ▷ right boundary character ◁
  short *bch_label*; ▷ left boundary starting location ◁
  short *ll*;
  short *lll*; ▷ registers used for lig/kern processing ◁
  short *label_loc*[257]; ▷ lig/kern starting addresses ◁
  eight_bits *label_char*[257]; ▷ characters for *label_loc* ◁
  short *label_ptr*; ▷ highest position occupied in *label_loc* ◁

1164. ⟨ Allocate or initialize variables 32 ⟩ +≡
  mp→header_last ← 7; *mp→header_size* ← 128; ▷ just for init ◁
  mp→header_byte ← *xmalloc*(*mp→header_size*, **sizeof**(**char**));

1165. ⟨Dealloc variables 31⟩ +≡

$xfree(mp\rightarrow header\_byte)$; $xfree(mp\rightarrow lig\_kern)$;
if $(mp\rightarrow kern)$ {
  int i;
  for $(i \leftarrow 0;\ i < (max\_tfm\_int + 1);\ i{+}{+})$ {
    $free\_number(mp\rightarrow kern[i])$;
  }
  $xfree(mp\rightarrow kern)$;
}
if $(mp\rightarrow param)$ {
  int i;
  for $(i \leftarrow 0;\ i < (max\_tfm\_int + 1);\ i{+}{+})$ {
    $free\_number(mp\rightarrow param[i])$;
  }
  $xfree(mp\rightarrow param)$;
}

1166. ⟨Set initial values of key variables 42⟩ +≡

for $(k \leftarrow 0;\ k \le 255;\ k{+}{+})$ {
  $mp\rightarrow tfm\_width[k] \leftarrow 0$; $mp\rightarrow tfm\_height[k] \leftarrow 0$; $mp\rightarrow tfm\_depth[k] \leftarrow 0$; $mp\rightarrow tfm\_ital\_corr[k] \leftarrow 0$;
  $mp\rightarrow char\_exists[k] \leftarrow false$; $mp\rightarrow char\_tag[k] \leftarrow no\_tag$; $mp\rightarrow char\_remainder[k] \leftarrow 0$;
  $mp\rightarrow skip\_table[k] \leftarrow undefined\_label$;
}
$memset(mp\rightarrow header\_byte, 0, (\mathbf{size\_t})\, mp\rightarrow header\_size)$; $mp\rightarrow bc \leftarrow 255$; $mp\rightarrow ec \leftarrow 0$; $mp\rightarrow nl \leftarrow 0$;
$mp\rightarrow nk \leftarrow 0$; $mp\rightarrow ne \leftarrow 0$; $mp\rightarrow np \leftarrow 0$; $set\_internal\_from\_number(mp\_boundary\_char, unity\_t)$;
$number\_negate(internal\_value(mp\_boundary\_char))$; $mp\rightarrow bch\_label \leftarrow undefined\_label$;
$mp\rightarrow label\_loc[0] \leftarrow -1$; $mp\rightarrow label\_ptr \leftarrow 0$;

1167. ⟨Declarations 10⟩ +≡

static mp_node $mp\_tfm\_check(\mathbf{MP}\ mp, \mathbf{quarterword}\ m)$;

1168. **static mp_node** *mp_tfm_check*(**MP** *mp*, **quarterword** *m*)

```
{
  mp_number absm;
  mp_node p ← mp_get_value_node(mp);
  new_number(absm); number_clone(absm, internal_value(m)); number_abs(absm);
  if (number_greaterequal(absm, fraction_half_t)) {
    char msg[256];
    const char *hlp[] ← {"Font metric dimensions must be less than 2048pt.", Λ};
    mp_snprintf(msg, 256, "Enormous %s has been reduced", internal_name(m));
    mp_back_error(mp, msg, hlp, true); mp_get_x_next(mp);
    if (number_positive(internal_value(m))) {
      set_value_number(p, fraction_half_t); number_add_scaled(value_number(p), −1);
    }
    else {
      set_value_number(p, fraction_half_t); number_negate(value_number(p));
      number_add_scaled(value_number(p), 1);
    }
  }
  else {
    set_value_number(p, internal_value(m));
  }
  free_number(absm); return p;
}
```

1169. ⟨ Store the width information for character code *c* 1169 ⟩ ≡

```
if (c < mp→bc) mp→bc ← (eight_bits) c;
if (c > mp→ec) mp→ec ← (eight_bits) c;
mp→char_exists[c] ← true; mp_free_value_node(mp, mp→tfm_width[c]);
mp→tfm_width[c] ← mp_tfm_check(mp, mp_char_wd); mp_free_value_node(mp, mp→tfm_height[c]);
mp→tfm_height[c] ← mp_tfm_check(mp, mp_char_ht); mp_free_value_node(mp, mp→tfm_depth[c]);
mp→tfm_depth[c] ← mp_tfm_check(mp, mp_char_dp); mp_free_value_node(mp, mp→tfm_ital_corr[c]);
mp→tfm_ital_corr[c] ← mp_tfm_check(mp, mp_char_ic)
```

This code is used in section 1135.

1170. Now let's consider METAPOST's special TFM-oriented commands.

```
#define char_list_code 0
#define lig_table_code 1
#define extensible_code 2
#define header_byte_code 3
#define font_dimen_code 4
```

⟨ Put each of METAPOST's primitives into the hash table 204 ⟩ +≡

```
mp_primitive(mp, "charlist", mp_tfm_command, char_list_code);
mp_primitive(mp, "ligtable", mp_tfm_command, lig_table_code);
mp_primitive(mp, "extensible", mp_tfm_command, extensible_code);
mp_primitive(mp, "headerbyte", mp_tfm_command, header_byte_code);
mp_primitive(mp, "fontdimen", mp_tfm_command, font_dimen_code);
```

1171. ⟨ Cases of *print_cmd_mod* for symbolic printing of primitives 239 ⟩ +≡

```
case mp_tfm_command:
  switch (m) {
  case char_list_code: mp_print(mp, "charlist"); break;
  case lig_table_code: mp_print(mp, "ligtable"); break;
  case extensible_code: mp_print(mp, "extensible"); break;
  case header_byte_code: mp_print(mp, "headerbyte"); break;
  default: mp_print(mp, "fontdimen"); break;
  }
  break;
```

1172. ⟨ Declare action procedures for use by *do_statement* 1050 ⟩ +≡

```
  static eight_bits mp_get_code(MP mp);
```

1173.

```
eight_bits mp_get_code(MP mp)
  {    ▷ scans a character code value ◁
    integer c;    ▷ the code value found ◁
    mp_value new_expr;
    const char *hlp[] ← {"I␣was␣looking␣for␣a␣number␣between␣0␣and␣255,␣or␣for␣a",
        "string␣of␣length␣1.␣Didn't␣find␣it;␣will␣use␣0␣instead.", Λ};
    memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n); mp_get_x_next(mp);
    mp_scan_expression(mp);
    if (mp→cur_exp.type ≡ mp_known) {
      c ← round_unscaled(cur_exp_value_number());
      if (c ≥ 0)
        if (c < 256) return (eight_bits) c;
    }
    else if (mp→cur_exp.type ≡ mp_string_type) {
      if (cur_exp_str()→len ≡ 1) {
        c ← (integer)(*(cur_exp_str()→str)); return (eight_bits) c;
      }
    }
    mp_disp_err(mp, Λ); set_number_to_zero(new_expr.data.n);
    mp_back_error(mp, "Invalid␣code␣has␣been␣replaced␣by␣0", hlp, true); mp_get_x_next(mp);
    mp_flush_cur_exp(mp, new_expr); c ← 0; return (eight_bits) c;
  }
```

1174. ⟨ Declare action procedures for use by *do_statement* 1050 ⟩ +≡

```
  static void mp_set_tag(MP mp, halfword c, quarterword t, halfword r);
```

1175.

```
void mp_set_tag(MP mp, halfword c, quarterword t, halfword r)
  {
    if (mp→char_tag[c] ≡ no_tag) {
      mp→char_tag[c] ← t; mp→char_remainder[c] ← r;
      if (t ≡ lig_tag) {
        mp→label_ptr++; mp→label_loc[mp→label_ptr] ← (short) r;
        mp→label_char[mp→label_ptr] ← (eight_bits) c;
      }
    }
    else ⟨ Complain about a character tag conflict 1176 ⟩
  }
```

1176. ⟨ Complain about a character tag conflict 1176 ⟩ ≡

```
{
  const char *xtra ← Λ;
  char msg[256];
  const char *hlp[] ← {"It's␣not␣legal␣to␣label␣a␣character␣more␣than␣once.",
      "So␣I'll␣not␣change␣anything␣just␣now.", Λ};
  switch (mp→char_tag[c]) {
  case lig_tag: xtra ← "in␣a␣ligtable"; break;
  case list_tag: xtra ← "in␣a␣charlist"; break;
  case ext_tag: xtra ← "extensible"; break;
  default: xtra ← ""; break;
  }
  if ((c > '␣') ∧ (c < 127)) {
    mp_snprintf(msg, 256, "Character␣%c␣is␣already␣%s", xord(c), xtra);
  }
  else if (c ≡ 256) {
    mp_snprintf(msg, 256, "Character␣||␣is␣already␣%s", xtra);
  }
  else {
    mp_snprintf(msg, 256, "Character␣code␣%d␣is␣already␣%s", c, xtra);
  }
  mp_back_error(mp, msg, hlp, true); mp_get_x_next(mp);
}
```

This code is used in section 1175.

1177. ⟨ Declare action procedures for use by *do_statement* 1050 ⟩ +≡

```
static void mp_do_tfm_command(MP mp);
```

1178.
```
void mp_do_tfm_command(MP mp)
{
  int c, cc;   ▷ character codes ◁
  int k;   ▷ index into the kern array ◁
  int j;   ▷ index into header_byte or param ◁
  mp_value new_expr;

  memset(&new_expr, 0, sizeof(mp_value)); new_number(new_expr.data.n);
  switch (cur_mod()) {
  case char_list_code: c ← mp_get_code(mp);   ▷ we will store a list of character successors ◁
    while (cur_cmd() ≡ mp_colon) {
      cc ← mp_get_code(mp); mp_set_tag(mp, c, list_tag, cc); c ← cc;
    }
    break;
  case lig_table_code:
    if (mp→lig_kern ≡ Λ) mp→lig_kern ← xmalloc((max_tfm_int + 1), sizeof(four_quarters));
    if (mp→kern ≡ Λ) {
      int i;

      mp→kern ← xmalloc((max_tfm_int + 1), sizeof(mp_number));
      for (i ← 0; i < (max_tfm_int + 1); i++) new_number(mp→kern[i]);
    }
    ⟨Store a list of ligature/kern steps 1179⟩;
    break;
  case extensible_code: ⟨Define an extensible recipe 1185⟩;
    break;
  case header_byte_code: case font_dimen_code: c ← cur_mod(); mp_get_x_next(mp);
    mp_scan_expression(mp);
    if ((mp→cur_exp.type ≠ mp_known) ∨ number_less(cur_exp_value_number(), half_unit_t)) {
      const char *hlp[] ← {"I␣was␣looking␣for␣a␣known,␣positive␣number.",
          "For␣safety's␣sake␣I'll␣ignore␣the␣present␣command.", Λ};

      mp_disp_err(mp, Λ); mp_back_error(mp, "Improper␣location", hlp, true); mp_get_x_next(mp);
    }
    else {
      j ← round_unscaled(cur_exp_value_number());
      if (cur_cmd() ≠ mp_colon) {
        const char *hlp[] ← {"A␣colon␣should␣follow␣a␣headerbyte␣or␣fontinfo␣location.", Λ};

        mp_back_error(mp, "Missing␣`:'␣has␣been␣inserted", hlp, true);
      }
      if (c ≡ header_byte_code) ⟨Store a list of header bytes 1186⟩
      else {
        if (mp→param ≡ Λ) {
          int i;

          mp→param ← xmalloc((max_tfm_int + 1), sizeof(mp_number));
          for (i ← 0; i < (max_tfm_int + 1); i++) new_number(mp→param[i]);
        }
        ⟨Store a list of font dimensions 1187⟩;
      }
    }
    break;
  }   ▷ there are no other cases ◁
}
```

1179. ⟨Store a list of ligature/kern steps 1179⟩ ≡

```
{
  mp→lk_started ← false;
CONTINUE: mp_get_x_next(mp);
  if ((cur_cmd() ≡ mp_skip_to) ∧ mp→lk_started) ⟨Process a skip_to command and goto done 1182⟩;
  if (cur_cmd() ≡ mp_bchar_label) {
    c ← 256; set_cur_cmd((mp_variable_type) mp_colon);
  }
  else {
    mp_back_input(mp); c ← mp_get_code(mp);
  }
  if ((cur_cmd() ≡ mp_colon) ∨ (cur_cmd() ≡ mp_double_colon))
    ⟨Record a label in a lig/kern subprogram and goto continue 1183⟩
  if (cur_cmd() ≡ mp_lig_kern_token) ⟨Compile a ligature/kern command 1184⟩
  else {
    const char *hlp[] ← {"I␣was␣looking␣for␣`=:'␣or␣`kern'␣here.", Λ};
    mp_back_error(mp, "Illegal␣ligtable␣step", hlp, true); next_char(mp→nl) ← qi(0);
    op_byte(mp→nl) ← qi(0); rem_byte(mp→nl) ← qi(0); skip_byte(mp→nl) ← stop_flag + 1;
      ▷ this specifies an unconditional stop ◁
  }
  if (mp→nl ≡ max_tfm_int) mp_fatal_error(mp, "ligtable␣too␣large");
  mp→nl++;
  if (cur_cmd() ≡ mp_comma) goto CONTINUE;
  if (skip_byte(mp→nl − 1) < stop_flag) skip_byte(mp→nl − 1) ← stop_flag;
}
DONE:
```

This code is used in section 1178.

1180. ⟨Put each of METAPOST's primitives into the hash table 204⟩ +≡

```
mp_primitive(mp, "=:", mp_lig_kern_token, 0); mp_primitive(mp, "=:|", mp_lig_kern_token, 1);
mp_primitive(mp, "=:|>", mp_lig_kern_token, 5); mp_primitive(mp, "|=:", mp_lig_kern_token, 2);
mp_primitive(mp, "|=:>", mp_lig_kern_token, 6); mp_primitive(mp, "|=:|", mp_lig_kern_token, 3);
mp_primitive(mp, "|=:|>", mp_lig_kern_token, 7); mp_primitive(mp, "|=:|>>", mp_lig_kern_token, 11);
mp_primitive(mp, "kern", mp_lig_kern_token, mp_kern_flag);
```

1181. ⟨Cases of *print_cmd_mod* for symbolic printing of primitives 239⟩ +≡

```
case mp_lig_kern_token:
  switch (m) {
  case 0: mp_print(mp, "=:"); break;
  case 1: mp_print(mp, "=:|"); break;
  case 2: mp_print(mp, "|=:"); break;
  case 3: mp_print(mp, "|=:|"); break;
  case 5: mp_print(mp, "=:|>"); break;
  case 6: mp_print(mp, "|=:>"); break;
  case 7: mp_print(mp, "|=:|>"); break;
  case 11: mp_print(mp, "|=:|>>"); break;
  default: mp_print(mp, "kern"); break;
  }
  break;
```

1182. Local labels are implemented by maintaining the *skip_table* array, where *skip_table*[*c*] is either *undefined_label* or the address of the most recent lig/kern instruction that skips to local label *c*. In the latter case, the *skip_byte* in that instruction will (temporarily) be zero if there were no prior skips to this label, or it will be the distance to the prior skip.

We may need to cancel skips that span more than 127 lig/kern steps.

```
#define cancel_skips(A)  mp→ll ← (A);
    do {
      mp→lll ← qo(skip_byte(mp→ll)); skip_byte(mp→ll) ← stop_flag;
      mp→ll ← (short)(mp→ll − mp→lll);
    } while (mp→lll ≠ 0)
#define skip_error(A)
    {
      const char *hlp[] ← {"At most 127 lig/kern steps can separate skipto1 from 1::.",
          Λ};
      mp_error(mp, "Too far to skip", hlp, true); cancel_skips((A));
    }
⟨ Process a skip_to command and goto done 1182 ⟩ ≡
  {
    c ← mp_get_code(mp);
    if (mp→nl − mp→skip_table[c] > 128) {
      skip_error(mp→skip_table[c]); mp→skip_table[c] ← (short) undefined_label;
    }
    if (mp→skip_table[c] ≡ undefined_label) skip_byte(mp→nl − 1) ← qi(0);
    else skip_byte(mp→nl − 1) ← qi(mp→nl − mp→skip_table[c] − 1);
    mp→skip_table[c] ← (short)(mp→nl − 1); goto DONE;
  }
```

This code is used in section 1179.

1183.

```
⟨ Record a label in a lig/kern subprogram and goto continue 1183 ⟩ ≡
  {
    if (cur_cmd() ≡ mp_colon) {
      if (c ≡ 256) mp→bch_label ← mp→nl;
      else mp_set_tag(mp, c, lig_tag, mp→nl);
    }
    else if (mp→skip_table[c] < undefined_label) {
      mp→ll ← mp→skip_table[c]; mp→skip_table[c] ← undefined_label;
      do {
        mp→lll ← qo(skip_byte(mp→ll));
        if (mp→nl − mp→ll > 128) {
          skip_error(mp→ll); goto CONTINUE;
        }
        skip_byte(mp→ll) ← qi(mp→nl − mp→ll − 1); mp→ll ← (short)(mp→ll − mp→lll);
      } while (mp→lll ≠ 0);
    }
    goto CONTINUE;
  }
```

This code is used in section 1179.

1184. ⟨ Compile a ligature/kern command 1184 ⟩ ≡

```
{
  next_char(mp→nl) ← qi(c); skip_byte(mp→nl) ← qi(0);
  if (cur_mod() < 128) {    ▷ ligature op ◁
    op_byte(mp→nl) ← qi(cur_mod()); rem_byte(mp→nl) ← qi(mp_get_code(mp));
  }
  else {
    mp_get_x_next(mp); mp_scan_expression(mp);
    if (mp→cur_exp.type ≠ mp_known) {
      const char *hlp[] ← {"The amount of kern should be a known numeric value.",
          "I'm zeroing this one. Proceed, with fingers crossed.", Λ};
      mp_disp_err(mp, Λ); set_number_to_zero(new_expr.data.n);
      mp_back_error(mp, "Improper kern", hlp, true); mp_get_x_next(mp);
      mp_flush_cur_exp(mp, new_expr);
    }
    number_clone(mp→kern[mp→nk], cur_exp_value_number()); k ← 0;
    while (¬number_equal(mp→kern[k], cur_exp_value_number())) incr(k);
    if (k ≡ mp→nk) {
      if (mp→nk ≡ max_tfm_int) mp_fatal_error(mp, "too many TFM kerns");
      mp→nk++;
    }
    op_byte(mp→nl) ← qi(kern_flag + (k/256)); rem_byte(mp→nl) ← qi((k % 256));
  }
  mp→lk_started ← true;
}
```

This code is used in section 1179.

1185.

```
#define missing_extensible_punctuation(A)
        {
          char msg[256];
          const char *hlp[] ← {"I'm processing `extensible c: t,m,b,r'.", Λ};
          mp_snprintf(msg, 256, "Missing %s has been inserted", (A));
          mp_back_error(mp, msg, hlp, true);
        }
```

⟨ Define an extensible recipe 1185 ⟩ ≡

```
{
  if (mp→ne ≡ 256) mp_fatal_error(mp, "too many extensible recipes");
  c ← mp_get_code(mp); mp_set_tag(mp, c, ext_tag, mp→ne);
  if (cur_cmd() ≠ mp_colon) missing_extensible_punctuation(":");
  ext_top(mp→ne) ← qi(mp_get_code(mp));
  if (cur_cmd() ≠ mp_comma) missing_extensible_punctuation(",");
  ext_mid(mp→ne) ← qi(mp_get_code(mp));
  if (cur_cmd() ≠ mp_comma) missing_extensible_punctuation(",");
  ext_bot(mp→ne) ← qi(mp_get_code(mp));
  if (cur_cmd() ≠ mp_comma) missing_extensible_punctuation(",");
  ext_rep(mp→ne) ← qi(mp_get_code(mp)); mp→ne++;
}
```

This code is used in section 1178.

1186. The header could contain ASCII zeroes, so can't use *strdup*. The index j can be beyond the index *header_last*, hence we have to sure to update the end of stream marker to reflect the actual position.

⟨Store a list of header bytes 1186⟩ ≡

```
{
  j−−;
  if (mp→header_last < j) {
    mp→header_last ← j;
  }
  do {
    if (j ≥ mp→header_size) {
      size_t l ← (size_t)(mp→header_size + (mp→header_size/4));
      char *t ← xmalloc(l, 1);
      memset(t, 0, l);  (void) memcpy(t, mp→header_byte, (size_t) mp→header_size);
      xfree(mp→header_byte);  mp→header_byte ← t;  mp→header_size ← (int) l;
    }
    mp→header_byte[j] ← (char) mp_get_code(mp);
    if (mp→header_last < j) {
      incr(mp→header_last);
    }
    incr(j);
  } while (cur_cmd() ≡ mp_comma);
}
```

This code is used in section 1178.

1187. ⟨Store a list of font dimensions 1187⟩ ≡

```
do {
  if (j > max_tfm_int) mp_fatal_error(mp, "too␣many␣fontdimens");
  while (j > mp→np) {
    mp→np++;  set_number_to_zero(mp→param[mp→np]);
  }
  mp_get_x_next(mp);  mp_scan_expression(mp);
  if (mp→cur_exp.type ≠ mp_known) {
    const char *hlp[] ← {"I'm␣zeroing␣this␣one.␣Proceed,␣with␣fingers␣crossed.", Λ};
    mp_disp_err(mp, Λ);  set_number_to_zero(new_expr.data.n);
    mp_back_error(mp, "Improper␣font␣parameter", hlp, true);  mp_get_x_next(mp);
    mp_flush_cur_exp(mp, new_expr);
  }
  number_clone(mp→param[j], cur_exp_value_number());  incr(j);
} while (cur_cmd() ≡ mp_comma)
```

This code is used in section 1178.

1188. OK: We've stored all the data that is needed for the TFM file. All that remains is to output it in the correct format.

An interesting problem needs to be solved in this connection, because the TFM format allows at most 256 widths, 16 heights, 16 depths, and 64 italic corrections. If the data has more distinct values than this, we want to meet the necessary restrictions by perturbing the given values as little as possible.

METAPOST solves this problem in two steps. First the values of a given kind (widths, heights, depths, or italic corrections) are sorted; then the list of sorted values is perturbed, if necessary.

The sorting operation is facilitated by having a special node of essentially infinite *value* at the end of the current list.

⟨Initialize table entries 186⟩ +≡
mp→inf_val ← *mp_get_value_node*(*mp*); *set_value_number*(*mp→inf_val*, *fraction_four_t*);

1189. ⟨Free table entries 187⟩ +≡
mp_free_value_node(*mp*, *mp→inf_val*);

1190. Straight linear insertion is good enough for sorting, since the lists are usually not terribly long. As we work on the data, the current list will start at *mp_link*(*temp_head*) and end at *inf_val*; the nodes in this list will be in increasing order of their *value* fields.

Given such a list, the *sort_in* function takes a value and returns a pointer to where that value can be found in the list. The value is inserted in the proper place, if necessary.

At the time we need to do these operations, most of METAPOST's work has been completed, so we will have plenty of memory to play with. The value nodes that are allocated for sorting will never be returned to free storage.

```
#define clear_the_list mp_link(mp→temp_head) ← mp→inf_val

static mp_node mp_sort_in(MP mp, mp_number v)
{
  mp_node p, q, r;    ▷ list manipulation registers ◁
  p ← mp→temp_head;
  while (1) {
    q ← mp_link(p);
    if (number_lessequal(v, value_number(q))) break;
    p ← q;
  }
  if (number_less(v, value_number(q))) {
    r ← mp_get_value_node(mp); set_value_number(r, v); mp_link(r) ← q; mp_link(p) ← r;
  }
  return mp_link(p);
}
```

1191. Now we come to the interesting part, where we reduce the list if necessary until it has the required size. The *min_cover* routine is basic to this process; it computes the minimum number m such that the values of the current sorted list can be covered by m intervals of width d. It also sets the global value *perturbation* to the smallest value $d' > d$ such that the covering found by this algorithm would be different.

In particular, *min_cover*(0) returns the number of distinct values in the current list and sets *perturbation* to the minimum distance between adjacent values.

```
static integer mp_min_cover(MP mp, mp_number d)
{
  mp_node p;    ▷ runs through the current list ◁
  mp_number l;    ▷ the least element covered by the current interval ◁
  mp_number test;
  integer m;    ▷ lower bound on the size of the minimum cover ◁
  m ← 0; new_number(l); new_number(test); p ← mp_link(mp→temp_head);
  set_number_to_inf(mp→perturbation);
  while (p ≠ mp→inf_val) {
    incr(m); number_clone(l, value_number(p));
    do {
      p ← mp_link(p); set_number_from_addition(test, l, d);
    } while (number_lessequal(value_number(p), test));
    set_number_from_substraction(test, value_number(p), l);
    if (number_less(test, mp→perturbation)) {
      number_clone(mp→perturbation, test);
    }
  }
  free_number(test); free_number(l); return m;
}
```

1192. ⟨ Global variables 18 ⟩ +≡

```
mp_number perturbation;    ▷ quantity related to TFM rounding ◁
integer excess;    ▷ the list is this much too long ◁
```

1193. ⟨ Initialize table entries 186 ⟩ +≡

```
new_number(mp→perturbation);
```

1194. ⟨ Dealloc variables 31 ⟩ +≡

```
free_number(mp→perturbation);
```

1195. The smallest d such that a given list can be covered with m intervals is determined by the *threshold* routine, which is sort of an inverse to *min_cover*. The idea is to increase the interval size rapidly until finding the range, then to go sequentially until the exact borderline has been discovered.

```
static void mp_threshold(MP mp, mp_number *ret, integer m)
{
  mp_number d, arg1;   ▷ lower bound on the smallest interval size ◁
  new_number(d); new_number(arg1); mp→excess ← mp_min_cover(mp, zero_t) − m;
  if (mp→excess ≤ 0) {
    number_clone(*ret, zero_t);
  }
  else {
    do {
      number_clone(d, mp→perturbation); set_number_from_addition(arg1, d, d);
    } while (mp_min_cover(mp, arg1) > m);
    while (mp_min_cover(mp, d) > m) {
      number_clone(d, mp→perturbation);
    }
    number_clone(*ret, d);
  }
  free_number(d); free_number(arg1);
}
```

1196. The *skimp* procedure reduces the current list to at most m entries, by changing values if necessary. It also sets *indep_value*(p): $\leftarrow k$ if *value*(p) is the kth distinct value on the resulting list, and it sets *perturbation* to the maximum amount by which a *value* field has been changed. The size of the resulting list is returned as the value of *skimp*.

```
static integer mp_skimp(MP mp, integer m)
{
  mp_number d;   ▷ the size of intervals being coalesced ◁
  mp_node p, q, r;   ▷ list manipulation registers ◁
  mp_number l;   ▷ the least value in the current interval ◁
  mp_number v;   ▷ a compromise value ◁
  mp_number l_d;
  new_number(d); mp_threshold(mp, &d, m); new_number(l); new_number(l_d); new_number(v);
  set_number_to_zero(mp→perturbation); q ← mp→temp_head; m ← 0; p ← mp_link(mp→temp_head);
  while (p ≠ mp→inf_val) {
    incr(m); number_clone(l, value_number(p)); set_indep_value(p, m);
    set_number_from_addition(l_d, l, d);
    if (number_lessequal(value_number(mp_link(p)), l_d))
      ⟨Replace an interval of values by its midpoint 1197⟩
    q ← p; p ← mp_link(p);
  }
  free_number(l_d); free_number(d); free_number(l); free_number(v); return m;
}
```

1197. ⟨Replace an interval of values by its midpoint 1197⟩ ≡

```
{
  mp_number test;
  new_number(test);
  do {
    p ← mp_link(p); set_indep_value(p, m); decr(mp→excess);
    if (mp→excess ≡ 0) {
      number_clone(l_d, l); set_number_to_zero(d);
    }
  } while (number_lessequal(value_number(mp_link(p)), l_d));
  set_number_from_substraction(test, value_number(p), l); number_halfp(test);
  set_number_from_addition(v, l, test); set_number_from_substraction(test, value_number(p), v);
  if (number_greater(test, mp→perturbation)) number_clone(mp→perturbation, test);
  r ← q;
  do {
    r ← mp_link(r); set_value_number(r, v);
  } while (r ≠ p);
  mp_link(q) ← p;   ▷ remove duplicate values from the current list ◁
  free_number(test);
}
```

This code is used in section 1196.

1198. A warning message is issued whenever something is perturbed by more than 1/16 pt.

```
static void mp_tfm_warning(MP mp, quarterword m)
{
  mp_print_nl(mp, "(some␣"); mp_print(mp, internal_name(m));
  mp_print(mp, "␣values␣had␣to␣be␣adjusted␣by␣as␣much␣as␣"); print_number(mp→perturbation);
  mp_print(mp, "pt)");
}
```

1199. Here's an example of how we use these routines. The width data needs to be perturbed only if there are 256 distinct widths, but METAPOST must check for this case even though it is highly unusual.

An integer variable k will be defined when we use this code. The *dimen_head* array will contain pointers to the sorted lists of dimensions.

```
#define tfm_warn_threshold_k ((math_data *) mp→math)→tfm_warn_threshold_t
```

⟨Massage the TFM widths 1199⟩ ≡

```
  clear_the_list;
  for (k ← mp→bc; k ≤ mp→ec; k++) {
    if (mp→char_exists[k]) mp→tfm_width[k] ← mp_sort_in(mp, value_number(mp→tfm_width[k]));
  }
  mp→nw ← (short)(mp_skimp(mp, 255) + 1); mp→dimen_head[1] ← mp_link(mp→temp_head);
  if (number_greaterequal(mp→perturbation, tfm_warn_threshold_k)) mp_tfm_warning(mp, mp_char_wd)
```

This code is used in section 1285.

1200. ⟨Global variables 18⟩ +≡

```
  mp_node dimen_head[5];   ▷ lists of TFM dimensions ◁
```

1201. Heights, depths, and italic corrections are different from widths not only because their list length is more severely restricted, but also because zero values do not need to be put into the lists.

⟨ Massage the TFM heights, depths, and italic corrections 1201 ⟩ ≡

```
clear_the_list;
for (k ← mp→bc; k ≤ mp→ec; k++) {
  if (mp→char_exists[k]) {
    if (number_zero(value_number(mp→tfm_height[k]))) mp→tfm_height[k] ← mp→zero_val;
    else mp→tfm_height[k] ← mp_sort_in(mp, value_number(mp→tfm_height[k]));
  }
}
mp→nh ← (short)(mp_skimp(mp, 15) + 1); mp→dimen_head[2] ← mp_link(mp→temp_head);
if (number_greaterequal(mp→perturbation, tfm_warn_threshold_k)) mp_tfm_warning(mp, mp_char_ht);
clear_the_list;
for (k ← mp→bc; k ≤ mp→ec; k++) {
  if (mp→char_exists[k]) {
    if (number_zero(value_number(mp→tfm_depth[k]))) mp→tfm_depth[k] ← mp→zero_val;
    else mp→tfm_depth[k] ← mp_sort_in(mp, value_number(mp→tfm_depth[k]));
  }
}
mp→nd ← (short)(mp_skimp(mp, 15) + 1); mp→dimen_head[3] ← mp_link(mp→temp_head);
if (number_greaterequal(mp→perturbation, tfm_warn_threshold_k)) mp_tfm_warning(mp, mp_char_dp);
clear_the_list;
for (k ← mp→bc; k ≤ mp→ec; k++) {
  if (mp→char_exists[k]) {
    if (number_zero(value_number(mp→tfm_ital_corr[k]))) mp→tfm_ital_corr[k] ← mp→zero_val;
    else mp→tfm_ital_corr[k] ← mp_sort_in(mp, value_number(mp→tfm_ital_corr[k]));
  }
}
mp→ni ← (short)(mp_skimp(mp, 63) + 1); mp→dimen_head[4] ← mp_link(mp→temp_head); if
    (number_greaterequal(mp→perturbation, tfm_warn_threshold_k)) mp_tfm_warning(mp, mp_char_ic)
```

This code is used in section 1285.

1202. ⟨ Initialize table entries 186 ⟩ +≡

```
mp→zero_val ← mp_get_value_node(mp); set_value_number(mp→zero_val, zero_t);
```

1203. ⟨ Free table entries 187 ⟩ +≡

```
mp_free_value_node(mp, mp→zero_val);
```

1204. Bytes 5–8 of the header are set to the design size, unless the user has some crazy reason for specifying them differently.

Error messages are not allowed at the time this procedure is called, so a warning is printed instead.

The value of *max_tfm_dimen* is calculated so that

$$make\_scaled(16 * max\_tfm\_dimen, internal\_value(mp\_design\_size)) < three\_bytes.$$

```
#define three_bytes °100000000   ▷ 2^24 ◁
  static void mp_fix_design_size(MP mp)
  {
    mp_number d;   ▷ the design size ◁
    new_number(d); number_clone(d, internal_value(mp_design_size));
    if (number_less(d, unity_t) ∨ number_greaterequal(d, fraction_half_t)) {
      if (¬number_zero(d)) mp_print_nl(mp, "(illegal␣design␣size␣has␣been␣changed␣to␣128pt)");
      set_number_from_scaled(d, °40000000); number_clone(internal_value(mp_design_size), d);
    }
    if (mp→header_byte[4] ≡ 0 ∧ mp→header_byte[5] ≡ 0 ∧ mp→header_byte[6] ≡ 0 ∧ mp→header_byte[7] ≡ 0) {
      integer dd ← number_to_scaled(d);
      mp→header_byte[4] ← (char)(dd/°4000000); mp→header_byte[5] ← (char)((dd/4096) % 256);
      mp→header_byte[6] ← (char)((dd/16) % 256); mp→header_byte[7] ← (char)((dd % 16) * 16);
    }
       ▷ mp→max_tfm_dimen ← 16 * internal_value(mp_design_size) − 1 −
        internal_value(mp_design_size)/°10000000 ◁
    {
      mp_number secondpart;
      new_number(secondpart); number_clone(secondpart, internal_value(mp_design_size));
      number_clone(mp→max_tfm_dimen, secondpart); number_divide_int(secondpart, °10000000);
      number_multiply_int(mp→max_tfm_dimen, 16); number_add_scaled(mp→max_tfm_dimen, −1);
      number_substract(mp→max_tfm_dimen, secondpart); free_number(secondpart);
    }
    if (number_greaterequal(mp→max_tfm_dimen, fraction_half_t)) {
      number_clone(mp→max_tfm_dimen, fraction_half_t); number_add_scaled(mp→max_tfm_dimen, −1);
    }
    free_number(d);
  }
```

1205. The *dimen_out* procedure computes a *fix_word* relative to the design size. If the data was out of range, it is corrected and the global variable *tfm_changed* is increased by one.

```
static integer mp_dimen_out(MP mp, mp_number x_orig)
{
  integer ret;
  mp_number abs_x;
  mp_number x;

  new_number(abs_x); new_number(x); number_clone(x, x_orig); number_clone(abs_x, x_orig);
  number_abs(abs_x);
  if (number_greater(abs_x, mp→max_tfm_dimen)) {
    incr(mp→tfm_changed);
    if (number_positive(x)) number_clone(x, mp→max_tfm_dimen);
    else {
      number_clone(x, mp→max_tfm_dimen); number_negate(x);
    }
  }
  {
    mp_number arg1;

    new_number(arg1); number_clone(arg1, x); number_multiply_int(arg1, 16);
    make_scaled(x, arg1, internal_value(mp_design_size)); free_number(arg1);
  }
  free_number(abs_x); ret ← number_to_scaled(x); free_number(x); return ret;
}
```

1206. ⟨ Global variables 18 ⟩ +≡

```
mp_number max_tfm_dimen;    ▷ bound on widths, heights, kerns, etc. ◁
integer tfm_changed;    ▷ the number of data entries that were out of bounds ◁
```

1207. ⟨ Initialize table entries 186 ⟩ +≡

```
new_number(mp→max_tfm_dimen);
```

1208. ⟨ Dealloc variables 31 ⟩ +≡

```
free_number(mp→max_tfm_dimen);
```

1209. If the user has not specified any of the first four header bytes, the *fix_check_sum* procedure replaces them by a "check sum" computed from the *tfm_width* data relative to the design size.

```
static void mp_fix_check_sum(MP mp)
{
  eight_bits k;    ▷ runs through character codes ◁
  eight_bits B1, B2, B3, B4;    ▷ bytes of the check sum ◁
  integer x;    ▷ hash value used in check sum computation ◁

  if (mp→header_byte[0] ≡ 0 ∧ mp→header_byte[1] ≡ 0 ∧ mp→header_byte[2] ≡ 0 ∧ mp→header_byte[3] ≡ 0) {
    ⟨ Compute a check sum in (b1, b2, b3, b4) 1210 ⟩;
    mp→header_byte[0] ← (char) B1; mp→header_byte[1] ← (char) B2; mp→header_byte[2] ← (char) B3;
    mp→header_byte[3] ← (char) B4; return;
  }
}
```

1210. ⟨Compute a check sum in $(b1, b2, b3, b4)$ 1210⟩ ≡

```
B1 ← mp→bc; B2 ← mp→ec; B3 ← mp→bc; B4 ← mp→ec; mp→tfm_changed ← 0;
for (k ← mp→bc; k ≤ mp→ec; k++) {
  if (mp→char_exists[k]) {
    x ← mp_dimen_out(mp, value_number(mp→tfm_width[k])) + (k + 4) * °20000000;   ▷ this is positive ◁
    B1 ← (eight_bits)((B1 + B1 + x) % 255); B2 ← (eight_bits)((B2 + B2 + x) % 253);
    B3 ← (eight_bits)((B3 + B3 + x) % 251); B4 ← (eight_bits)((B4 + B4 + x) % 247);
  }
  if (k ≡ mp→ec) break;
}
```

This code is used in section 1209.

1211. Finally we're ready to actually write the TFM information. Here are some utility routines for this purpose.

```
#define tfm_out(A)
        do {   ▷ output one byte to tfm_file ◁
          unsigned char s ← (unsigned char)(A);
          (mp→write_binary_file)(mp, mp→tfm_file, (void *) &s, 1);
        } while (0)
  static void mp_tfm_two(MP mp, integer x)
  {   ▷ output two bytes to tfm_file ◁
    tfm_out(x/256); tfm_out(x % 256);
  }
  static void mp_tfm_four(MP mp, integer x)
  {   ▷ output four bytes to tfm_file ◁
    if (x ≥ 0) tfm_out(x/three_bytes);
    else {
      x ← x + °10000000000;   ▷ use two's complement for negative values ◁
      x ← x + °10000000000; tfm_out((x/three_bytes) + 128);
    }
    x ← x % three_bytes; tfm_out(x/number_to_scaled(unity_t)); x ← x % number_to_scaled(unity_t);
    tfm_out(x/°400); tfm_out(x % °400);
  }
  static void mp_tfm_qqqq(MP mp, four_quarters x)
  {   ▷ output four quarterwords to tfm_file ◁
    tfm_out(qo(x.b0)); tfm_out(qo(x.b1)); tfm_out(qo(x.b2)); tfm_out(qo(x.b3));
  }
```

1212. ⟨Finish the TFM file 1212⟩ ≡

```
if (mp→job_name ≡ Λ) mp_open_log_file(mp);
mp_pack_job_name(mp, ".tfm");
while (¬mp_open_out(mp, &mp→tfm_file, mp_filetype_metrics))
  mp_prompt_file_name(mp, "file␣name␣for␣font␣metrics", ".tfm");
mp→metric_file_name ← xstrdup(mp→name_of_file); ⟨Output the subfile sizes and header bytes 1213⟩;
⟨Output the character information bytes, then output the dimensions themselves 1214⟩;
⟨Output the ligature/kern program 1217⟩;
⟨Output the extensible character recipes and the font metric parameters 1218⟩;
if (number_positive(internal_value(mp_tracing_stats))) ⟨Log the subfile sizes of the TFM file 1219⟩;
mp_print_nl(mp, "Font␣metrics␣written␣on␣"); mp_print(mp, mp→metric_file_name);
mp_print_char(mp, xord('.')); (mp→close_file)(mp, mp→tfm_file)
```

This code is used in section 1285.

1213. Integer variables *lh*, *k*, and *lk_offset* will be defined when we use this code.

⟨ Output the subfile sizes and header bytes 1213 ⟩ ≡

```
k ← mp→header_last; LH ← (k + 4)/4;    ▷ this is the number of header words ◁
if (mp→bc > mp→ec) mp→bc ← 1;    ▷ if there are no characters, ec ← 0 and bc ← 1 ◁
⟨ Compute the ligature/kern program offset and implant the left boundary label 1215 ⟩;
mp_tfm_two(mp, 6 + LH + (mp→ec − mp→bc + 1) + mp→nw + mp→nh + mp→nd + mp→ni + mp→nl +
    lk_offset + mp→nk + mp→ne + mp→np);    ▷ this is the total number of file words that will be output ◁
mp_tfm_two(mp, LH); mp_tfm_two(mp, mp→bc); mp_tfm_two(mp, mp→ec); mp_tfm_two(mp, mp→nw);
mp_tfm_two(mp, mp→nh); mp_tfm_two(mp, mp→nd); mp_tfm_two(mp, mp→ni);
mp_tfm_two(mp, mp→nl + lk_offset); mp_tfm_two(mp, mp→nk); mp_tfm_two(mp, mp→ne);
mp_tfm_two(mp, mp→np);
for (k ← 0; k < 4 * LH; k++) {
  tfm_out(mp→header_byte[k]);
}
```

This code is used in section 1212.

1214. ⟨ Output the character information bytes, then output the dimensions themselves 1214 ⟩ ≡

```
for (k ← mp→bc; k ≤ mp→ec; k++) {
  if (¬mp→char_exists[k]) {
    mp_tfm_four(mp, 0);
  }
  else {
    tfm_out(indep_value(mp→tfm_width[k]));    ▷ the width index ◁
    tfm_out((indep_value(mp→tfm_height[k])) * 16 + indep_value(mp→tfm_depth[k]));
    tfm_out((indep_value(mp→tfm_ital_corr[k])) * 4 + mp→char_tag[k]); tfm_out(mp→char_remainder[k]);
  }
}
mp→tfm_changed ← 0;
for (k ← 1; k ≤ 4; k++) {
  mp_tfm_four(mp, 0); p ← mp→dimen_head[k];
  while (p ≠ mp→inf_val) {
    mp_tfm_four(mp, mp_dimen_out(mp, value_number(p))); p ← mp_link(p);
  }
}
```

This code is used in section 1212.

1215. We need to output special instructions at the beginning of the *lig_kern* array in order to specify the right boundary character and/or to handle starting addresses that exceed 255. The *label_loc* and *label_char* arrays have been set up to record all the starting addresses; we have $-1 = label\_loc[0] < label\_loc[1] \le \cdots \le label\_loc[label\_ptr]$.

⟨ Compute the ligature/kern program offset and implant the left boundary label 1215 ⟩ ≡

$mp\to bchar \leftarrow round\_unscaled(internal\_value(mp\_boundary\_char));$
if $((mp\to bchar < 0) \lor (mp\to bchar > 255))$ {
  $mp\to bchar \leftarrow -1;$ $mp\to lk\_started \leftarrow false;$ $lk\_offset \leftarrow 0;$
}
else {
  $mp\to lk\_started \leftarrow true;$ $lk\_offset \leftarrow 1;$
}
⟨ Find the minimum *lk_offset* and adjust all remainders 1216 ⟩;
if $(mp\to bch\_label < undefined\_label)$ {
  $skip\_byte(mp\to nl) \leftarrow qi(255);$ $next\_char(mp\to nl) \leftarrow qi(0);$
  $op\_byte(mp\to nl) \leftarrow qi(((mp\to bch\_label + lk\_offset)/256));$
  $rem\_byte(mp\to nl) \leftarrow qi(((mp\to bch\_label + lk\_offset) \% 256));$ $mp\to nl{+}{+};$
    ▷ possibly $nl \leftarrow lig\_table\_size + 1$ ◁
}

This code is used in section 1213.

1216. ⟨ Find the minimum *lk_offset* and adjust all remainders 1216 ⟩ ≡

$k \leftarrow mp\to label\_ptr;$ ▷ pointer to the largest unallocated label ◁
if $(mp\to label\_loc[k] + lk\_offset > 255)$ {
  $lk\_offset \leftarrow 0;$ $mp\to lk\_started \leftarrow false;$ ▷ location 0 can do double duty ◁
  do {
    $mp\to char\_remainder[mp\to label\_char[k]] \leftarrow lk\_offset;$
    while $(mp\to label\_loc[k-1] \equiv mp\to label\_loc[k])$ {
      $decr(k);$ $mp\to char\_remainder[mp\to label\_char[k]] \leftarrow lk\_offset;$
    }
    $incr(lk\_offset);$ $decr(k);$
  } **while** $(\neg(lk\_offset + mp\to label\_loc[k] < 256));$ ▷ N.B.: $lk\_offset \leftarrow 256$ satisfies this when $k \leftarrow 0$ ◁
}
if $(lk\_offset > 0)$ {
  while $(k > 0)$ {
    $mp\to char\_remainder[mp\to label\_char[k]] \leftarrow mp\to char\_remainder[mp\to label\_char[k]] + lk\_offset;$ $decr(k);$
  }
}

This code is used in section 1215.

1217. ⟨ Output the ligature/kern program 1217 ⟩ ≡

```
for (k ← 0; k ≤ 255; k++) {
  if (mp→skip_table[k] < undefined_label) {
    mp_print_nl(mp, "(local␣label␣"); mp_print_int(mp, k); mp_print(mp, "::␣was␣missing)");
    cancel_skips(mp→skip_table[k]);
  }
}
if (mp→lk_started) {    ▷ lk_offset ← 1 for the special bchar ◁
  tfm_out(255); tfm_out(mp→bchar); mp_tfm_two(mp, 0);
}
else {
  for (k ← 1; k ≤ lk_offset; k++) {    ▷ output the redirection specs ◁
    mp→ll ← mp→label_loc[mp→label_ptr];
    if (mp→bchar < 0) {
      tfm_out(254); tfm_out(0);
    }
    else {
      tfm_out(255); tfm_out(mp→bchar);
    }
    mp_tfm_two(mp, mp→ll + lk_offset);
    do {
      mp→label_ptr −−;
    } while (¬(mp→label_loc[mp→label_ptr] < mp→ll));
  }
}
for (k ← 0; k < mp→nl; k++) mp_tfm_qqqq(mp, mp→lig_kern[k]);
{
  mp_number arg;
  new_number(arg);
  for (k ← 0; k < mp→nk; k++) {
    number_clone(arg, mp→kern[k]); mp_tfm_four(mp, mp_dimen_out(mp, arg));
  }
  free_number(arg);
}
```

This code is used in section 1212.

1218. ⟨Output the extensible character recipes and the font metric parameters 1218⟩ ≡

```
for (k ← 0; k < mp→ne; k++) mp_tfm_qqqq(mp, mp→exten[k]);
{
  mp_number arg;

  new_number(arg);
  for (k ← 1; k ≤ mp→np; k++) {
    if (k ≡ 1) {
      number_clone(arg, mp→param[1]); number_abs(arg);
      if (number_less(arg, fraction_half_t)) {
        mp_tfm_four(mp, number_to_scaled(mp→param[1]) * 16);
      }
      else {
        incr(mp→tfm_changed);
        if (number_positive(mp→param[1])) mp_tfm_four(mp, max_integer);
        else mp_tfm_four(mp, −max_integer);
      }
    }
    else {
      number_clone(arg, mp→param[k]); mp_tfm_four(mp, mp_dimen_out(mp, arg));
    }
  }
  free_number(arg);
}
if (mp→tfm_changed > 0) {
  if (mp→tfm_changed ≡ 1) {
    mp_print_nl(mp, "(a␣font␣metric␣dimension");
  }
  else {
    mp_print_nl(mp, "("); mp_print_int(mp, mp→tfm_changed);
    mp_print(mp, "␣font␣metric␣dimensions");
  }
  mp_print(mp, "␣had␣to␣be␣decreased)");
}
```

This code is used in section 1212.

1219. ⟨Log the subfile sizes of the TFM file 1219⟩ ≡

```
{
  char s[200];

  wlog_ln("␣");
  if (mp→bch_label < undefined_label) mp→nl −−;
  mp_snprintf(s, 128, "(You␣used␣%iw,%ih,%id,%ii,%il,%ik,%ie,%ip␣metric␣file␣positions)",
      mp→nw, mp→nh, mp→nd, mp→ni, mp→nl, mp→nk, mp→ne, mp→np); wlog_ln(s);
}
```

This code is used in section 1212.

1220. Reading font metric data.
METAPOST isn't a typesetting program but it does need to find the bounding box of a sequence of typeset characters. Thus it needs to read TFM files as well as write them.

⟨ Global variables 18 ⟩ +≡
void $*$*tfm_infile*;

1221. All the width, height, and depth information is stored in an array called *font_info*. This array is allocated sequentially and each font is stored as a series of *char_info* words followed by the width, height, and depth tables. Since *font_name* entries are permanent, their *str_ref* values are set to `MAX_STR_REF`.

⟨ Types in the outer block 37 ⟩ +≡
typedef unsigned int font_number; ▷ 0.._F *ont_max* ◁

1222. The *font_info* array is indexed via a group directory arrays. For example, the *char_info* data for character c in font f will be in *font_info*[*char_base*[f] + c].*qqqq*.

⟨ Global variables 18 ⟩ +≡
font_number *font_max*; ▷ maximum font number for included text fonts ◁
size_t *font_mem_size*; ▷ number of words for TFM information for text fonts ◁
font_data $*$*font_info*; ▷ height, width, and depth data ◁
char $**$*font_enc_name*; ▷ encoding names, if any ◁
boolean $*$*font_ps_name_fixed*; ▷ are the postscript names fixed already? ◁
size_t *next_fmem*; ▷ next unused entry in *font_info* ◁
font_number *last_fnum*; ▷ last font number used so far ◁
integer $*$*font_dsize*; ▷ 16 times the "design" size in PostScript points ◁
char $**$*font_name*; ▷ name as specified in the **infont** command ◁
char $**$*font_ps_name*; ▷ PostScript name for use when *internal*[*mp_prologues*] > 0 ◁
font_number *last_ps_fnum*; ▷ last valid *font_ps_name* index ◁
eight_bits $*$*font_bc*;
eight_bits $*$*font_ec*; ▷ first and last character code ◁
int $*$*char_base*; ▷ base address for *char_info* ◁
int $*$*width_base*; ▷ index for zeroth character width ◁
int $*$*height_base*; ▷ index for zeroth character height ◁
int $*$*depth_base*; ▷ index for zeroth character depth ◁
mp_node $*$*font_sizes*;

1223. ⟨ Allocate or initialize variables 32 ⟩ +≡
mp→font_mem_size ← 10000; *mp→font_info* ← *xmalloc*((*mp→font_mem_size* + 1), **sizeof**(**font_data**));
memset(*mp→font_info*, 0, **sizeof**(**font_data**) $*$ (*mp→font_mem_size* + 1)); *mp→last_fnum* ← *null_font*;

1224. ⟨ Dealloc variables 31 ⟩ +≡
for (k ← 1; $k \le$ (**int**) *mp→last_fnum*; k++) {
xfree(*mp→font_enc_name*[k]); *xfree*(*mp→font_name*[k]); *xfree*(*mp→font_ps_name*[k]);
}
for (k ← 0; $k \le 255$; k++) {
▷ These are disabled for now following a bug-report about double free errors. TO BE FIXED, bug tracker id 831 ◁ ▷ *mp_free_value_node*(*mp*, *mp→tfm_width*[k]); *mp_free_value_node*(*mp*, *mp→tfm_height*[k]); *mp_free_value_node*(*mp*, *mp→tfm_depth*[k]); *mp_free_value_node*(*mp*, *mp→tfm_ital_corr*[k]); ◁
}
xfree(*mp→font_info*); *xfree*(*mp→font_enc_name*); *xfree*(*mp→font_ps_name_fixed*); *xfree*(*mp→font_dsize*);
xfree(*mp→font_name*); *xfree*(*mp→font_ps_name*); *xfree*(*mp→font_bc*); *xfree*(*mp→font_ec*);
xfree(*mp→char_base*); *xfree*(*mp→width_base*); *xfree*(*mp→height_base*); *xfree*(*mp→depth_base*);
xfree(*mp→font_sizes*);

1225. **void** *mp_reallocate_fonts*(**MP** *mp*, **font_number** *l*)

```
{
  font_number f;
  XREALLOC(mp→font_enc_name, l, char *); XREALLOC(mp→font_ps_name_fixed, l, boolean);
  XREALLOC(mp→font_dsize, l, integer); XREALLOC(mp→font_name, l, char *);
  XREALLOC(mp→font_ps_name, l, char *); XREALLOC(mp→font_bc, l, eight_bits);
  XREALLOC(mp→font_ec, l, eight_bits); XREALLOC(mp→char_base, l, int);
  XREALLOC(mp→width_base, l, int); XREALLOC(mp→height_base, l, int); XREALLOC(mp→depth_base, l, int);
  XREALLOC(mp→font_sizes, l, mp_node);
  for (f ← (mp→last_fnum + 1); f ≤ l; f++) {
    mp→font_enc_name[f] ← Λ; mp→font_ps_name_fixed[f] ← false; mp→font_name[f] ← Λ;
    mp→font_ps_name[f] ← Λ; mp→font_sizes[f] ← Λ;
  }
  mp→font_max ← l;
}
```

1226. ⟨ Internal library declarations 14 ⟩ +≡

```
void mp_reallocate_fonts(MP mp, font_number l);
```

1227. A *null_font* containing no characters is useful for error recovery. Its *font_name* entry starts out empty but is reset each time an erroneous font is found. This helps to cut down on the number of duplicate error messages without wasting a lot of space.

```
#define null_font 0   ▷ the font_number for an empty font ◁
```

⟨ Set initial values of key variables 42 ⟩ +≡

```
mp→font_dsize[null_font] ← 0; mp→font_bc[null_font] ← 1; mp→font_ec[null_font] ← 0;
mp→char_base[null_font] ← 0; mp→width_base[null_font] ← 0; mp→height_base[null_font] ← 0;
mp→depth_base[null_font] ← 0; mp→next_fmem ← 0; mp→last_fnum ← null_font;
mp→last_ps_fnum ← null_font;
{
  static char nullfont_name[] ← "nullfont";
  static char nullfont_psname[] ← "";
  mp→font_name[null_font] ← nullfont_name; mp→font_ps_name[null_font] ← nullfont_psname;
}
mp→font_ps_name_fixed[null_font] ← false; mp→font_enc_name[null_font] ← Λ;
mp→font_sizes[null_font] ← Λ;
```

1228. Each *char_info* word is of type **four_quarters**. The *b0* field contains the *width index*; the *b1* field contains the height index; the *b2* fields contains the depth index, and the *b3* field used only for temporary storage. (It is used to keep track of which characters occur in an edge structure that is being shipped out.) The corresponding words in the width, height, and depth tables are stored as *scaled* values in units of PostScript points.

With the macros below, the *char_info* word for character c in font f is *char_mp_info*(f,c) and the width is

$$char\_width(f, char\_mp\_info(f,c)).sc.$$

```
#define char_mp_info(A, B) mp→font_info[mp→char_base[(A)] + (B)].qqqq
#define char_width(A, B) mp→font_info[mp→width_base[(A)] + (B).b0].sc
#define char_height(A, B) mp→font_info[mp→height_base[(A)] + (B).b1].sc
#define char_depth(A, B) mp→font_info[mp→depth_base[(A)] + (B).b2].sc
#define ichar_exists(A) ((A).b0 > 0)
```

1229. When we have a font name and we don't know whether it has been loaded yet, we scan the *font_name* array before calling *read_font_info*.

⟨ Declarations 10 ⟩ +≡
```
static font_number mp_find_font(MP mp, char *f);
```

1230.
```
font_number mp_find_font(MP mp, char *f)
{
  font_number n;
  for (n ← 0; n ≤ mp→last_fnum; n++) {
    if (mp_xstrcmp(f, mp→font_name[n]) ≡ 0) {
      return n;
    }
  }
  n ← mp_read_font_info(mp, f); return n;
}
```

1231. This is an interface function for getting the width of character, as a double in ps units
```
double mp_get_char_dimension(MP mp, char *fname, int c, int t)
{
  unsigned n;
  four_quarters cc;
  font_number f ← 0;
  double w ← −1.0;
  for (n ← 0; n ≤ mp→last_fnum; n++) {
    if (mp_xstrcmp(fname, mp→font_name[n]) ≡ 0) {
      f ← n; break;
    }
  }
  if (f ≡ 0) return 0.0;
  cc ← char_mp_info(f, c);
  if (¬ichar_exists(cc)) return 0.0;
  if (t ≡ 'w') w ← (double) char_width(f, cc);
  else if (t ≡ 'h') w ← (double) char_height(f, cc);
  else if (t ≡ 'd') w ← (double) char_depth(f, cc);
  return w/655.35 ∗ (72.27/72);
}
```

1232. ⟨ Exported function headers 22 ⟩ +≡
```
double mp_get_char_dimension(MP mp, char *fname, int n, int t);
```

1233. If we discover that the font doesn't have a requested character, we omit it from the bounding box computation and expect the PostScript interpreter to drop it. This routine issues a warning message if the user has asked for it.

⟨ Declarations 10 ⟩ +≡
```
static void mp_lost_warning(MP mp, font_number f, int k);
```

1234. **void** *mp_lost_warning*(**MP** *mp*, **font_number** *f*, **int** *k*)

```
{
  if (number_positive(internal_value(mp_tracing_lost_chars))) {
    mp_begin_diagnostic(mp);
    if (mp→selector ≡ log_only) incr(mp→selector);
    mp_print_nl(mp, "Missing␣character:␣There␣is␣no␣"); mp_print_int(mp, k);
    mp_print(mp, "␣in␣font␣"); mp_print(mp, mp→font_name[f]); mp_print_char(mp, xord('!'));
    mp_end_diagnostic(mp, false);
  }
}
```

1235. The whole purpose of saving the height, width, and depth information is to be able to find the bounding box of an item of text in an edge structure. The *set_text_box* procedure takes a text node and adds this information.

⟨ Declarations 10 ⟩ +≡

```
static void mp_set_text_box(MP mp, mp_text_node p);
```

1236. **void** *mp_set_text_box*(**MP** *mp*, **mp_text_node** *p*)

```
{
  font_number f;   ▷ mp_font_n(p) ◁
  ASCII_code bc, ec;   ▷ range of valid characters for font f ◁
  size_t k, kk;   ▷ current character and character to stop at ◁
  four_quarters cc;   ▷ the char_info for the current character ◁
  mp_number h, d;   ▷ dimensions of the current character ◁
  mp_number minus_inf_t;   ▷ check the -inf of height and depth ◁

  new_number(h); new_number(d); new_number(minus_inf_t); number_clone(minus_inf_t, inf_t);
  number_negate(minus_inf_t); set_number_to_zero(p→width); set_number_to_neg_inf(p→height);
  set_number_to_neg_inf(p→depth); f ← (font_number) mp_font_n(p); bc ← mp→font_bc[f];
  ec ← mp→font_ec[f]; kk ← mp_text_p(p)→len; k ← 0;
  while (k < kk) ⟨ Adjust p's bounding box to contain str_pool[k]; advance k 1237 ⟩
  ⟨ Set the height and depth to zero if the bounding box is empty 1238 ⟩;
  free_number(h); free_number(d); free_number(minus_inf_t);
}
```

1237. ⟨ Adjust p's bounding box to contain *str_pool*[k]; advance k 1237 ⟩ ≡

```
{
  if ((*(mp_text_p(p)→str + k) < bc) ∨ (*(mp_text_p(p)→str + k) > ec)) {
    mp_lost_warning(mp, f, *(mp_text_p(p)→str + k));
  }
  else {
    cc ← char_mp_info(f, *(mp_text_p(p)→str + k));
    if (¬ichar_exists(cc)) {
      mp_lost_warning(mp, f, *(mp_text_p(p)→str + k));
    }
    else {
      set_number_from_scaled(p→width, number_to_scaled(p→width) + char_width(f, cc));
      set_number_from_scaled(h, char_height(f, cc)); set_number_from_scaled(d, char_depth(f, cc));
      if (number_greater(h, p→height)) number_clone(p→height, h);
      if (number_greater(d, p→depth)) number_clone(p→depth, d);
    }
  }
  incr(k);
}
```

This code is used in section 1236.

1238. Let's hope modern compilers do comparisons correctly when the difference would overflow.

⟨ Set the height and depth to zero if the bounding box is empty 1238 ⟩ ≡

```
if (number_equal(p→height, p→depth) ∧ number_equal(p→height, minus_inf_t)) {
  set_number_to_zero(p→height); set_number_to_zero(p→depth);
}
else if (number_to_scaled(p→height) < −number_to_scaled(p→depth)) {
  set_number_to_zero(p→height); set_number_to_zero(p→depth);
}
```

This code is used in section 1236.

1239. The new primitives fontmapfile and fontmapline.

⟨ Declare action procedures for use by *do_statement* 1050 ⟩ +≡

```
static void mp_do_mapfile(MP mp);
static void mp_do_mapline(MP mp);
```

1240. **static void** *mp_do_mapfile*(**MP** *mp*)

```
{
  mp_get_x_next(mp); mp_scan_expression(mp);
  if (mp→cur_exp.type ≠ mp_string_type) ⟨Complain about improper map operation 1241⟩
  else {
    mp_map_file(mp, cur_exp_str());
  }
}
static void mp_do_mapline(MP mp)
{
  mp_get_x_next(mp); mp_scan_expression(mp);
  if (mp→cur_exp.type ≠ mp_string_type) ⟨Complain about improper map operation 1241⟩
  else {
    mp_map_line(mp, cur_exp_str());
  }
}
```

1241. ⟨Complain about improper map operation 1241⟩ ≡

```
{
  const char *hlp[] ← {"Only␣known␣strings␣can␣be␣map␣files␣or␣map␣lines.", Λ};
  mp_disp_err(mp, Λ); mp_back_error(mp, "Unsuitable␣expression", hlp, true); mp_get_x_next(mp);
}
```

This code is used in section 1240.

1242. To print *scaled* value to PDF output we need some subroutines to ensure accuracy.

#define *max_integer* #7FFFFFFF ▷ $2^{31} - 1$ ◁

⟨Global variables 18⟩ +≡

```
integer ten_pow[10];   ▷ 10^0..10^9 ◁
integer scaled_out;   ▷ amount of scaled that was taken out in divide_scaled ◁
```

1243. ⟨Set initial values of key variables 42⟩ +≡

```
mp→ten_pow[0] ← 1;
for (i ← 1; i ≤ 9; i++) {
  mp→ten_pow[i] ← 10 * mp→ten_pow[i − 1];
}
```

1244. Shipping pictures out. The *ship_out* procedure, to be described below, is given a pointer to an edge structure. Its mission is to output a file containing the PostScript description of an edge structure.

1245. Each time an edge structure is shipped out we write a new PostScript output file named according to the current **charcode**.

This is the only backend function that remains in the main *mpost.w* file. There are just too many variable accesses needed for status reporting etcetera to make it worthwhile to move the code to *psout.w*.

⟨ Internal library declarations 14 ⟩ +≡
void *mp_open_output_file*(**MP** *mp*);
char ∗*mp_get_output_file_name*(**MP** *mp*);
char ∗*mp_set_output_file_name*(**MP** *mp*, **integer** *c*);

1246. **static void** *mp_append_to_template*(**MP** *mp*, **integer** *ff*, **integer** *c*, **boolean** *rounding*)

```
{
  if (internal_type(c) ≡ mp_string_type) {
    char *ss ← mp_str(mp, internal_string(c));
    mp_print(mp, ss);
  }
  else if (internal_type(c) ≡ mp_known) {
    if (rounding) {
      int cc ← round_unscaled(internal_value(c));
      print_with_leading_zeroes(cc, ff);
    }
    else {
      print_number(internal_value(c));
    }
  }
}
char *mp_set_output_file_name(MP mp, integer c)
{
  char *ss ← Λ;   ▷ filename extension proposal ◁
  char *nn ← Λ;   ▷ temp string for str() ◁
  unsigned old_setting;   ▷ previous selector setting ◁
  size_t i;   ▷ indexes into filename_template ◁
  integer f;   ▷ field width ◁
  str_room(1024);
  if (mp→job_name ≡ Λ) mp_open_log_file(mp);
  if (internal_string(mp_output_template) ≡ Λ) {
    char *s;   ▷ a file extension derived from c ◁
    if (c < 0) s ← xstrdup(".ps");
    else ⟨Use c to compute the file extension s 1247⟩
    mp_pack_job_name(mp, s); free(s); ss ← xstrdup(mp→name_of_file);
  }
  else {   ▷ initializations ◁
    mp_string s, n, ftemplate;   ▷ a file extension derived from c ◁
    mp_number saved_char_code;
    new_number(saved_char_code); number_clone(saved_char_code, internal_value(mp_char_code));
    set_internal_from_number(mp_char_code, unity_t);
    number_multiply_int(internal_value(mp_char_code), c);
    if (internal_string(mp_job_name) ≡ Λ) {
      if (mp→job_name ≡ Λ) {
        mp→job_name ← xstrdup("mpout");
      }
      ⟨Fix up mp→internal[mp_job_name] 872⟩;
    }
    old_setting ← mp→selector; mp→selector ← new_string; i ← 0; n ← mp_rts(mp, "");   ▷ initialize ◁
    ftemplate ← internal_string(mp_output_template);
    while (i < ftemplate→len) {
      f ← 0;
      if (*(ftemplate→str + i) ≡ '%') {
      CONTINUE: incr(i);
        if (i < ftemplate→len) {
          switch (*(ftemplate→str + i)) {
```

```
case 'j': mp_append_to_template(mp, f, mp_job_name, true); break;
case 'c':
  if (number_negative(internal_value(mp_char_code))) {
    mp_print(mp, "ps");
  }
  else {
    mp_append_to_template(mp, f, mp_char_code, true);
  }
  break;
case 'o': mp_append_to_template(mp, f, mp_output_format, true); break;
case 'd': mp_append_to_template(mp, f, mp_day, true); break;
case 'm': mp_append_to_template(mp, f, mp_month, true); break;
case 'y': mp_append_to_template(mp, f, mp_year, true); break;
case 'H': mp_append_to_template(mp, f, mp_hour, true); break;
case 'M': mp_append_to_template(mp, f, mp_minute, true); break;
case '{':
  {    ▷ look up a name ◁
    size_t l ← 0;
    size_t frst ← i + 1;
    while (i < ftemplate→len) {
      i++;
      if (*(ftemplate→str + i) ≡ '}') break;
      l++;
    }
    if (l > 0) {
      mp_sym p ← mp_id_lookup(mp, (char *)(ftemplate→str + frst), l, false);
      char *id ← xmalloc((l + 1), 1);
      (void) memcpy(id, (char *)(ftemplate→str + frst), (size_t) l); *(id + l) ← '\0';
      if (p ≡ Λ) {
        char err[256];
        mp_snprintf(err, 256,
            "requested␣identifier␣(%s)␣in␣outputtemplate␣not␣found.", id);
        mp_warn(mp, err);
      }
      else {
        if (eq_type(p) ≡ mp_internal_quantity) {
          if (equiv(p) ≡ mp_output_template) {
            char err[256];
            mp_snprintf(err, 256, "The␣appearance␣of␣outputtemplate␣inside\
                ␣outputtemplate␣is␣ignored.");
            mp_warn(mp, err);
          }
          else {
            mp_append_to_template(mp, f, equiv(p), false);
          }
        }
        else {
          char err[256];
          mp_snprintf(err, 256,
              "requested␣identifier␣(%s)␣in␣outputtemplate␣is␣not␣an␣internal.",
              id); mp_warn(mp, err);
```

```
                }
              }
              free(id);
            }
          }
          break;
        case '0': case '1': case '2': case '3': case '4': case '5': case '6': case '7':
          case '8': case '9':
          if ((f < 10)) f ← (f * 10) + ftemplate→str[i] − '0';
          goto CONTINUE; break;
        case '%': mp_print_char(mp, '%'); break;
        default:
          {
            char err[256];
            mp_snprintf(err, 256, "requested␣format␣(%c)␣in␣outputtemplate␣is␣unknown.",
                *(ftemplate→str + i)); mp_warn(mp, err);
          }
          mp_print_char(mp, *(ftemplate→str + i));
        }
      }
    }
    else {
      if (*(ftemplate→str + i) ≡ '.')
        if (n→len ≡ 0) n ← mp_make_string(mp);
      mp_print_char(mp, *(ftemplate→str + i));
    }
    incr(i);
  }
  s ← mp_make_string(mp); number_clone(internal_value(mp_char_code), saved_char_code);
  free_number(saved_char_code); mp→selector ← old_setting;
  if (n→len ≡ 0) {
    n ← s; s ← mp_rts(mp, "");
  }
  ss ← mp_str(mp, s); nn ← mp_str(mp, n); mp_pack_file_name(mp, nn, "", ss); delete_str_ref(n);
  delete_str_ref(s);
}
return ss;
}
char *mp_get_output_file_name(MP mp)
{
  char *f;
  char *saved_name;   ▷ saved name_of_file ◁
  saved_name ← xstrdup(mp→name_of_file);
  (void) mp_set_output_file_name(mp, round_unscaled(internal_value(mp_char_code)));
  f ← xstrdup(mp→name_of_file); mp_pack_file_name(mp, saved_name, Λ, Λ); free(saved_name);
  return f;
}
void mp_open_output_file(MP mp)
{
  char *ss;   ▷ filename extension proposal ◁
  int c;   ▷ charcode rounded to the nearest integer ◁
```

```
    c ← round_unscaled(internal_value(mp_char_code)); ss ← mp_set_output_file_name(mp, c);
    while (¬mp_open_out(mp, (void *) &mp→output_file, mp_filetype_postscript))
      mp_prompt_file_name(mp, "file␣name␣for␣output", ss);
    mp_store_true_output_filename(mp, c);
  }
```

1247. The file extension created here could be up to five characters long in extreme cases so it may have to be shortened on some systems.

```
⟨Use c to compute the file extension s 1247⟩ ≡
  {
    s ← xmalloc(14, 1); mp_snprintf(s, 13, ".%i", (int) c); s[13] ← '\0';
  }
```

This code is used in section 1246.

1248. The user won't want to see all the output file names so we only save the first and last ones and a count of how many there were. For this purpose files are ordered primarily by **charcode** and secondarily by order of creation.

```
⟨Internal library declarations 14⟩ +≡
  void mp_store_true_output_filename(MP mp, int c);
```

1249.

```
void mp_store_true_output_filename(MP mp, int c)
  {
    if ((c < mp→first_output_code) ∧ (mp→first_output_code ≥ 0)) {
      mp→first_output_code ← c; xfree(mp→first_file_name);
      mp→first_file_name ← xstrdup(mp→name_of_file);
    }
    if (c ≥ mp→last_output_code) {
      mp→last_output_code ← c; xfree(mp→last_file_name); mp→last_file_name ← xstrdup(mp→name_of_file);
    }
    set_internal_string(mp_output_filename, mp_rts(mp, mp→name_of_file));
  }
```

1250.

```
⟨Global variables 18⟩ +≡
  char *first_file_name;
  char *last_file_name;    ▷ full file names ◁
  integer first_output_code;
  integer last_output_code;    ▷ rounded charcode values ◁
  integer total_shipped;    ▷ total number of ship_out operations completed ◁
```

1251.

```
⟨Set initial values of key variables 42⟩ +≡
  mp→first_file_name ← xstrdup(""); mp→last_file_name ← xstrdup(""); mp→first_output_code ← 32768;
  mp→last_output_code ← −32768; mp→total_shipped ← 0;
```

1252.

```
⟨Dealloc variables 31⟩ +≡
  xfree(mp→first_file_name); xfree(mp→last_file_name);
```

1253.

```
⟨Begin the progress report for the output of picture c 1253⟩ ≡
  if ((int) mp→term_offset > mp→max_print_line − 6) mp_print_ln(mp);
  else if ((mp→term_offset > 0) ∨ (mp→file_offset > 0)) mp_print_char(mp, xord('␣'));
  mp_print_char(mp, xord('['));
  if (c ≥ 0) mp_print_int(mp, c)
```

This code is used in section 1268.

1254. ⟨ End progress report 1254 ⟩ ≡

mp_print_char(*mp*, *xord*('`]`')); *update_terminal*( ); *incr*(*mp*→*total_shipped*)

This code is used in section 1268.

1255. ⟨ Explain what output files were written 1255 ⟩ ≡

```
if (mp→total_shipped > 0) {
  mp_print_nl(mp, "");  mp_print_int(mp, mp→total_shipped);
  if (mp→noninteractive) {
    mp_print(mp, "␣figure");
    if (mp→total_shipped > 1) mp_print_char(mp, xord('s'));
    mp_print(mp, "␣created.");
  }
  else {
    mp_print(mp, "␣output␣file");
    if (mp→total_shipped > 1) mp_print_char(mp, xord('s'));
    mp_print(mp, "␣written:␣");  mp_print(mp, mp→first_file_name);
    if (mp→total_shipped > 1) {
      if (31 + strlen(mp→first_file_name) + strlen(mp→last_file_name) > (unsigned) mp→max_print_line)
        mp_print_ln(mp);
      mp_print(mp, "␣..␣");  mp_print(mp, mp→last_file_name);
    }
    mp_print_nl(mp, "");
  }
}
```

This code is used in section 1281.

1256. ⟨ Internal library declarations 14 ⟩ +≡

boolean *mp_has_font_size*(**MP** *mp*, **font_number** *f*);

1257. **boolean** *mp_has_font_size*(**MP** *mp*, **font_number** *f*)

```
{
  return (mp→font_sizes[f] ≠ Λ);
}
```

1258. The **special** command saves up lines of text to be printed during the next *ship_out* operation. The saved items are stored as a list of capsule tokens.

⟨ Global variables 18 ⟩ +≡

mp_node *last_pending*; ▷ the last token in a list of pending specials ◁

1259. ⟨ Declare action procedures for use by *do_statement* 1050 ⟩ +≡

static void *mp_do_special*(**MP** *mp*);

1260. **void** *mp_do_special*(**MP** *mp*)

```
{
  mp_get_x_next(mp);  mp_scan_expression(mp);
  if (mp→cur_exp.type ≠ mp_string_type) ⟨ Complain about improper special operation 1261 ⟩
  else {
    mp_link(mp→last_pending) ← mp_stash_cur_exp(mp);
    mp→last_pending ← mp_link(mp→last_pending);  mp_link(mp→last_pending) ← Λ;
  }
}
```

1261. ⟨ Complain about improper special operation 1261 ⟩ ≡

{
  const char $*hlp[\,] \leftarrow \{$"Only␣known␣strings␣are␣allowed␣for␣output␣as␣specials.", $\Lambda\}$;
  mp_disp_err(*mp*, Λ); *mp_back_error*(*mp*, "Unsuitable␣expression", *hlp*, *true*); *mp_get_x_next*(*mp*);
}

This code is used in section 1260.

1262. On the export side, we need an extra object type for special strings.

⟨ Graphical object codes 463 ⟩ +≡
  mp_special_code ← 8,

1263. ⟨ Export pending specials 1263 ⟩ ≡

  $p \leftarrow$ *mp_link*(*mp*→*spec_head*);
  while ($p \neq \Lambda$) {
    mp_special_object $*tp$;
    tp ← (**mp_special_object** ∗) *mp_new_graphic_object*(*mp*, *mp_special_code*);
    gr_pre_script(*tp*) ← *mp_xstrdup*(*mp*, *mp_str*(*mp*, *value_str*(*p*)));
    if (*hh*→*body* ≡ Λ) *hh*→*body* ← (**mp_graphic_object** ∗) *tp*;
    else *gr_link*(*hp*) ← (**mp_graphic_object** ∗) *tp*;
    hp ← (**mp_graphic_object** ∗) *tp*; $p \leftarrow$ *mp_link*(*p*);
  }
  mp_flush_token_list(*mp*, *mp_link*(*mp*→*spec_head*)); *mp_link*(*mp*→*spec_head*) ← Λ;
  mp→*last_pending* ← *mp*→*spec_head*

This code is used in section 1265.

1264. We are now ready for the main output procedure. Note that the *selector* setting is saved in a global variable so that *begin_diagnostic* can access it.

⟨ Declare the PostScript output procedures 1264 ⟩ ≡
  static void *mp_ship_out*(**MP** *mp*, **mp_node** *h*);

This code is used in section 1134.

1265. Once again, the *gr_XXXX* macros are defined in *mppsout.h*

```
#define export_color(q, p)
    if (mp_color_model(p) ≡ mp_uninitialized_model) {
      gr_color_model(q) ← (unsigned char)
          (number_to_scaled(internal_value(mp_default_color_model))/65536); gr_cyan_val(q) ← 0;
      gr_magenta_val(q) ← 0; gr_yellow_val(q) ← 0;
      gr_black_val(q) ← ((gr_color_model(q) ≡ mp_cmyk_model ?
          number_to_scaled(unity_t) : 0)/65536.0);
    }
    else {
      gr_color_model(q) ← (unsigned char) mp_color_model(p);
      gr_cyan_val(q) ← number_to_double(p→cyan);
      gr_magenta_val(q) ← number_to_double(p→magenta);
      gr_yellow_val(q) ← number_to_double(p→yellow); gr_black_val(q) ← number_to_double(p→black);
    }
#define export_scripts(q, p)
    if (mp_pre_script(p) ≠ Λ) gr_pre_script(q) ← mp_xstrdup(mp, mp_str(mp, mp_pre_script(p)));
    if (mp_post_script(p) ≠ Λ) gr_post_script(q) ← mp_xstrdup(mp, mp_str(mp, mp_post_script(p)));

  struct mp_edge_object *mp_gr_export(MP mp, mp_edge_header_node h)
  {
    mp_node p;   ▷ the current graphical object ◁
    integer t;   ▷ a temporary value ◁
    integer c;   ▷ a rounded charcode ◁
    mp_number d_width;   ▷ the current pen width ◁
    mp_edge_object *hh;   ▷ the first graphical object ◁
    mp_graphic_object *hq;   ▷ something hp points to ◁
    mp_text_object *tt;
    mp_fill_object *tf;
    mp_stroked_object *ts;
    mp_clip_object *tc;
    mp_bounds_object *tb;
    mp_graphic_object *hp ← Λ;   ▷ the current graphical object ◁

    mp_set_bbox(mp, h, true); hh ← xmalloc(1, sizeof(mp_edge_object)); hh→body ← Λ; hh→next ← Λ;
    hh→parent ← mp; hh→minx ← number_to_double(h→minx);
    hh→minx ← (fabs(hh→minx) < 0.00001 ? 0 : hh→minx); hh→miny ← number_to_double(h→miny);
    hh→miny ← (fabs(hh→miny) < 0.00001 ? 0 : hh→miny); hh→maxx ← number_to_double(h→maxx);
    hh→maxx ← (fabs(hh→maxx) < 0.00001 ? 0 : hh→maxx); hh→maxy ← number_to_double(h→maxy);
    hh→maxy ← (fabs(hh→maxy) < 0.00001 ? 0 : hh→maxy); hh→filename ← mp_get_output_file_name(mp);
    c ← round_unscaled(internal_value(mp_char_code)); hh→charcode ← c;
    hh→width ← number_to_double(internal_value(mp_char_wd));
    hh→height ← number_to_double(internal_value(mp_char_ht));
    hh→depth ← number_to_double(internal_value(mp_char_dp));
    hh→ital_corr ← number_to_double(internal_value(mp_char_ic)); ⟨Export pending specials 1263⟩;
    p ← mp_link(edge_list(h));
    while (p ≠ Λ) {
      hq ← mp_new_graphic_object(mp, (int)((mp_type(p) − mp_fill_node_type) + 1));
      switch (mp_type(p)) {
      case mp_fill_node_type:
        {
          mp_fill_node p0 ← (mp_fill_node) p;
```

```
      tf ← (mp_fill_object *) hq;  gr_pen_p(tf) ← mp_export_knot_list(mp, mp_pen_p(p0));
      new_number(d_width);  mp_get_pen_scale(mp, &d_width, mp_pen_p(p0));    ▷ whats the point ? ◁
      free_number(d_width);
      if ((mp_pen_p(p0) ≡ Λ) ∨ pen_is_elliptical(mp_pen_p(p0))) {
        gr_path_p(tf) ← mp_export_knot_list(mp, mp_path_p(p0));
      }
      else {
        mp_knot pc, pp;
        pc ← mp_copy_path(mp, mp_path_p(p0));
        pp ← mp_make_envelope(mp, pc, mp_pen_p(p0), p0→ljoin, 0, p0→miterlim);
        gr_path_p(tf) ← mp_export_knot_list(mp, pp);  mp_toss_knot_list(mp, pp);
        pc ← mp_htap_ypoc(mp, mp_path_p(p0));
        pp ← mp_make_envelope(mp, pc, mp_pen_p((mp_fill_node) p), p0→ljoin, 0, p0→miterlim);
        gr_htap_p(tf) ← mp_export_knot_list(mp, pp);  mp_toss_knot_list(mp, pp);
      }
      export_color(tf, p0);  export_scripts(tf, p);  gr_ljoin_val(tf) ← p0→ljoin;
      gr_miterlim_val(tf) ← number_to_double(p0→miterlim);
    }
    break;
  case mp_stroked_node_type:
    {
      mp_stroked_node p0 ← (mp_stroked_node) p;
      ts ← (mp_stroked_object *) hq;  gr_pen_p(ts) ← mp_export_knot_list(mp, mp_pen_p(p0));
      new_number(d_width);  mp_get_pen_scale(mp, &d_width, mp_pen_p(p0));
      if (pen_is_elliptical(mp_pen_p(p0))) {
        gr_path_p(ts) ← mp_export_knot_list(mp, mp_path_p(p0));
      }
      else {
        mp_knot pc;
        pc ← mp_copy_path(mp, mp_path_p(p0));  t ← p0→lcap;
        if (mp_left_type(pc) ≠ mp_endpoint) {
          mp_left_type(mp_insert_knot(mp, pc, pc→x_coord, pc→y_coord)) ← mp_endpoint;
          mp_right_type(pc) ← mp_endpoint;  pc ← mp_next_knot(pc);  t ← 1;
        }
        pc ← mp_make_envelope(mp, pc, mp_pen_p(p0), p0→ljoin, (quarterword) t, p0→miterlim);
        gr_path_p(ts) ← mp_export_knot_list(mp, pc);  mp_toss_knot_list(mp, pc);
      }
      export_color(ts, p0);  export_scripts(ts, p);  gr_ljoin_val(ts) ← p0→ljoin;
      gr_miterlim_val(ts) ← number_to_double(p0→miterlim);  gr_lcap_val(ts) ← p0→lcap;
      gr_dash_p(ts) ← mp_export_dashes(mp, p0, d_width);  free_number(d_width);
    }
    break;
  case mp_text_node_type:
    {
      mp_text_node p0 ← (mp_text_node) p;
      tt ← (mp_text_object *) hq;
      gr_text_p(tt) ← mp_xstrldup(mp, mp_str(mp, mp_text_p(p)), mp_text_p(p)→len);
      gr_text_l(tt) ← (size_t) mp_text_p(p)→len;  gr_font_n(tt) ← (unsigned int) mp_font_n(p);
      gr_font_name(tt) ← mp_xstrdup(mp, mp→font_name[mp_font_n(p)]);
      gr_font_dsize(tt) ← mp→font_dsize[mp_font_n(p)]/65536.0;  export_color(tt, p0);
      export_scripts(tt, p);  gr_width_val(tt) ← number_to_double(p0→width);
```

```
        gr_height_val(tt) ← number_to_double(p0→height);
        gr_depth_val(tt) ← number_to_double(p0→depth); gr_tx_val(tt) ← number_to_double(p0→tx);
        gr_ty_val(tt) ← number_to_double(p0→ty); gr_txx_val(tt) ← number_to_double(p0→txx);
        gr_txy_val(tt) ← number_to_double(p0→txy); gr_tyx_val(tt) ← number_to_double(p0→tyx);
        gr_tyy_val(tt) ← number_to_double(p0→tyy);
      }
      break;
    case mp_start_clip_node_type: tc ← (mp_clip_object *) hq;
      gr_path_p(tc) ← mp_export_knot_list(mp, mp_path_p((mp_start_clip_node) p)); break;
    case mp_start_bounds_node_type: tb ← (mp_bounds_object *) hq;
      gr_path_p(tb) ← mp_export_knot_list(mp, mp_path_p((mp_start_bounds_node) p)); break;
    case mp_stop_clip_node_type: case mp_stop_bounds_node_type:   ▷ nothing to do here ◁
      break;
    default:   ▷ there are no other valid cases, but please the compiler ◁
      break;
    }
    if (hh→body ≡ Λ) hh→body ← hq;
    else gr_link(hp) ← hq;
    hp ← hq; p ← mp_link(p);
  }
  return hh;
}
```

1266. This function is only used for the *glyph* operator, so it takes quite a few shortcuts for cases that cannot appear in the output of *mp_ps_font_charstring*.

```
mp_edge_header_node mp_gr_import(MP mp, struct mp_edge_object *hh)
{
  mp_edge_header_node h;   ▷ the edge object ◁
  mp_node ph, pn, pt;   ▷ for adding items ◁
  mp_graphic_object *p;   ▷ the current graphical object ◁
  h ← mp_get_edge_header_node(mp); mp_init_edges(mp, h); ph ← edge_list(h); pt ← ph; p ← hh→body;
  set_number_from_double(h→minx, hh→minx); set_number_from_double(h→miny, hh→miny);
  set_number_from_double(h→maxx, hh→maxx); set_number_from_double(h→maxy, hh→maxy);
  while (p ≠ Λ) {
    switch (gr_type(p)) {
    case mp_fill_code:
      if (gr_pen_p((mp_fill_object *) p) ≡ Λ) {
        mp_number turns;
        new_number(turns); pn ← mp_new_fill_node(mp, Λ);
        mp_path_p((mp_fill_node) pn) ← mp_import_knot_list(mp, gr_path_p((mp_fill_object *) p));
        mp_color_model(pn) ← mp_grey_model;
        mp_turn_cycles(mp, &turns, mp_path_p((mp_fill_node) pn));
        if (number_negative(turns)) {
          set_number_to_unity(((mp_fill_node) pn)→grey); mp_link(pt) ← pn; pt ← mp_link(pt);
        }
        else {
          set_number_to_zero(((mp_fill_node) pn)→grey); mp_link(pn) ← mp_link(ph);
          mp_link(ph) ← pn;
          if (ph ≡ pt) pt ← pn;
        }
        free_number(turns);
      }
      break;
    case mp_stroked_code: case mp_text_code: case mp_start_clip_code: case mp_stop_clip_code:
      case mp_start_bounds_code: case mp_stop_bounds_code: case mp_special_code: break;
    }   ▷ all cases are enumerated ◁
    p ← p→next;
  }
  mp_gr_toss_objects(hh); return h;
}
```

1267. ⟨ Declarations 10 ⟩ +≡

```
struct mp_edge_object *mp_gr_export(MP mp, mp_edge_header_node h);
mp_edge_header_node mp_gr_import(MP mp, struct mp_edge_object *h);
```

1268. This function is now nearly trivial.

```
void mp_ship_out(MP mp, mp_node h)
{    ▷ output edge structure h ◁
  int c;    ▷ charcode rounded to the nearest integer ◁
  c ← round_unscaled(internal_value(mp_char_code));
  ⟨Begin the progress report for the output of picture c 1253⟩;
  (mp→shipout_backend)(mp, h); ⟨End progress report 1254⟩;
  if (number_positive(internal_value(mp_tracing_output)))
    mp_print_edges(mp, h, "␣(just␣shipped␣out)", true);
}
```

1269. ⟨Declarations 10⟩ +≡

```
static void mp_shipout_backend(MP mp, void *h);
```

1270.

```
void mp_shipout_backend(MP mp, void *voidh)
{
  char *s;
  mp_edge_object *hh;    ▷ the first graphical object ◁
  mp_edge_header_node h ← (mp_edge_header_node) voidh;
  hh ← mp_gr_export(mp, h); s ← Λ;
  if (internal_string(mp_output_format) ≠ Λ) s ← mp_str(mp, internal_string(mp_output_format));
  if (s ∧ strcmp(s, "svg") ≡ 0) {
    (void) mp_svg_gr_ship_out(hh, (number_to_scaled(internal_value(mp_prologues))/65536), false);
  }
  else if (s ∧ strcmp(s, "png") ≡ 0) {
    (void) mp_png_gr_ship_out(hh, (const char *)((internal_string(mp_output_format_options))→str),
        false);
  }
  else {
    (void) mp_gr_ship_out(hh, (number_to_scaled(internal_value(mp_prologues))/65536),
        (number_to_scaled(internal_value(mp_procset))/65536), false);
  }
  mp_gr_toss_objects(hh);
}
```

1271. ⟨Exported types 19⟩ +≡

```
typedef void (*mp_backend_writer)(MP, void *);
```

1272. ⟨Option variables 30⟩ +≡

```
mp_backend_writer shipout_backend;
```

1273. Now that we've finished *ship_out*, let's look at the other commands by which a user can send things to the `GF` file.

1274. ⟨Global variables 18⟩ +≡

```
psout_data ps;
svgout_data svg;
pngout_data png;
```

1275. ⟨Allocate or initialize variables 32⟩ +≡

```
mp_ps_backend_initialize(mp); mp_svg_backend_initialize(mp); mp_png_backend_initialize(mp);
```

1276. ⟨ Dealloc variables 31 ⟩ +≡
$mp\_ps\_backend\_free(mp)$; $mp\_svg\_backend\_free(mp)$; $mp\_png\_backend\_free(mp)$;

1277. Dumping and undumping the tables.

When MP is started, it is possible to preload a macro file containing definitions that will be usable in the main input file. This action even takes place automatically, based on the name of the executable (`mpost` will attempt to preload the macros in the file `mpost.mp`). If such a preload is not desired, the option variable *ini_version* has to be set *true*.

The variable *mem_file* holds the open file pointer.

⟨ Global variables 18 ⟩ +≡
void ∗*mem_file*; ▷ file for input or preloaded macros ◁

1278. ⟨ Declarations 10 ⟩ +≡
extern boolean *mp_load_preload_file*(**MP** *mp*);

1279. Preloading a file is a lot like *mp_run* itself, except that METAPOST should not exit and that a bit of trickery is needed with the input buffer to make sure that the preloading does not interfere with the actual job.

```
boolean mp_load_preload_file(MP mp)
{
  size_t k;
  in_state_record old_state;
  integer old_in_open ← mp→in_open;
  void *old_cur_file ← cur_file;
  char *fname ← xstrdup(mp→name_of_file);
  size_t l ← strlen(fname);
  old_state ← mp→cur_input; str_room(l);
  for (k ← 0; k < l; k++) {
    append_char(*(fname + k));
  }
  name ← mp_make_string(mp);
  if (¬mp→log_opened) {
    mp_open_log_file(mp);
  }    ▷ open_log_file doesn't show_context, so limit and loc needn't be set to meaningful values yet ◁
  if (((int) mp→term_offset + (int) strlen(fname)) > (mp→max_print_line − 2)) mp_print_ln(mp);
  else if ((mp→term_offset > 0) ∨ (mp→file_offset > 0)) mp_print_char(mp, xord('␣'));
  mp_print_char(mp, xord('(')); incr(mp→open_parens); mp_print(mp, fname); update_terminal( );
  {
    line ← 1; start ← loc ← limit + (mp→noninteractive ? 0 : 1); cur_file ← mp→mem_file;
    (void) mp_input_ln(mp, cur_file); mp_firm_up_the_line(mp); mp→buffer[limit] ← xord('%');
    mp→first ← (size_t)(limit + 1); loc ← start;
  }
  mp→reading_preload ← true;
  do {
    mp_do_statement(mp);
  } while (¬(cur_cmd( ) ≡ mp_stop));    ▷ "dump" or EOF ◁
  mp→reading_preload ← false; mp_primitive(mp, "dump", mp_relax, 0);    ▷ reset dump ◁
  while (mp→input_ptr > 0) {
    if (token_state) mp_end_token_list(mp);
    else mp_end_file_reading(mp);
  }
  while (mp→loop_ptr ≠ Λ) mp_stop_iteration(mp);
  while (mp→open_parens > 0) {
    mp_print(mp, "␣)"); decr(mp→open_parens);
  }
  while (mp→cond_ptr ≠ Λ) {
    mp_print_nl(mp, "(dump␣occurred␣when␣"); mp_print_cmd_mod(mp, mp_fi_or_else, mp→cur_if);
      ▷ 'if' or 'elseif' or 'else' ◁
    if (mp→if_line ≠ 0) {
      mp_print(mp, "␣on␣line␣"); mp_print_int(mp, mp→if_line);
    }
    mp_print(mp, "␣was␣incomplete)"); mp→if_line ← if_line_field(mp→cond_ptr);
    mp→cur_if ← mp_name_type(mp→cond_ptr); mp→cond_ptr ← mp_link(mp→cond_ptr);
  }    ▷ (mp→close_file)(mp, mp→mem_file); ◁
  cur_file ← old_cur_file; mp→cur_input ← old_state; mp→in_open ← old_in_open; return true;
}
```

1280. The main program. This is it: the part of METAPOST that executes all those procedures we have written.

Well—almost. We haven't put the parsing subroutines into the program yet; and we'd better leave space for a few more routines that may have been forgotten.

⟨Declare the basic parsing subroutines 934⟩;
⟨Declare miscellaneous procedures that were declared *forward* 253⟩

1281. Here we do whatever is needed to complete METAPOST's job gracefully on the local operating system. The code here might come into play after a fatal error; it must therefore consist entirely of "safe" operations that cannot produce error messages. For example, it would be a mistake to call *str_room* or *make_string* at this time, because a call on *overflow* might lead to an infinite loop.

```
void mp_close_files_and_terminate(MP mp)
{
  integer k;    ▷ all-purpose index ◁
  integer LH;    ▷ the length of the TFM header, in words ◁
  int lk_offset;    ▷ extra words inserted at beginning of lig_kern array ◁
  mp_node p;    ▷ runs through a list of TFM dimensions ◁

  if (mp→finished) return;
  ⟨Close all open files in the rd_file and wr_file arrays 1283⟩;
  if (number_positive(internal_value(mp_tracing_stats))) ⟨Output statistics about this job 1286⟩;
  wake_up_terminal(); ⟨Do all the finishing work on the TFM file 1285⟩;
  ⟨Explain what output files were written 1255⟩;
  if (mp→log_opened ∧ ¬mp→noninteractive) {
    wlog_cr; (mp→close_file)(mp, mp→log_file); mp→selector ← mp→selector − 2;
    if (mp→selector ≡ term_only) {
      mp_print_nl(mp, "Transcript␣written␣on␣"); mp_print(mp, mp→log_name);
      mp_print_char(mp, xord('.'));
    }
  }
  mp_print_ln(mp); mp→finished ← true;
}
```

1282. ⟨Declarations 10⟩ +≡

```
static void mp_close_files_and_terminate(MP mp);
```

1283. ⟨Close all open files in the *rd_file* and *wr_file* arrays 1283⟩ ≡

```
if (mp→rd_fname ≠ Λ) {
  for (k ← 0; k < (int) mp→read_files; k++) {
    if (mp→rd_fname[k] ≠ Λ) {
      (mp→close_file)(mp, mp→rd_file[k]); xfree(mp→rd_fname[k]);
    }
  }
}
if (mp→wr_fname ≠ Λ) {
  for (k ← 0; k < (int) mp→write_files; k++) {
    if (mp→wr_fname[k] ≠ Λ) {
      (mp→close_file)(mp, mp→wr_file[k]); xfree(mp→wr_fname[k]);
    }
  }
}
```

This code is used in section 1281.

1284. ⟨ Dealloc variables 31 ⟩ +≡

```
for (k ← 0; k < (int) mp→max_read_files; k++) {
  if (mp→rd_fname[k] ≠ Λ) {
    (mp→close_file)(mp, mp→rd_file[k]); xfree(mp→rd_fname[k]);
  }
}
xfree(mp→rd_file); xfree(mp→rd_fname);
for (k ← 0; k < (int) mp→max_write_files; k++) {
  if (mp→wr_fname[k] ≠ Λ) {
    (mp→close_file)(mp, mp→wr_file[k]); xfree(mp→wr_fname[k]);
  }
}
xfree(mp→wr_file); xfree(mp→wr_fname);
```

1285. We want to produce a TFM file if and only if *mp_fontmaking* is positive.

We reclaim all of the variable-size memory at this point, so that there is no chance of another memory overflow after the memory capacity has already been exceeded.

⟨ Do all the finishing work on the TFM file 1285 ⟩ ≡

```
if (number_positive(internal_value(mp_fontmaking))) {
  ⟨ Massage the TFM widths 1199 ⟩;
  mp_fix_design_size(mp); mp_fix_check_sum(mp);
  ⟨ Massage the TFM heights, depths, and italic corrections 1201 ⟩;
  set_number_to_zero(internal_value(mp_fontmaking));    ▷ avoid loop in case of fatal error ◁
  ⟨ Finish the TFM file 1212 ⟩;
}
```

This code is used in section 1281.

1286. The present section goes directly to the log file instead of using *print* commands, because there's no need for these strings to take up *str_pool* memory when a non-**stat** version of METAPOST is being used.

⟨ Output statistics about this job 1286 ⟩ ≡

```
if (mp→log_opened) {
  char s[128];
  wlog_ln("␣"); wlog_ln("Here␣is␣how␣much␣of␣MetaPost's␣memory␣you␣used:");
  mp_snprintf(s, 128, "␣%i␣string%s␣using␣%i␣character%s", (int) mp→max_strs_used,
      (mp→max_strs_used ≠ 1 ? "s" : ""), (int) mp→max_pl_used, (mp→max_pl_used ≠ 1 ? "s" : ""));
  wlog_ln(s); mp_snprintf(s, 128, "␣%i␣bytes␣of␣node␣memory", (int) mp→var_used_max); wlog_ln(s);
  mp_snprintf(s, 128, "␣%i␣symbolic␣tokens", (int) mp→st_count); wlog_ln(s);
  mp_snprintf(s, 128, "␣%ii,%in,%ip,%ib,%if␣stack␣positions␣out␣of␣%ii,%in,%ip,%ib,%if",
      (int) mp→max_in_stack, (int) mp→int_ptr, (int) mp→max_param_stack, (int) mp→max_buf_stack + 1,
      (int) mp→in_open_max − file_bottom, (int) mp→stack_size, (int) mp→max_internal,
      (int) mp→param_size, (int) mp→buf_size, (int) mp→max_in_open − file_bottom); wlog_ln(s);
}
```

This code is used in section 1281.

1287. It is nice to have some of the stats available from the API.

⟨ Exported function headers 22 ⟩ +≡

```
int mp_memory_usage(MP mp);
int mp_hash_usage(MP mp);
int mp_param_usage(MP mp);
int mp_open_usage(MP mp);
```

1288. **int** *mp_memory_usage*(**MP** *mp*)

```
{
  return (int) mp→var_used;
}
int mp_hash_usage(MP mp)
{
  return (int) mp→st_count;
}
int mp_param_usage(MP mp)
{
  return (int) mp→max_param_stack;
}
int mp_open_usage(MP mp)
{
  return (int) mp→max_in_stack;
}
```

1289. We get to the *final_cleanup* routine when **end** or **dump** has been scanned.

```
void mp_final_cleanup(MP mp)
{    ▷ -Wunused: integer c; ◁    ▷ 0 for end, 1 for dump ◁    ▷ clang: never read: c ← cur_mod( ); ◁
  if (mp→job_name ≡ Λ) mp_open_log_file(mp);
  while (mp→input_ptr > 0) {
    if (token_state) mp_end_token_list(mp);
    else mp_end_file_reading(mp);
  }
  while (mp→loop_ptr ≠ Λ) mp_stop_iteration(mp);
  while (mp→open_parens > 0) {
    mp_print(mp, "␣)"); decr(mp→open_parens);
  }
  while (mp→cond_ptr ≠ Λ) {
    mp_print_nl(mp, "(end␣occurred␣when␣"); mp_print_cmd_mod(mp, mp_fi_or_else, mp→cur_if);
      ▷ 'if' or 'elseif' or 'else' ◁
    if (mp→if_line ≠ 0) {
      mp_print(mp, "␣on␣line␣"); mp_print_int(mp, mp→if_line);
    }
    mp_print(mp, "␣was␣incomplete)"); mp→if_line ← if_line_field(mp→cond_ptr);
    mp→cur_if ← mp_name_type(mp→cond_ptr); mp→cond_ptr ← mp_link(mp→cond_ptr);
  }
  if (mp→history ≠ mp_spotless)
    if (((mp→history ≡ mp_warning_issued) ∨ (mp→interaction < mp_error_stop_mode)))
      if (mp→selector ≡ term_and_log) {
        mp→selector ← term_only;
        mp_print_nl(mp, "(see␣the␣transcript␣file␣for␣additional␣information)");
        mp→selector ← term_and_log;
      }
}
```

1290. ⟨Declarations 10⟩ +≡

```
static void mp_final_cleanup(MP mp);
static void mp_init_prim(MP mp);
static void mp_init_tab(MP mp);
```

1291. **void** *mp_init_prim*(**MP** *mp*)
{ ▷ initialize all the primitives ◁
⟨Put each of METAPOST's primitives into the hash table 204⟩;
}
void *mp_init_tab*(**MP** *mp*)
{ ▷ initialize other tables ◁
⟨Initialize table entries 186⟩;
}

1292. When we begin the following code, METAPOST's tables may still contain garbage; thus we must proceed cautiously to get bootstrapped in.

But when we finish this part of the program, METAPOST is ready to call on the *main_control* routine to do its work.

⟨Get the first line of input and prepare to start 1292⟩ ≡
{
⟨Initialize the input routines 720⟩;
if (¬*mp*→*ini_version*) {
if (¬*mp_load_preload_file*(*mp*)) {
mp→*history* ← *mp_fatal_error_stop*; **return** *mp*;
}
}
⟨Initializations following first line 1293⟩;
}

This code is used in section 20.

1293. ⟨Initializations following first line 1293⟩ ≡
mp→*buffer*[*limit*] ← (**ASCII_code**) '%'; *mp_fix_date_and_time*(*mp*);
if (*mp*→*random_seed* ≡ 0)
mp→*random_seed* ← (*number_to_scaled*(*internal_value*(*mp_time*))/*number_to_scaled*(*unity_t*)) + *number_to_scaled*(*internal_value*(*mp_day*));
init_randoms(*mp*→*random_seed*); *initialize_print_selector*( ); *mp_normalize_selector*(*mp*);
if (*loc* < *limit*)
if (*mp*→*buffer*[*loc*] ≠ '\\') *mp_start_input*(*mp*); ▷ **input** assumed ◁

This code is used in section 1292.

1294. Debugging.

1295. System-dependent changes. This section should be replaced, if necessary, by any special modification of the program that are necessary to make METAPOST work at a particular installation. It is usually best to design your change file so that all changes to previous sections preserve the section numbering; then everybody's version will be consistent with the published program. More extensive changes, which introduce new sections, can be inserted here; then only the index itself will get a new section number.

1296. Index. Here is where you can find all uses of each identifier in the program, with underlined entries pointing to where the identifier was defined. If the identifier is only one letter long, however, you get to see only the underlined entries. *All references are to section numbers instead of page numbers.*

This index also lists error messages and other aspects of the program that you might want to look up some day. For example, the entry for "system dependencies" lists all sections that should receive special attention from people who are installing METAPOST in a new operating environment. A list of various things that can't happen appears under "this can't happen". Approximately 25 sections are listed under "inner loop"; these account for more than 60% of METAPOST's running time, exclusive of input and output.