User's Guide

to

the PARI library

(version 2.3.5)

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Chapter 4:
Programming PARI in Library Mode

The *User's Guide to Pari/GP* gives in three chapters a general presentation of the system, of the `gp` calculator, and detailed explanation of high level PARI routines available through the calculator. The present manual assumes general familiarity with the contents of these chapters and the basics of ANSI C programming, and focuses on the usage of the PARI library. In this chapter, we introduce the general concepts of PARI programming and describe useful general purpose functions. Chapter 5 describes all available public low-level functions.

4.1 Introduction: initializations, universal objects.

To use PARI in library mode, you must write a C program and link it to the PARI library. See the installation guide or the Appendix to the *User's Guide to Pari/GP* on how to create and install the library and include files. A sample Makefile is presented in Appendix A, and a more elaborate one in `examples/Makefile`. The best way to understand how programming is done is to work through a complete example. We will write such a program in Section 4.8. Before doing this, a few explanations are in order.

First, one must explain to the outside world what kind of objects and routines we are going to use. This is done with the directive

```
#include <pari.h>
```

In particular, this header defines the fundamental type for all PARI objects: the type **GEN**, which is simply a pointer to `long`.

Before any PARI routine is called, one must initialize the system, and in particular the PARI stack which is both a scratchboard and a repository for computed objects. This is done with a call to the function

`void` **pari_init**`(size_t size, ulong maxprime)`

The first argument is the number of bytes given to PARI to work with, and the second is the upper limit on a precomputed prime number table; `size` should not reasonably be taken below 500000 but you may set `maxprime` = 0, although the system still needs to precompute all primes up to about 2^{16}.

We have now at our disposal:

• a PARI *stack* containing nothing. It is a big connected chunk of `size` bytes of memory. All your computations take place here. In large computations, unwanted intermediate results quickly clutter up memory so some kind of garbage collecting is needed. Most large systems do garbage collecting when the memory is getting scarce, and this slows down the performance. PARI takes a different approach: you must do your own cleaning up when the intermediate results are not needed anymore. Special purpose routines have been written to do this; we will see later how (and when) you should use them.

• the following *universal objects* (by definition, objects which do not belong to the stack): the integers 0, 1, −1 and 2 (respectively called `gen_0`, `gen_1`, `gen_m1` and `gen_2`), the fraction $\frac{1}{2}$ (`ghalf`), the complex number i (`gi`). All of these are of type `GEN`.

In addition, space is reserved for the polynomials x_v (`pol_x[`v`]`), and the polynomials 1_v (`pol_1[`v`]`). Here, x_v is the name of variable number v, where $0 \le v \le$ `MAXVARN`. Both `pol_1` and `pol_x` are arrays of `GEN`s, the index being the polynomial variable number.

However, except for the ones corresponding to variables 0 and `MAXVARN`, these polynomials are *not* created upon initialization. It is the programmer's responsibility to fill them before use. We will see how this is done in Section 4.6 (*never* through direct assignment).

• a *heap* which is just a linked list of permanent universal objects. For now, it contains exactly the ones listed above. You will probably very rarely use the heap yourself; and if so, only as a collection of copies of objects taken from the stack (called clones in the sequel). Thus you need not bother with its internal structure, which may change as PARI evolves. Some complex PARI functions create clones for special garbage collecting purposes, usually destroying them when returning.

• a table of primes (in fact of *differences* between consecutive primes), called **diffptr**, of type `byteptr` (pointer to `unsigned char`). Its use is described in appendix B.

• access to all the built-in functions of the PARI library. These are declared to the outside world when you include `pari.h`, but need the above things to function properly. So if you forget the call to `pari_init`, you will get a fatal error when running your program.

4.2 Important technical notes.

4.2.1 Types.

Although PARI objects all have the C type `GEN`, we will freely use the word **type** to refer to PARI dynamic subtypes: `t_INT`, `t_REAL`, etc. The declaration

```
GEN x;
```

declares a C variable of type `GEN`, but its "value" will be said to have type `t_INT`, `t_REAL`, etc. The meaning should always be clear from the context.

4.2.2 Type recursivity.

Conceptually, most PARI types are recursive. But the `GEN` type is a pointer to `long`, not to `GEN`. So special macros must be used to access `GEN`'s components. The simplest one is `gel`(V, i), where **el** stands for **el**ement, to access component number i of the `GEN` V. This is a valid `lvalue` (may be put on the left side of an assignment), and the following two constructions are exceedingly frequent

```
gel(V, i) = x;
x = gel(V, i);
```

where `x` and `V` are `GEN`s. This macro accesses and modifies directly the components of V and do not create a copy of the coefficient, contrary to all the library *functions*.

More generally, to retrieve the values of elements of lists of ... of lists of vectors we have the `gmael` macros (for **m**ultidimensional **a**rray **el**ement). The syntax is **gmael**$n(V, a_1, \ldots, a_n)$, where V is a `GEN`, the a_i are indexes, and n is an integer between 1 and 5. This stands for $x[a_1][a_2]\ldots[a_n]$, and returns a `GEN`. The macros `gel` (resp. `gmael`) are synonyms for `gmael1` (resp. `gmael2`).

Finally, the macro `gcoeff`(M, i, j) has exactly the meaning of `M[i,j]` in GP when `M` is a matrix. Note that due to the implementation of `t_MAT`s as horizontal lists of vertical vectors, `gcoeff(x,y)` is actually equivalent to `gmael(y,x)`. One should use `gcoeff` in matrix context, and `gmael` otherwise.

4.2.3 Variations on basic functions. In the library syntax descriptions in Chapter 3, we have only given the basic names of the functions. For example `gadd`(x, y) assumes that x and y are `GEN`s, and *creates* the result $x+y$ on the PARI stack. For most of the basic operators and functions, many other variants are available. We give some examples for `gadd`, but the same is true for all the basic operators, as well as for some simple common functions (a complete list is given in Chapter 5):

`GEN` **`gaddgs`**`(GEN x, long y)`

`GEN` **`gaddsg`**`(long x, GEN y)`

In the following three, `z` is a preexisting `GEN` and the result of the corresponding operation is put into `z`. The size of the PARI stack does not change:

`void` **`gaddz`**`(GEN x, GEN y, GEN z)`

`void` **`gaddgsz`**`(GEN x, long y, GEN z)`

`void` **`gaddsgz`**`(GEN x, GEN y, GEN z)`

There are also low level functions which are special cases of the above:

`GEN` **`addii`**`(GEN x, GEN y)`: here x and y are `GEN`s of type `t_INT` (this is not checked).

`GEN` **`addrr`**`(GEN x, GEN y)`: here x and y are `GEN`s of type `t_REAL` (this is not checked).

There also exist functions **addir**, **addri**, **mpadd** (whose two arguments can be of type `t_INT` or `t_REAL`), **addis** (to add a `t_INT` and a `long`) and so on.

All these specialized functions are of course more efficient than the general purpose ones, but note the hidden danger here: the types of the objects involved, if they are themselves results of a previous computation, are not completely predetermined. For instance the multiplication of a `t_REAL` by a `t_INT` *usually* gives a `t_REAL` result, except when the integer is 0, in which case according to the PARI philosophy the result is the exact integer 0. Hence if afterwards you call a function which specifically needs a `t_REAL` argument, you are in trouble.

The names are self-explanatory once you know that **i** stands for a `t_INT`, **r** for a `t_REAL`, **mp** for i or r, **s** for a signed C long integer, **u** for an unsigned C long integer; finally the suffix **z** means that the result is not created on the PARI stack but assigned to a preexisting GEN object passed as an extra argument. For completeness, Chapter 5 gives a description of these low-level functions.

4.2.4 Portability: 32-bit / 64-bit architectures.

PARI supports both 32-bit and 64-bit based machines, but not simultaneously! The library will have been compiled assuming a given architecture, and some of the header files you include (through `pari.h`) will have been modified to match the library.

Portable macros are defined to bypass most machine dependencies. If you want your programs to run identically on 32-bit and 64-bit machines, you have to use these, and not the corresponding numeric values, whenever the precise size of your `long` integers might matter. Here are the most important ones:

	64-bit	32-bit	
`BITS_IN_LONG`	64	32	
`LONG_IS_64BIT`	defined	undefined	
`DEFAULTPREC`	3	4	($\approx$ 19 decimal digits, see formula below)
`MEDDEFAULTPREC`	4	6	($\approx$ 38 decimal digits)
`BIGDEFAULTPREC`	5	8	($\approx$ 57 decimal digits)

For instance, suppose you call a transcendental function, such as

```
GEN gexp(GEN x, long prec).
```

The last argument `prec` is only used if `x` is an exact object, otherwise the relative precision is determined by the precision of `x`. But since `prec` sets the size of the inexact result counted in (`long`) *words* (including codewords), the same value of `prec` will yield different results on 32-bit and 64-bit machines. Real numbers have two codewords (see Section 4.5), so the formula for computing the bit accuracy is

$$\texttt{bit_accuracy}(\texttt{prec}) = (\texttt{prec} - 2) * \texttt{BITS_IN_LONG}$$

(this is actually the definition of a macro). The corresponding accuracy expressed in decimal digits would be

$$\texttt{bit_accuracy}(\texttt{prec}) * \log(2)/\log(10).$$

For example if the value of `prec` is 5, the corresponding accuracy for 32-bit machines is $(5-2) * \log(2^{32})/\log(10) \approx 28$ decimal digits, while for 64-bit machines it is $(5-2) * \log(2^{64})/\log(10) \approx 57$ decimal digits.

Thus, you must take care to change the `prec` parameter you are supplying according to the bit size, either using the default precisions given by the various `DEFAULTPREC`s, or by using conditional constructs of the form:

```
#ifndef LONG_IS_64BIT
  prec = 4;
#else
  prec = 6;
#endif
```

which is in this case equivalent to the statement `prec = MEDDEFAULTPREC;`.

Note that for parity reasons, half the accuracies available on 32-bit architectures (the odd ones) have no precise equivalents on 64-bit machines.

4.3 Garbage collection.

4.3.1 Why and how.

As we have seen, the `pari_init` routine allocates a big range of addresses, the *stack*, that are going to be used throughout. Recall that all PARI objects are pointers. Except for a few universal objects, they all point at some part of the stack.

The stack starts at the address `bot` and ends just before `top`. This means that the quantity

$$(\texttt{top} - \texttt{bot}) \,/\, \texttt{sizeof}(\texttt{long})$$

is (roughly) equal to the `size` argument of `pari_init`. The PARI stack also has a "current stack pointer" called **avma**, which stands for **av**ailable **m**emory **a**ddress. These three variables are global (declared by `pari.h`). They are of type `pari_sp`, which means *pari stack pointer*.

The stack is oriented upside-down: the more recent an object, the closer to `bot`. Accordingly, initially `avma` = `top`, and `avma` gets *decremented* as new objects are created. As its name indicates,

`avma` always points just *after* the first free address on the stack, and `(GEN)avma` is always (a pointer to) the latest created object. When `avma` reaches `bot`, the stack overflows, aborting all computations, and an error message is issued. To avoid this *you* need to clean up the stack from time to time, when intermediate objects are not needed anymore. This is called "*garbage collecting*."

We are now going to describe briefly how this is done. We will see many concrete examples in the next subsection.

• First, PARI routines do their own garbage collecting, which means that whenever a documented function from the library returns, only its result(s) have been added to the stack (non-documented ones may not do this). In particular, a PARI function that does not return a `GEN` does not clutter the stack. Thus, if your computation is small enough (e.g. you call few PARI routines, or most of them return `long` integers), then you do not need to do any garbage collecting. This is probably the case in many of your subroutines. Of course the objects that were on the stack *before* the function call are left alone. Except for the ones listed below, PARI functions only collect their own garbage.

• It may happen that all objects that were created after a certain point can be deleted — for instance, if the final result you need is not a `GEN`, or if some search proved futile. Then, it is enough to record the value of `avma` just *before* the first garbage is created, and restore it upon exit:

```
pari_sp av = avma; /* record initial avma */

garbage ...
avma = av; /* restore it */
```

All objects created in the `garbage` zone will eventually be overwritten: they should not be accessed anymore once `avma` has been restored.

• If you want to destroy (i.e. give back the memory occupied by) the *latest* PARI object on the stack (e.g. the latest one obtained from a function call), you can use the function

`void` **cgiv**`(GEN z)`

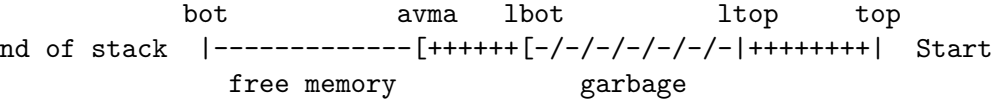
where `z` is the object you want to give back. This is equivalent to the above where the initial `av` is computed from `z`.

• Unfortunately life is not so simple, and sometimes you will want to give back accumulated garbage *during* a computation without losing recent data. For this you need the `gerepile` function (or one of its simpler variants described hereafter):

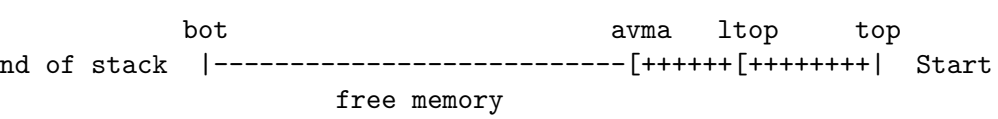
`GEN` **gerepile**`(pari_sp ltop, pari_sp lbot, GEN q)`

This function cleans up the stack between `ltop` and `lbot`, where `lbot` $<$ `ltop`, and returns the updated object `q`. This means:

1) we translate (copy) all the objects in the interval [`avma`, `lbot`[, so that its right extremity abuts the address `ltop`. Graphically



becomes:



where ++ denote significant objects, -- the unused part of the stack, and -/- the garbage we remove.

2) The function then inspects all the PARI objects between `avma` and `lbot` (i.e. the ones that we want to keep and that have been translated) and looks at every component of such an object which is not a codeword. Each such component is a pointer to an object whose address is either

— between `avma` and `lbot`, in which case it is suitably updated,

— larger than or equal to `ltop`, in which case it does not change, or

— between `lbot` and `ltop` in which case `gerepile` raises an error ("significant pointers lost in gerepile").

3) **avma** is updated (we add `ltop` − `lbot` to the old value).

4) We return the (possibly updated) object `q`: if `q` initially pointed between `avma` and `lbot`, we return the updated address, as in 2). If not, the original address is still valid, and is returned!

As stated above, no component of the remaining objects (in particular `q`) should belong to the erased segment [`lbot`, `ltop`[, and this is checked within `gerepile`. But beware as well that the addresses of the objects in the translated zone change after a call to `gerepile`, so you must not access any pointer which previously pointed into the zone below `ltop`. If you need to recover more than one object, use one of the `gerepilemany` functions below.

As a consequence of the preceding explanation, if a PARI object is to be relocated by gerepile then, apart from universal objects, the chunks of memory used by its components should be in consecutive memory locations. All `GEN`s created by documented PARI functions are guaranteed to satisfy this. This is because the `gerepile` function knows only about *two connected zones*: the garbage that is erased (between `lbot` and `ltop`) and the significant pointers that are copied and updated. If there is garbage interspersed with your objects, disaster occurs when we try to update them and consider the corresponding "pointers". In most cases of course the said garbage is in fact a bunch of other `GEN`s, in which case we simply waste time copying and updating them for nothing. But be wary when you allow objects to become disconnected.

In practice this is achieved by the following programming idiom:

```
ltop = avma; garbage(); lbot = avma; q = anything();
return gerepile(ltop, lbot, q); /* returns the updated q */
```

Beware that

```
ltop = avma; garbage();
return gerepile(ltop, avma, anything())
```

might work, but should be frowned upon. We cannot predict whether `avma` is evaluated after or before the call to `anything()`: it depends on the compiler. If we are out of luck, it is *after* the call, so the result belongs to the garbage zone and the `gerepile` statement becomes equivalent to `avma = ltop`. Thus we return a pointer to random garbage.

• A simple variant is

`GEN` **gerepileupto**`(pari_sp ltop, GEN q)`

which cleans the stack between `ltop` and the *connected* object `q` and returns `q` updated. For this to work, `q` must have been created *before* all its components, otherwise they would belong to the garbage zone! Unless mentioned otherwise, documented PARI functions guarantee this.

• Another variant (a special case of `gerepileall` below, where $n = 1$) is

`GEN` **gerepilecopy**`(pari_sp ltop, GEN x))`

which is functionally equivalent to `gerepileupto(ltop, gcopy(x))` but more efficient. In this case, the `GEN` parameter `x` need not satisfy any property before the garbage collection (it may be disconnected, components created before the root and so on). Of course, this is less efficient than either `gerepileupto` or `gerepile`, because `x` has to be copied to a clean stack zone first.

• To cope with complicated cases where many objects have to be preserved, you can use

`void` **gerepileall**`(pari_sp ltop, int n, ...)`

where the routine expects n further arguments, which are the *addresses* of the `GEN`s you want to preserve. It cleans up the most recent part of the stack (between `ltop` and `avma`), updating all the `GEN`s added to the argument list. A copy is done just before the cleaning to preserve them, so they do not need to be connected before the call. With `gerepilecopy`, this is the most robust of the `gerepile` functions (the less prone to user error), hence the slowest.

An alternative syntax, obsolete but kept for backward compatibility, is given by

`void` **gerepilemany**`(pari_sp ltop, GEN *gptr[], int n)`

which works exactly as above, except that the preserved `GEN`s are the elements of the array `gptr` (of length n): `gptr[0]`, `gptr[1]`, ..., `gptr[`n`-1]`.

• More efficient, but tricky to use is

`void` **gerepilemanysp**`(pari_sp ltop, pari_sp lbot, GEN *gptr[], int n)`

which cleans the stack between `lbot` and `ltop` and updates the `GEN`s pointed at by the elements of `gptr` without doing any copying. This is subject to the same restrictions as `gerepile`, the only difference being that more than one address gets updated.

4.3.2 Examples.

4.3.2.1 gerepile

Let `x` and `y` be two preexisting PARI objects and suppose that we want to compute $\mathtt{x}^2 + \mathtt{y}^2$. This is done using the following program:

```
GEN p1 = gsqr(x);
GEN p2 = gsqr(y), z = gadd(p1,p2);
```

The `GEN z` indeed points at the desired quantity. However, consider the stack: it contains as unnecessary garbage `p1` and `p2`. More precisely it contains (in this order) `z`, `p2`, `p1`. (Recall that, since the stack grows downward from the top, the most recent object comes first.)

It is not possible to get rid of `p1`, `p2` before `z` is computed, since they are used in the final operation. We cannot record `avma` before `p1` is computed and restore it later, since this would destroy `z` as well. It is not possible either to use the function `cgiv` since `p1` and `p2` are not at the bottom of the stack and we do not want to give back `z`.

But using `gerepile`, we can give back the memory locations corresponding to `p1`, `p2`, and move the object `z` upwards so that no space is lost. Specifically:

```
pari_sp ltop = avma;  /* remember the current address of the top of the stack */
GEN p1 = gsqr(x);
```

```
GEN p2 = gsqr(y);
pari_sp lbot = avma;  /* keep the address of the bottom of the garbage pile */
GEN z = gadd(p1, p2); /* z is now the last object on the stack */
z = gerepile(ltop, lbot, z);
```

Of course, the last two instructions could also have been written more simply:

```
z = gerepile(ltop, lbot, gadd(p1,p2));
```

In fact `gerepileupto` is even simpler to use, because the result of `gadd` is the last object on the stack and `gadd` is guaranteed to return an object suitable for `gerepileupto`:

```
ltop = avma;
z = gerepileupto(ltop, gadd(gsqr(x), gsqr(y)));
```

Make sure you understand exactly what has happened before you go on (use the figure from the preceding section).

Remark on assignments and gerepile: When the tree structure and the size of the PARI objects which will appear in a computation are under control, one may allocate sufficiently large objects at the beginning, use assignment statements, then simply restore `avma`. Coming back to the above example, note that *if* we know that x and y are of type real fitting into `DEFAULTPREC` words, we can program without using `gerepile` at all:

```
z = cgetr(DEFAULTPREC); ltop = avma;
gaffect(gadd(gsqr(x), gsqr(y)), z);
avma = ltop;
```

This is often *slower* than a craftily used `gerepile` though, and certainly more cumbersome to use. As a rule, assignment statements should generally be avoided.

Variations on a theme: it is often necessary to do several `gerepile`s during a computation. However, the fewer the better. The only condition for `gerepile` to work is that the garbage be connected. If the computation can be arranged so that there is a minimal number of connected pieces of garbage, then it should be done that way.

For example suppose we want to write a function of two `GEN` variables `x` and `y` which creates the vector $[\mathtt{x}^2 + \mathtt{y}, \mathtt{y}^2 + \mathtt{x}]$. Without garbage collecting, one would write:

```
p1 = gsqr(x); p2 = gadd(p1, y);
p3 = gsqr(y); p4 = gadd(p3, x); z = cgetg(3, t_VEC);
gel(z, 1) = p2;
gel(z, 2) = p4;
```

This leaves a dirty stack containing (in this order) `z`, `p4`, `p3`, `p2`, `p1`. The garbage here consists of `p1` and `p3`, which are separated by `p2`. But if we compute `p3` *before* `p2` then the garbage becomes connected, and we get the following program with garbage collecting:

```
ltop = avma; p1 = gsqr(x); p3 = gsqr(y);
lbot = avma; z = cgetg(3, t_VEC);
gel(z, 1) = gadd(p1,y);
gel(z, 2) = gadd(p3,x); z = gerepile(ltop,lbot,z);
```

Finishing by `z = gerepileupto(ltop, z)` would be ok as well. Beware that

```
ltop = avma; p1 = gadd(gsqr(x), y); p3 = gadd(gsqr(y), x);
```

```
z = cgetg(3, t_VEC);
gel(z, 1) = p1;
gel(z, 2) = p3; z = gerepileupto(ltop,z); /* WRONG */
```

is a disaster since `p1` and `p3` are created before `z`, so the call to `gerepileupto` overwrites them, leaving `gel(z, 1)` and `gel(z, 2)` pointing at random data! On the other hand

```
ltop = avma; z = cgetg(3, t_VEC);
gel(z, 1) = gadd(gsqr(x), y);
gel(z, 2) = gadd(gsqr(y), x); z = gerepileupto(ltop,z); /* INEFFICIENT */
```

leaves the results of `gsqr(x)` and `gsqr(y)` on the stack (and lets `gerepileupto` update them for naught). Finally, the most elegant and efficient version (with respect to time and memory use) is as follows

```
z = cgetg(3, t_VEC);
ltop = avma; gel(z, 1) = gerepileupto(ltop, gadd(gsqr(x), y));
ltop = avma; gel(z, 2) = gerepileupto(ltop, gadd(gsqr(y), x));
```

which avoids updating the container `z` and cleans up its components individually, as soon as they are computed.

One last example. Let us compute the product of two complex numbers x and y, using the $3M$ method which requires 3 multiplications instead of the obvious 4. Let $z = x*y$, and set $x = x_r + i*x_i$ and similarly for y and z. We compute $p_1 = x_r * y_r$, $p_2 = x_i * y_i$, $p_3 = (x_r + x_i) * (y_r + y_i)$, and then we have $z_r = p_1 - p_2$, $z_i = p_3 - (p_1 + p_2)$. The program is as follows:

```
ltop = avma;
p1 = gmul(gel(x,1), gel(y,1));
p2 = gmul(gel(x,2), gel(y,2));
p3 = gmul(gadd(gel(x,1), gel(x,2)), gadd(gel(y,1), gel(y,2)));
p4 = gadd(p1,p2);
lbot = avma; z = cgetg(3, t_COMPLEX);
gel(z, 1) = gsub(p1,p2);
gel(z, 2) = gsub(p3,p4); z = gerepile(ltop,lbot,z);
```

Exercise. Write a function which multiplies a matrix by a column vector. Hint: start with a `cgetg` of the result, and use `gerepile` whenever a coefficient of the result vector is computed. You can look at the answer in `src/basemath/gen1.c:MC_mul()`.

4.3.2.2 gerepileall

Let us now see why we may need the `gerepileall` variants. Although it is not an infrequent occurrence, we do not give a specific example but a general one: suppose that we want to do a computation (usually inside a larger function) producing more than one PARI object as a result, say two for instance. Then even if we set up the work properly, before cleaning up we have a stack which has the desired results `z1`, `z2` (say), and then connected garbage from lbot to ltop. If we write

```
z1 = gerepile(ltop, lbot, z1);
```

then the stack is cleaned, the pointers fixed up, but we have lost the address of `z2`. This is where we need the gerepileall function:

```
gerepileall(ltop, 2, &z1, &z2)
```

copies `z1` and `z2` to new locations, cleans the stack from `ltop` to the old `avma`, and updates the pointers `z1` and `z2`. Here we do not assume anything about the stack: the garbage can be disconnected and `z1`, `z2` need not be at the bottom of the stack. If all of these assumptions are in fact satisfied, then we can call `gerepilemanysp` instead, which is usually faster since we do not need the initial copy (on the other hand, it is less cache friendly).

A most important usage is "random" garbage collection during loops whose size requirements we cannot (or do not bother to) control in advance:

```
pari_sp ltop = avma, limit = stack_lim(avma, 1);
GEN x, y;
while (...)
{
  garbage(); x = anything();
  garbage(); y = anything(); garbage();
  if (avma < limit) /* memory is running low (half spent since entry) */
    gerepileall(ltop, 2, &x, &y);
}
```

Here we assume that only `x` and `y` are needed from one iteration to the next. As it would be costly to call gerepile once for each iteration, we only do it when it seems to have become necessary. The macro `stack_lim(avma,`n`)` denotes an address where $2^{n-1}/(2^{n-1}+1)$ of the remaining stack space is exhausted ($1/2$ for $n=1$, $2/3$ for $n=2$).

4.3.3 Comments.

First, `gerepile` has turned out to be a flexible and fast garbage collector for number-theoretic computations, which compares favorably with more sophisticated methods used in other systems. Our benchmarks indicate that the price paid for using `gerepile` and `gerepile`-related copies, when properly used, is usually less than 1 percent of the total running time, which is quite acceptable!

Second, it is of course harder on the programmer, and quite error-prone if you do not stick to a consistent PARI programming style. If all seems lost, just use `gerepilecopy` (or `gerepileall`) to fix up the stack for you. You can always optimize later when you have sorted out exactly which routines are crucial and what objects need to be preserved and their usual sizes.

If you followed us this far, congratulations, and rejoice: the rest is much easier.

4.4 Creation of PARI objects, assignments, conversions.

4.4.1 Creation of PARI objects. The basic function which creates a PARI object is the function **cgetg** whose prototype is:

`GEN` **`cgetg`**`(long length, long type)`.

Here `length` specifies the number of longwords to be allocated to the object, and type is the type number of the object, preferably in symbolic form (see Section 4.5 for the list of these). The precise effect of this function is as follows: it first creates on the PARI *stack* a chunk of memory of size `length` longwords, and saves the address of the chunk which it will in the end return. If the stack has been used up, a message to the effect that "the PARI stack overflows" is printed, and an error raised. Otherwise, it sets the type and length of the PARI object. In effect, it fills its first codeword (`z[0]` or `*z`). Many PARI objects also have a second codeword (types `t_INT`, `t_REAL`,

t_PADIC, t_POL, and t_SER). In case you want to produce one of those from scratch, which should be exceedingly rare, *it is your responsibility to fill this second codeword*, either explicitly (using the macros described in Section 4.5), or implicitly using an assignment statement (using gaffect).

Note that the argument length is predetermined for a number of types: 3 for types t_INTMOD, t_FRAC, t_COMPLEX, t_POLMOD, t_RFRAC, 4 for type t_QUAD and t_QFI, and 5 for type t_PADIC and t_QFR. However for the sake of efficiency, no checking is done in the function cgetg, so disasters will occur if you give an incorrect length.

Notes: 1) The main use of this function is create efficiently a constant object, or to prepare for later assignments (see Section 4.4.2). Most of the time you will use GEN objects as they are created and returned by PARI functions. In this case you do not need to use cgetg to create space to hold them.

2) For the creation of leaves, i.e. t_INT or t_REAL,

GEN **cgeti**(long length)

GEN **cgetr**(long length)

should be used instead of cgetg(length, t_INT) and cgetg(length, t_REAL) respectively. Finally

GEN **cgetc**(long prec)

creates a t_COMPLEX whose real and imaginary part are t_REALs allocated by cgetr(prec).

Examples: 1) Both z = cgeti(DEFAULTPREC) and cgetg(DEFAULTPREC, t_INT) create a t_INT whose "precision" is bit_accuracy(DEFAULTPREC) = 64. This means z can hold rational integers of absolute value less than 2^{64}. Note that in both cases, the second codeword is *not* filled. Of course we could use numerical values, e.g. cgeti(4), but this would have different meanings on different machines as bit_accuracy(4) equals 64 on 32-bit machines, but 128 on 64-bit machines.

2) The following creates a *complex number* whose real and imaginary parts can hold real numbers of precision bit_accuracy(MEDDEFAULTPREC) = 96 bits:

```
z = cgetg(3, t_COMPLEX);
gel(z, 1) = cgetr(MEDDEFAULTPREC);
gel(z, 2) = cgetr(MEDDEFAULTPREC);
```

or simply z = cgetc(MEDDEFAULTPREC).

3) To create a matrix object for 4×3 matrices:

```
z = cgetg(4, t_MAT);
for(i=1; i<4; i++) gel(z, i) = cgetg(5, t_COL);
```

If one wishes to create space for the matrix elements themselves, one has to follow this with a double loop to fill each column vector.

These last two examples illustrate the fact that since PARI types are recursive, all the branches of the tree must be created. The function **cgetg** creates only the "root", and other calls to cgetg must be made to produce the whole tree. For matrices, a common mistake is to think that z = cgetg(4, t_MAT) (for example) creates the root of the matrix: one needs also to create the column vectors of the matrix (obviously, since we specified only one dimension in the first cgetg!). This is because a matrix is really just a row vector of column vectors (hence a priori not a basic type), but it has been given a special type number so that operations with matrices become possible.

Finally, to facilitate input of constant objects when speed is not paramount, there are four `varargs` functions:

`GEN` **mkintn**`(long n, ...)` returns the non-negative `t_INT` whose development in base 2^{32} is given by the following n words (`unsigned long`). It is assumed that all such arguments are less than 2^{32} (the actual `sizeof(long)` is irrelevant, the behaviour is also as above on 64-bit machines).

```
mkintn(3, a2, a1, a0);
```

returns $a_2 2^{64} + a_1 2^{32} + a_0$.

`GEN` **mkpoln**`(long n, ...)` Returns the `t_POL` whose n coefficients (`GEN`) follow, in order of decreasing degree.

```
mkpoln(3, gen_1, gen_2, gen_0);
```

returns the polynomial $X^2 + 2X$ (in variable 0, use `setvarn` if you want other variable numbers). Beware that n is the number of coefficients, hence *one more* than the degree.

`GEN` **mkvecn**`(long n, ...)` returns the `t_VEC` whose n coefficients (`GEN`) follow.

`GEN` **mkcoln**`(long n, ...)` returns the `t_COL` whose n coefficients (`GEN`) follow.

Warning: Contrary to the policy of general PARI functions, the latter three functions do *not* copy their arguments, nor do they produce an object a priori suitable for `gerepileupto`. For instance

```
/* gerepile-safe: components are universal objects */
z = mkvecn(3, gen_1, gen_0, gen_2);

/* not OK for gerepileupto: stoi(3) creates component before root */
z = mkvecn(3, stoi(3), gen_0, gen_2);

/* NO! First vector component x is destroyed */
x = gclone(gen_1);
z = mkvecn(3, x, gen_0, gen_2);
gunclone(x);
```

The following function is also available as a special case of `mkintn`:

`GEN` **u2toi**`(ulong a, ulong b)`

Returns the `GEN` equal to $2^{32}a + b$, *assuming* that $a, b < 2^{32}$. This does not depend on `sizeof(long)`: the behaviour is as above on both 32 and 64-bit machines.

4.4.2 Assignments. Firstly, if `x` and `y` are both declared as `GEN` (i.e. pointers to something), the ordinary C assignment `y = x` makes perfect sense: we are just moving a pointer around. However, physically modifying either `x` or `y` (for instance, `x[1] = 0`) also changes the other one, which is usually not desirable.

Very important note: Using the functions described in this paragraph is inefficient and often awkward: one of the `gerepile` functions (see Section 4.3) should be preferred. See the paragraph end for one exception to this rule.

The general PARI assignment function is the function **gaffect** with the following syntax:

`void` **gaffect**`(GEN x, GEN y)`

Its effect is to assign the PARI object `x` into the *preexisting* object `y`. This copies the whole structure of `x` into `y` so many conditions must be met for the assignment to be possible. For instance it is allowed to assign a `t_INT` into a `t_REAL`, but the converse is forbidden. For that, you must use the truncation or rounding function of your choice (see section 3.2). It can also happen that `y` is not large enough or does not have the proper tree structure to receive the object `x`. For instance, let `y` the zero integer with length equal to 2; then `y` is too small to accommodate any non-zero `t_INT`. In general common sense tells you what is possible, keeping in mind the PARI philosophy which says that if it makes sense it is valid. For instance, the assignment of an imprecise object into a precise one does *not* make sense. However, a change in precision of imprecise objects is allowed.

All functions ending in "`z`" such as **gaddz** (see Section 4.2.3) implicitly use this function. In fact what they exactly do is record **avma** (see Section 4.3), perform the required operation, **gaffect** the result to the last operand, then restore the initial `avma`.

You can assign ordinary C long integers into a PARI object (not necessarily of type `t_INT`). Use the function **gaffsg** with the following syntax:

`void` **gaffsg**`(long s, GEN y)`

Note: due to the requirements mentioned above, it is usually a bad idea to use `gaffect` statements. There is one exception: for simple objects (e.g. leaves) whose size is controlled, they can be easier to use than gerepile, and about as efficient.

Coercion. It is often useful to coerce an inexact object to a given precision. For instance at the beginning of a routine where precision can be kept to a minimum; otherwise the precision of the input is used in all subsequent computations, which is inefficient if the latter is known to thousands of digits. One may use the `gaffect` function for this, but it is easier and more efficient to call

`GEN` **gtofp**`(GEN x, long prec)` converts the complex number `x` (`t_INT`, `t_REAL`, `t_FRAC`, `t_QUAD` or `t_COMPLEX`) to either a `t_REAL` or `t_COMPLEX` whose components are `t_REAL` of length `prec`.

4.4.3 Copy. It is also very useful to copy a PARI object, not just by moving around a pointer as in the `y = x` example, but by creating a copy of the whole tree structure, without pre-allocating a possibly complicated `y` to use with `gaffect`. The function which does this is called **gcopy**. Its syntax is:

`GEN` **gcopy**`(GEN x)`

and the effect is to create a new copy of x on the PARI stack.

Sometimes, on the contrary, a quick copy of the skeleton of `x` is enough, leaving pointers to the original data in `x` for the sake of speed instead of making a full recursive copy. Use `GEN` **shallowcopy**`(GEN x)` for this. Note that the result is not suitable for `gerepileupto` !

Make sure at this point that you understand the difference between `y = x`, `y = gcopy(x)`, `y = shallowcopy(x)` and `gaffect(x,y)`.

4.4.4 Clones. Sometimes, it is more efficient to create a *persistent* copy of a PARI object. This is not created on the stack but on the heap, hence unaffected by `gerepile` and friends. The function which does this is called **gclone**. Its syntax is:

`GEN` **gclone**`(GEN x)`

A clone can be removed from the heap (thus destroyed) using

`void` **gunclone**`(GEN x)`

No PARI object should keep references to a clone which has been destroyed!

4.4.5 Conversions. The following functions convert C objects to PARI objects (creating them on the stack as usual):

`GEN` **stoi**`(long s)`: C `long` integer ("small") to `t_INT`.

`GEN` **dbltor**`(double s)`: C `double` to `t_REAL`. The accuracy of the result is 19 decimal digits, i.e. a type `t_REAL` of length `DEFAULTPREC`, although on 32-bit machines only 16 of them are significant.

We also have the converse functions:

`long` **itos**`(GEN x)`: `x` must be of type `t_INT`,

`double` **rtodbl**`(GEN x)`: `x` must be of type `t_REAL`,

as well as the more general ones:

`long` **gtolong**`(GEN x)`,

`double` **gtodouble**`(GEN x)`.

4.5 Implementation of the PARI types.

We now go through each type and explain its implementation. Let `z` be a `GEN`, pointing at a PARI object. In the following paragraphs, we will constantly mix two points of view: on the one hand, `z` is treated as the C pointer it is, on the other, as PARI's handle on some mathematical entity, so we will shamelessly write $\texttt{z} \neq 0$ to indicate that the *value* thus represented is nonzero (in which case the *pointer* `z` is certainly non-`NULL`). We offer no apologies for this style. In fact, you had better feel comfortable juggling both views simultaneously in your mind if you want to write correct PARI programs.

Common to all the types is the first codeword `z[0]`, which we do not have to worry about since this is taken care of by `cgetg`. Its precise structure depends on the machine you are using, but it always contain the following data: the *internal type number* associated to the symbolic type name, the *length* of the root in longwords, and a technical bit which indicates whether the object is a clone or not (see Section 4.4.4). This last one is used by `gp` for internal garbage collecting, you will not have to worry about it.

These data can be handled through the following *macros*:

`long` **typ**`(GEN z)` returns the type number of `z`.

`void` **settyp**`(GEN z, long n)` sets the type number of `z` to `n` (you should not have to use this function if you use `cgetg`).

`long` **lg**`(GEN z)` returns the length (in longwords) of the root of `z`.

`long` **setlg**`(GEN z, long l)` sets the length of `z` to `l` (you should not have to use this function if you use `cgetg`; however, see an advanced example in Section 4.8).

`long` **isclone**`(GEN z)` is `z` a clone?

`void` **setisclone**`(GEN z)` sets the *clone* bit.

`void` **unsetisclone**`(GEN z)` unsets the *clone* bit.

Remark. The clone bit is there so that `gunclone` can check it is deleting an object which was allocated by `gclone`. Miscellaneous vector entries are often cloned by `gp` so that a GP statement like `v[1] = x` does not involve copying the whole of `v`: the component `v[1]` is deleted if its clone bit is set, and is replaced by a clone of `x`. Don't set/unset yourself the clone bit unless you know what you are doing: in particular *never* set the clone bit of a vector component when the said vector is scheduled to be uncloned. Hackish code may abuse the clone bit to tag objects for reasons unrelated to the above instead of using proper data structures. Don't do that.

These macros are written in such a way that you do not need to worry about type casts when using them: i.e. if `z` is a `GEN`, `typ(z[2])` is accepted by your compiler, as well as the more proper `typ(gel(z,2))`. Note that for the sake of efficiency, none of the codeword-handling macros check the types of their arguments even when there are stringent restrictions on their use.

Some types have a second codeword, used differently by each type, and we will describe it as we now consider each of them in turn.

4.5.1 Type `t_INT` (integer): this type has a second codeword `z[1]` which contains the following information:

the sign of `z`: coded as 1, 0 or -1 if `z` > 0, `z` $= 0$, `z` < 0 respectively.

the *effective length* of `z`, i.e. the total number of significant longwords. This means the following: apart from the integer 0, every integer is "normalized", meaning that the most significant mantissa longword is non-zero. However, the integer may have been created with a longer length. Hence the "length" which is in `z[0]` can be larger than the "effective length" which is in `z[1]`.

This information is handled using the following macros:

`long` **signe**`(GEN z)` returns the sign of `z`.

`void` **setsigne**`(GEN z, long s)` sets the sign of `z` to `s`.

`long` **lgefint**`(GEN z)` returns the effective length of `z`.

`void` **setlgefint**`(GEN z, long l)` sets the effective length of `z` to `l`.

The integer 0 can be recognized either by its sign being 0, or by its effective length being equal to 2. Now assume that `z` $\neq 0$, and let

$$|z| = \sum_{i=0}^{n} z_i B^i, \quad \text{where } z_n \neq 0 \text{ and } B = 2^{\texttt{BITS_IN_LONG}}.$$

With these notations, n is `lgefint(z) - 3`, and the mantissa of `z` may be manipulated via the following interface:

`GEN` **int_MSW**`(GEN z)` returns a pointer to the most significant word of `z`, z_n.

`GEN` **int_LSW**`(GEN z)` returns a pointer to the least significant word of `z`, z_0.

`GEN` **int_W**`(GEN z, long i)` returns the i-th significant word of `z`, z_i. Accessing the i-th significant word for $i > n$ yields unpredictable results.

`GEN` **int_precW**`(GEN z)` returns the previous (less significant) word of `z`, z_{i-1} assuming `z` points to z_i.

`GEN` **int_nextW**`(GEN z)` returns the next (more significant) word of `z`, z_{i+1} assuming `z` points to z_i.

Unnormalized integers, such that z_n is possibly 0, are explicitly forbidden. To enforce this, one may write an arbitrary mantissa then call

`void` **int_normalize**`(GEN z, long known0)`

normalizes in place a non-negative integer (such that z_n is possibly 0), assuming at least the first `known0` words are zero.

For instance a binary `and` could be implemented in the following way:

```
GEN AND(GEN x, GEN y) {
  long i, lx, ly, lout;
  long *xp, *yp, *outp; /* mantissa pointers */
  GEN out;

  if (!signe(x) || !signe(y)) return gen_0;
  lx = lgefint(x); xp = int_LSW(x);
  ly = lgefint(y); yp = int_LSW(y); lout = min(lx,ly); /* > 2 */

  out = cgeti(lout); out[1] = evalsigne(1) | evallgefint(lout);
  outp = int_LSW(out);
  for (i=2; i < lout; i++)
  {
    *outp = (*xp) & (*yp);
    outp  = int_nextW(outp);
    xp    = int_nextW(xp);
    yp    = int_nextW(yp);
  }
  if ( !*int_MSW(out) ) out = int_normalize(out, 1);
  return out;
}
```

This low-level interface is mandatory in order to write portable code since PARI can be compiled using various multiprecision kernels, for instance the native one or GNU MP, with incompatible internal structures (for one thing, the mantissa is oriented in different directions).

The following further macros are available:

`long` **mpodd**`(GEN x)` which is 1 if `x` is odd, and 0 otherwise.

`long` **mod2**`(GEN x)`, **mod4**`(x)`, and so on up to **mod64**`(x)`, which give the residue class of `x` modulo the corresponding power of 2, for *positive* `x`. By definition, `mod`$n(x) :=$ `mod`$n(|x|)$ for $x < 0$ (the macros disregard the sign), and the result is undefined if $x = 0$.

These macros directly access the binary data and are thus much faster than the generic modulo functions. Besides, they return long integers instead of `GEN`s, so they do not clutter up the stack.

4.5.2 Type `t_REAL` (real number): this type has a second codeword z[1] which also encodes its sign, obtained or set using the same functions as for a `t_INT`, and a binary exponent. This exponent is handled using the following macros:

`long` **expo**`(GEN z)` returns the exponent of `z`. This is defined even when `z` is equal to zero, see Section **??**.

`void` **setexpo**`(GEN z, long e)` sets the exponent of `z` to `e`.

Note the functions:

`long` **gexpo**`(GEN z)` which tries to return an exponent for `z`, even if `z` is not a real number.

`long` **gsigne**`(GEN z)` which returns a sign for `z`, even when `z` is neither real nor integer (a rational number for instance).

The real zero is characterized by having its sign equal to 0. If `z` is not equal to 0, then is is represented as $2^e M$, where e is the exponent, and $M \in [1, 2[$ is the mantissa of z, whose digits are stored in $\mathtt{z}[2], \ldots, \mathtt{z}[\mathtt{lg}(\mathtt{z}) - 1]$.

More precisely, let m be the integer (`z[2]`,..., `z[lg(z)-1]`) in base `2^BITS_IN_LONG`; here, `z[2]` is the most significant longword and is normalized, i.e. its most significant bit is 1. Then we have $M := m \cdot 2^{1-\mathtt{bit_accuracy}(\mathtt{lg}(\mathtt{z}))}$.

Thus, the real number 3.5 to accuracy `bit_accuracy(lg(z))` is represented as `z[0]` (encoding `type` = `t_REAL`, `lg(z)`), `z[1]` (encoding `sign` = 1, `expo` = 1), $\mathtt{z}[2] =$ `0xe0000000`, $\mathtt{z}[3] = \ldots = \mathtt{z}[\mathtt{lg}(\mathtt{z}) - 1] =$ `0x0`.

4.5.3 Type `t_INTMOD`: `z[1]` points to the modulus, and `z[2]` at the number representing the class `z`. Both are separate `GEN` objects, and both must be `t_INT`s, satisfying the inequality $0 \leq \mathtt{z}[2] < \mathtt{z}[1]$.

It is good practice to keep the modulus object on the heap, so that new `t_INTMOD`s resulting from operations can point at this common object, instead of carrying along their own copies of it on the stack. The library functions implement this practice almost by default.

4.5.4 Type `t_FRAC` (rational number): `z[1]` points to the numerator n, and `z[2]` to the denominator d. Both must be of type `t_INT` such that $d \neq 0$, $n > 0$ and $(n, d) = 1$ (see `gred_frac2`).

4.5.5 Type `t_COMPLEX` (complex number): `z[1]` points to the real part, and `z[2]` to the imaginary part. A priori `z[1]` and `z[2]` can be of any type, but only certain types are useful and make sense (mostly `t_INT`, `t_REAL` and `t_FRAC`).

4.5.6 Type `t_PADIC` (p-adic numbers): this type has a second codeword `z[1]` which contains the following information: the p-adic precision (the exponent of p modulo which the p-adic unit corresponding to `z` is defined if `z` is not 0), i.e. one less than the number of significant p-adic digits, and the exponent of `z`. This information can be handled using the following functions:

`long` **precp**`(GEN z)` returns the p-adic precision of `z`.

`void` **setprecp**`(GEN z, long l)` sets the p-adic precision of `z` to `l`.

`long` **valp**`(GEN z)` returns the p-adic valuation of `z` (i.e. the exponent). This is defined even if `z` is equal to 0, see Section **??**.

`void` **setvalp**`(GEN z, long e)` sets the p-adic valuation of `z` to `e`.

In addition to this codeword, `z[2]` points to the prime p, `z[3]` points to $p^{\mathrm{precp(z)}}$, and `z[4]` points to a`t_INT` representing the p-adic unit associated to `z` modulo `z[3]` (and to zero if `z` is zero). To summarize, if $z \neq 0$, we have the equality:

$$\mathtt{z} = p^{\mathrm{valp(z)}} * (\mathtt{z}[4] + O(\mathtt{z}[3])), \quad \text{where} \quad \mathtt{z}[3] = O(p^{\mathrm{precp(z)}}).$$

4.5.7 Type `t_QUAD` (quadratic number): `z[1]` points to the canonical polynomial P defining the quadratic field (as output by `quadpoly`), `z[2]` to the "real part" and `z[3]` to the "imaginary part". The latter are of type `t_INT`, `t_FRAC`, `t_INTMOD`, or `t_PADIC` and are to be taken as the coefficients of `z` with respect to the canonical basis $(1, X)$ or $\mathbf{Q}[X]/(P(X))$, see Section **??**. Exact complex numbers may be implemented as quadratics, but `t_COMPLEX` is in general more versatile (`t_REAL` components are allowed) and more efficient.

Operations involving a `t_QUAD` and `t_COMPLEX` are implemented by converting the `t_QUAD` to a `t_REAL` (or `t_COMPLEX` with `t_REAL` components) to the accuracy of the `t_COMPLEX`. As a consequence, operations between `t_QUAD` and *exact* `t_COMPLEX`s are not allowed.

4.5.8 Type `t_POLMOD` (polmod): as for `t_INTMOD`s, `z[1]` points to the modulus, and `z[2]` to a polynomial representing the class of `z`. Both must be of type `t_POL` in the same variable, satisfying the inequality $\deg \mathtt{z}[2] < \deg \mathtt{z}[1]$. However, `z[2]` is allowed to be a simplification of such a polynomial, e.g a scalar. This is tricky considering the hierarchical structure of the variables; in particular, a polynomial in variable of *lesser* priority (see Section **??**) than the modulus variable is valid, since it is considered as the constant term of a polynomial of degree 0 in the correct variable. On the other hand a variable of *greater* priority is not acceptable; see Section **??** for the problems which may arise.

4.5.9 Type `t_POL` (polynomial): this type has a second codeword. It contains a "*sign*": 0 if the polynomial is equal to 0, and 1 if not (see however the important remark below) and a *variable number* (e.g. 0 for x, 1 for y, etc...).

These data can be handled with the following macros: **signe** and **setsigne** as for `t_INT` and `t_REAL`,

`long` **varn**`(GEN z)` returns the variable number of the object `z`,

`void` **setvarn**`(GEN z, long v)` sets the variable number of `z` to `v`.

The variable numbers encode the relative priorities of variables as discussed in Section **??**. We will give more details in Section 4.6. Note also the function `long` **gvar**`(GEN z)` which tries to return a variable number for `z`, even if `z` is not a polynomial or power series. The variable number of a scalar type is set by definition equal to `BIGINT`, which has lower priority than any other variable number.

The components `z[2]`, `z[3]`,...`z[lg(z)-1]` point to the coefficients of the polynomial *in ascending order*, with `z[2]` being the constant term and so on.

For an object of type `t_POL`, `leading_term`, `constant_term`, `degpol` return a pointer to the leading term (with respect to the main variable of course), constant term, and degree of the polynomial (with the convention $\deg(0) = -1$). Applied to any other type, the result is unspecified. Note that no copy is made on the pari stack so the returned value is not safe for a basic `gerepile` call. Note that $\mathtt{degpol}(\mathtt{z}) = \mathtt{lg}(\mathtt{z}) - 3$.

The leading term is not allowed to be an exact 0 (*unnormalized polynomial*). To prevent this, one may use

`GEN` **normalizepol**`(GEN x)` applied to an unnormalized `t_POL x` (with all coefficients correctly set except that `leading_term(x)` might be zero), normalizes `x` correctly in place and returns `x`. For internal use.

`long` **degree**`(GEN x)` returns the degree of `x` with respect to its main variable even when `x` is not a polynomial (a rational function for instance). By convention, the degree of 0 is -1.

Important remark. A zero polynomial can be characterized by the fact that its sign is 0. However, its length may be greater than 2, meaning that all the coefficients of the polynomial are equal to zero, but the leading term `z[lg(z)-1]` is an inexact zero. More precisely, `gcmp0(x)` is true for all coefficients `x` of the polynomial, an `isexactzero(x)` is false for the leading coefficient. The same remark applies to `t_SER`s.

4.5.10 Type `t_SER` (power series): This type also has a second codeword, which encodes a "*sign*", i.e. 0 if the power series is 0, and 1 if not, a *variable number* as for polynomials, and an *exponent*. This information can be handled with the following functions: **signe**, **setsigne**, **varn**, **setvarn** as for polynomials, and **valp**, **setvalp** for the exponent as for p-adic numbers. Beware: do *not* use **expo** and **setexpo** on power series.

The coefficients `z[2]`, `z[3]`,...`z[lg(z)-1]` point to the coefficients of `z` in ascending order. As for polynomials (see remark there), the sign of a `t_SER` is 0 if and only if the leading coefficient of the series is an inexact 0. (It cannot be an exact 0.)

Note that the exponent of a power series can be negative, i.e. we are then dealing with a Laurent series (with a finite number of negative terms).

4.5.11 Type `t_RFRAC` (rational function): `z[1]` points to the numerator n, and `z[2]` on the denominator d. The denominator must be of type `t_POL`, with variable of higher priority than the numerator. The numerator n is not an exact 0 and $(n, d) = 1$ (see `gred_rfac2`).

4.5.12 Type `t_QFR` (indefinite binary quadratic form): `z[1]`, `z[2]`, `z[3]` point to the three coefficients of the form and are of type `t_INT`. `z[4]` is Shanks's distance function, and must be of type `t_REAL`.

4.5.13 Type `t_QFI` (definite binary quadratic form): `z[1]`, `z[2]`, `z[3]` point to the three coefficients of the form. All three are of type `t_INT`.

4.5.14 Type `t_VEC` and `t_COL` (vector): `z[1]`, `z[2]`,...`z[lg(z)-1]` point to the components of the vector.

4.5.15 Type `t_MAT` (matrix): `z[1]`, `z[2]`,...`z[lg(z)-1]` point to the column vectors of `z`, i.e. they must be of type `t_COL` and of the same length.

4.5.16 Type `t_VECSMALL` (vector of small integers): `z[1]`, `z[2]`,...`z[lg(z)-1]` are ordinary signed long integers. This type is used instead of a `t_VEC` of `t_INT`s for efficiency reasons, for instance to implement efficiently permutations, polynomial arithmetic and linear algebra over small finite fields, etc.

The next two types were introduced for specific `gp` use, and you are better off using the standard malloc'ed C constructs when programming in library mode. We quote them for completeness, advising you not to use them:

4.5.17 Type `t_LIST` (list): This one has a second codeword which contains an effective length (handled through **lgeflist** / **setlgeflist**). `z[2]`,..., `z[lgeflist(z)-1]` contain the components of the list.

4.5.18 Type `t_STR` (character string):

`char * GSTR(z)` (= `(z+1)`) points to the first character of the (`NULL`-terminated) string.

Implementation note: for the types including an exponent (or a valuation), we actually store a biased non-negative exponent (bit-ORing the biased exponent to the codeword), obtained by adding a constant to the true exponent: either `HIGHEXPOBIT` (for `t_REAL`) or `HIGHVALPBIT` (for `t_PADIC` and `t_SER`). Of course, this is encapsulated by the exponent/valuation-handling macros and needs not concern the library user.

4.6 PARI variables.

4.6.1 Multivariate objects

We now consider variables and formal computations, and give the technical details corresponding to the general discussion in Section **??**. As we have seen in Section 4.5, the codewords for types `t_POL` and `t_SER` encode a "variable number". This is an integer, ranging from 0 to `MAXVARN`. Relative priorities may be ascertained using

`int varncmp(long v, long w)`

which is > 0, $= 0$, < 0 whenever v has lower, resp. same, resp. higher priority than w.

The way an object is considered in formal computations depends entirely on its "principal variable number" which is given by the function

`long gvar(GEN z)`

which returns a variable number for `z`, even if `z` is not a polynomial or power series. The variable number of a scalar type is set by definition equal to `BIGINT` which has lower priority than any valid variable number. The variable number of a recursive type which is not a polynomial or power series is the variable number with highest priority among its components. But for polynomials and power series only the "outermost" number counts (we directly access `varn`(x) in the codewords): the representation is not symmetrical at all.

Under `gp`, one needs not worry too much since the interpreter defines the variables as it sees them* and do the right thing with the polynomials produced (however, have a look at the remark in Section **??**).

But in library mode, they are tricky objects if you intend to build polynomials yourself (and not just let PARI functions produce them, which is less efficient). For instance, it does not make sense to have a variable number occur in the components of a polynomial whose main variable has a lower priority, even though PARI cannot prevent you from doing it; see Section **??** for a discussion of possible problems in a similar situation.

* The first time a given identifier is read by the GP parser (and is not immediately interpreted as a function) a new variable is created, and it is assigned a strictly lower priority than any variable in use at this point. On startup, before any user input has taken place, 'x' is defined in this way and has initially maximal priority (and variable number 0).

4.6.2 Creating variables A basic difficulty is to "create" a variable. As we have seen in Section 4.1, a number of objects is associated to variable number v. Here is the complete list: `pol_1`[v] and `pol_x`[v], which you can use in library mode and which represent, respectively, the monic monomials of degrees 0 and 1 in v; **varentries**[v], and **polvar**[v]. The latter two are only meaningful to `gp`, but they have to be set nevertheless. All of them must be properly defined before you can use a given integer as a variable number.

Initially, this is done for 0 (the variable `x` under `gp`), and `MAXVARN`, which is there to address the need for a "temporary" new variable in library mode and cannot be input under `gp`. No documented library function can create from scratch an object involving `MAXVARN` (of course, if the operands originally involve `MAXVARN`, the function abides). We call the latter type a "temporary variable". The regular variables meant to be used in regular objects, are called "user variables".

4.6.2.1 User variables: When the program starts, `x` is the only user variable (number 0). To define new ones, use

`long` **fetch_user_var**`(char *`s`)`

which inspects the user variable named s (creating it if needed), and returns its variable number.

```
long v = fetch_user_var("y");
GEN gy = pol_x[v];
```

This function raises an error if s is already registered as a function name.

Caveat: you can use `gp_read_str` (see Section 4.7.1) to execute a GP command and create GP variables on the fly as needed:

```
GEN gy = gp_read_str("'y"); /* returns pol_x[v], for some v */
long v = varn(gy);
```

But please note the quote `'y` in the above. Using `gp_read_str("y")` might work, but is dangerous, especially when programming functions to be used under `gp`. The latter reads the value of `y`, as *currently* known by the `gp` interpreter, possibly creating it in the process. But if `y` has been modified by previous `gp` commands (e.g `y = 1`), then the value of `gy` is not what you expected it to be and corresponds instead to the current value of the `gp` variable (e.g `gen_1`).

Technical remark If you are rewriting the gp interpreter, you may use the lower level

`entree *` **fetch_named_var**`(char *`s`)`

which returns an `entree*` suitable for inclusion in the interpreter hashlists of symbols.

4.6.2.2 Temporary variables: `MAXVARN` is available, but is better left to pari internal functions (some of which do not check that `MAXVARN` is free for them to use, which can be considered a bug). You can create more temporary variables using

`long` **fetch_var**`()`

This returns a variable number which is guaranteed to be unused by the library at the time you get it and as long as you do not delete it (we will see how to do that shortly). This has *higher* priority than any temporary variable produced so far (`MAXVARN` is assumed to be the first such). This call updates all the aforementioned internal arrays. In particular, after the statement `v = fetch_var()`, you can use `pol_1[v]` and `pol_x[v]`. The variables created in this way have no identifier assigned to them though, and they is printed as `#<number>`, except for `MAXVARN` which

is printed as `#`. You can assign a name to a temporary variable, after creating it, by calling the function

`void` **name_var**`(long n, char *s)`

after which the output machinery will use the name `s` to represent the variable number `n`. The GP parser will *not* recognize it by that name, however, and calling this on a variable known to `gp` raises an error. Temporary variables are meant to be used as free variables, and you should never assign values or functions to them as you would do with variables under `gp`. For that, you need a user variable.

All objects created by `fetch_var` are on the heap and not on the stack, thus they are not subject to standard garbage collecting (they are not destroyed by a `gerepile` or `avma = ltop` statement). When you do not need a variable number anymore, you can delete it using

`long` **delete_var**`()`

which deletes the *latest* temporary variable created and returns the variable number of the previous one (or simply returns 0 if you try, in vain, to delete `MAXVARN`). Of course you should make sure that the deleted variable does not appear anywhere in the objects you use later on. Here is an example:

```
long first = fetch_var();
long n1 = fetch_var();
long n2 = fetch_var(); /* prepare three variables for internal use */
...
/* delete all variables before leaving */
do { num = delete_var(); } while (num && num <= first);
```

The (dangerous) statement

```
while (delete_var()) /* empty */;
```

removes all temporary variables in use, except `MAXVARN` which cannot be deleted.

4.7 Input and output.

Two important aspects have not yet been explained which are specific to library mode: input and output of PARI objects.

4.7.1 Input.

For input, PARI provides you with one powerful high level function which enables you to input your objects as if you were under `gp`. In fact, it *is* essentially the GP syntactical parser, hence you can use it not only for input but for (most) computations that you can do under `gp`. It has the following syntax:

`GEN` **gp_read_str**`(char *s)`

In fact this function starts by *filtering* out all spaces and comments in the input string. They it calls the underlying basic function, the GP parser proper: `GEN` **gp_read_str**`(char *s)`, which is slightly faster but which you probably do not need.

To read a `GEN` from a file, you can use the simpler interface

`GEN` **gp_read_stream**`(FILE *file)`

which reads a character string of arbitrary length from the stream `file` (up to the first complete expression sequence), applies `gp_read_str` to it, and returns the resulting `GEN`. This way, you do not have to worry about allocating buffers to hold the string. To interactively input an expression, use `gp_read_stream(stdin)`.

Finally, you can read in a whole file, as in GP's `read` statement

`GEN` **gp_read_file**`(char *name)`

As usual, the return value is that of the last non-empty expression evaluated. Note that `gp`'s metacommands are not recognized.

Once in a while, it may be necessary to evaluate a GP expression sequence involving a call to a function you have defined in C. This is easy using **install** which allows you to manipulate quite an arbitrary function (GP knows about pointers!). The syntax is

`void` **install**`(void *f, char *name, char *code)`

where `f` is the (address of) the function (cast to the C type `void*`), `name` is the name by which you want to access your function from within your GP expressions, and `code` is a character string describing the function call prototype (see Section 4.9.2 for the precise description of prototype strings). In case the function returns a `GEN`, it must satisfy `gerepileupto` assumptions (see Section 4.3).

4.7.2 Output.

For output, there exist essentially three different functions (with variants), corresponding to the three main `gp` output formats (as described in Section **??**), plus three extra ones, respectively devoted to TEX output, string output, and debugging.

• "raw" format, obtained by using the function **brute** with the following syntax:

`void` **brute**`(GEN obj, char x, long n)`

This prints the PARI object `obj` in format `x0.n`, using the notations from Section **??**. Recall that here `x` is either `'e'`, `'f'` or `'g'` corresponding to the three numerical output formats, and `n` is the number of printed significant digits, and should be set to -1 if all of them are wanted (these arguments only affect the printing of real numbers). Usually one does not need that much flexibility, and gets by with the function

`void` **outbrute**`(GEN obj)`, which is equivalent to `brute(x,'g',-1)`,

or even better, with

`void` **output**`(GEN obj)` which is equivalent to `outbrute(obj)` followed by a newline and a buffer flush. This is especially nice during debugging. For instance using `dbx` or `gdb`, if `obj` is a `GEN`, typing `print output(obj)` enables you to see the content of `obj` (provided the optimizer has not put it into a register, but it is rarely a good idea to debug optimized code).

• "prettymatrix" format: this format is identical to the preceding one except for matrices. The relevant functions are:

`void` **matbrute**`(GEN obj, char x, long n)`

`void` **outmat**`(GEN obj)`, which is followed by a newline and a buffer flush.

• "prettyprint" format: the basic function has an additional parameter `m`, corresponding to the (minimum) field width used for printing integers:

`void` **sor**`(GEN obj, char x, long n, long m)`

The simplified version is

`void` **outbeaut**`(GEN obj)` which is equivalent to `sor(obj,'g',-1,0)` followed by a newline and a buffer flush.

• The first extra format corresponds to the **texprint** GP function, and gives a TEX output of the result. It is obtained by using:

`void` **texe**`(GEN obj, char x, long n)`

• The second one is the function **GENtostr** which converts a PARI `GEN` to an ASCII string. The syntax is

`char*` **GENtostr**`(GEN obj)`, wich returns a `malloc`'ed character string (which you should `free` after use).

• The third and final one outputs the hexadecimal tree corresponding to the `gp` metacommand `\x` using the function

`void` **voir**`(GEN obj, long nb)`, which only outputs the first `nb` words corresponding to leaves (very handy when you have a look at big recursive structures). If you set this parameter to -1 all significant words are printed. This last type of output is only used for debugging purposes.

Remark. Apart from **GENtostr**, all PARI output is done on the stream **outfile**, which by default is initialized to **stdout**. If you want that your output be directed to another file, you should use the function `void` **switchout**`(char *name)` where `name` is a character string giving the name of the file you are going to use. The output is *appended* at the end of the file. In order to close the file, simply call `switchout(NULL)`.

Similarly, errors are sent to the stream **errfile** (**stderr** by default), and input is done on the stream **infile**, which you can change using the function **switchin** which is analogous to **switchout**.

(Advanced) Remark. All output is done according to the values of the **pariOut** / **pariErr** global variables which are pointers to structs of pointer to functions. If you really intend to use these, this probably means you are rewriting `gp`. In that case, have a look at the code in `language/es.c` (`init80()` or `GENtostr()` for instance).

4.7.3 Errors.

If you want your functions to issue error messages, you can use the general error handling routine `pari_err`. The basic syntax is

```
pari_err(talker, "error message");
```

This prints the corresponding error message and exit the program (in library mode; go back to the `gp` prompt otherwise). You can also use it in the more versatile guise

```
pari_err(talker, format, ...);
```

where `format` describes the format to use to write the remaining operands, as in the **printf** function (however, see the next section). The simple syntax above is just a special case with a constant format and no remaining arguments.

The general syntax is

`void` **pari_err**`(numerr,...)`

where `numerr` is a codeword which indicates what to do with the remaining arguments and what message to print. The list of valid keywords is in `language/errmessages.c` together with the basic corresponding message. For instance, `pari_err(typeer,"extgcd")` prints the message:

```
***   incorrect type in extgcd.
```

To issue a warning, use

`void` **pari_warn**`(warnerr,...)` In that case, of course, we do *not* abort the computation, just print the requested message and go on. The basic example is

```
pari_warn(warner, "Strategy 1 failed. Trying strategy 2")
```

which is the exact equivalent of `pari_err(talker,...)` except that you certainly do not want to stop the program at this point, just inform the user that something important has occurred (in particular, this output would be suitably highlighted under `gp`, whereas a simple `printf` would not).

The valid *warning* keywords are `warner` (general), `warnprec` (increasing precision), `warnmem` (garbage collecting) and `warnfile` (error in file operation), used as follows:

```
pari_warn(warnprec, "bnfinit", newprec);
pari_warn(warnmem,  "bnfinit");
pari_warn(warnfile, "close", "log");  /* error when closing "log" */
```

4.7.4 Debugging output.

The global variables **DEBUGLEVEL** and **DEBUGMEM** (corresponding to the default **debug** and **debugmem**, see Section **??**) are used throughout the PARI code to govern the amount of diagnostic and debugging output, depending on their values. You can use them to debug your own functions, especially after having made them accessible under `gp` through the command **install** (see Section **??**).

For debugging output, you can use `printf` and the standard output functions (**brute** or **output** mainly), but also some special purpose functions which embody both concepts, the main one being

`void` **fprintferr**`(char *pariformat, ...)`

Now let us define what a PARI format is. It is a character string, similar to the one `printf` uses, where `%` characters have a special meaning. It describes the format to use when printing the remaining operands. But, in addition to the standard format types, you can use `%Z` to denote a `GEN` object (we would have liked to pick `%G` but it was already in use!). For instance you could write:

```
pari_err(talker, "x[%d] = %Z is not invertible!", i, x[i])
```

since the `pari_err` function accepts PARI formats. Here `i` is an `int`, `x` a `GEN` which is not a leaf and this would insert in raw format the value of the `GEN` `x[i]`.

4.7.5 Timers and timing output.

To profile your functions, you can use the PARI timer. The functions `long` **timer**`()` and `long` **timer2**`()` return the elapsed time since the last call of the same function (in milliseconds). Two different functions (identical except for their independent time-of-last-call memories!) are provided so you can have both global timing and fine tuned profiling.

You can also use `void` **msgtimer**`(char *format,...)`, which prints prints `Time`, then the remaining arguments as specified by `format` (which is a PARI format), then the output of `timer2`.

This mechanism is simple to use but not foolproof. If some other function uses these timers, and many PARI functions do use `timer2` when `DEBUGLEVEL` is high enough, the timings will be meaningless. To handle timing in a reentrant way, PARI defines a dedicated data type, `pari_timer`. The functions

`void` **TIMERstart**`(pari_timer *T)`

`long` **TIMER**`(pari_timer *T)`

`long` **msgTIMER**`(pari_timer *T, char *format,...)`

provide an equivalent to `timer` and `msgtimer`, except they use a unique timer `T` containing all the information needed, so that no other function can mess with your timings. They are used as follows:

```
pari_timer T;
TIMERstart(&T); /* initialize timer */
...
printf("Total time: %ld\n", TIMER(&T));
```

or

```
pari_timer T;
TIMERstart(&T);
for (i = 1; i < 10; i++) {
  ...
  msgTIMER(&T, "for i = %ld (L[i] = %Z)", i, L[i]);
}
```

4.8 A complete program.

Now that the preliminaries are out of the way, the best way to learn how to use the library mode is to study a detailed example. We want to write a program which computes the gcd of two integers, together with the Bezout coefficients. We shall use the standard quadratic algorithm which is not optimal but is not too far from the one used in the PARI function **bezout**.

Let x, y two integers and initially $\begin{pmatrix} s_x & s_y \\ t_x & t_y \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$, so that

$$\begin{pmatrix} s_x & s_y \\ t_x & t_y \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} x \\ y \end{pmatrix}.$$

To apply the ordinary Euclidean algorithm to the right hand side, multiply the system from the left by $\begin{pmatrix} 0 & 1 \\ 1 & -q \end{pmatrix}$, with $q = \texttt{floor}(x/y)$. Iterate until $y = 0$ in the right hand side, then the first line of the system reads

$$s_x x + s_y y = \gcd(x, y).$$

In practice, there is no need to update s_y and t_y since $\gcd(x, y)$ and s_x are enough to recover s_y. The following program is now straightforward. A couple of new functions appear in there, whose description can be found in the technical reference manual in Chapter 5.

```
#include <pari/pari.h>
/*
GP;install("extgcd", "GG&&", "gcdex", "./libextgcd.so");
*/
/* return d = gcd(a,b), sets u, v such that au + bv = gcd(a,b) */
GEN
extgcd(GEN A, GEN B, GEN *U, GEN *V)
{
  pari_sp av = avma;
  GEN ux = gen_1, vx = gen_0, a = A, b = B;
  if (typ(a) != t_INT || typ(b) != t_INT) pari_err(typeer, "extgcd");
  if (signe(a) < 0) { a = negi(a); ux = negi(ux); }
  while (!gcmp0(b))
  {
    GEN r, q = dvmdii(a, b, &r), v = vx;
    vx = subii(ux, mulii(q, vx));
    ux = v;
    a = b; b = r;
  }
  *U = ux;
  *V = diviiexact( subii(a, mulii(A,ux)), B );
  gerepileall(av, 3, &a, U, V); return a;
}
int
main()
{
  GEN x, y, d, u, v;
  pari_init(1000000,2);
  printf("x = "); x = gp_read_stream(stdin);
  printf("y = "); y = gp_read_stream(stdin);
  d = extgcd(x, y, &u, &v);
  pariprintf("gcd = %Z\nu = %Z\nv = %Z\n", d,u,v);
  return 0;
}
```

Note that, for simplicity, the inner loop does not include any garbage collection, hence memory use is quadratic in the size of the inputs instead of linear.

4.9 Adding functions to PARI.

4.9.1 Nota Bene. As mentioned in the `COPYING` file, modified versions of the PARI package can be distributed under the conditions of the GNU General Public License. If you do modify PARI, however, it is certainly for a good reason, hence we would like to know about it, so that everyone can benefit from it. There is then a good chance that your improvements are incorporated into the next release.

We classify changes to PARI into four rough classes, where changes of the first three types are almost certain to be accepted. The first type includes all improvements to the documentation, in a broad sense. This includes correcting typos or inacurracies of course, but also items which are not really covered in this document, e.g. if you happen to write a tutorial, or pieces of code exemplifying fine points unduly omitted in the present manual.

The second type is to expand or modify the configuration routines and skeleton files (the `Configure` script and anything in the `config/` subdirectory) so that compilation is possible (or easier, or more efficient) on an operating system previously not catered for. This includes discovering and removing idiosyncrasies in the code that would hinder its portability.

The third type is to modify existing (mathematical) code, either to correct bugs, to add new functionalities to existing functions, or to improve their efficiency.

Finally the last type is to add new functions to PARI. We explain here how to do this, so that in particular the new function can be called from `gp`.

4.9.2 The calling interface from `gp`, parser codes. A parser code is a character string describing all the GP parser needs to know about the function prototype. It contains a sequence of the following atoms:

• Syntax requirements, used by functions like `for`, `sum`, etc.:
- `=` separator `=` required at this point (between two arguments)

• Mandatory arguments, appearing in the same order as the input arguments they describe:
- `G` `GEN`
- `&` `*GEN`
- `L` long (we implicitly identify `int` with `long`)
- `S` symbol (i.e. GP identifier name). Function expects a `*entree`
- `V` variable (as `S`, but rejects symbols associated to functions)
- `n` variable, expects a variable number (a `long`, not an `*entree`)
- `I` string containing a sequence of GP statements (a *seq*), to be processed by `gp_read_str` (useful for control statements)
- `E` string containing a *single* GP statement (an *expr*), to be processed by `readexpr`
- `r` raw input (treated as a string without quotes). Quoted args are copied as strings
  Stops at first unquoted `')'` or `','`. Special chars can be quoted using '\'
  Example: `aa"b\n)"c` yields the string `"aab\n)c"`
- `s` expanded string. Example: `Pi"x"2` yields `"3.142x2"`
  Unquoted components can be of any PARI type (converted following current output format)

• Optional arguments:
- `s*` any number of strings, possibly 0 (see `s`)
- `D`*xxx* argument has a default value

The `s*` code is technical and you probably do not need it, but we give its description for completeness. It reads all remaining arguments in *string context* (see Section ??), and sends a (`NULL`-terminated) list of `GEN*` pointing to these. The automatic concatenation rules in string context are implemented so that adjacent strings are read as different arguments, as if they had been comma-separated. For instance, if the remaining argument sequence is: `"xx" 1, "yy"`, the `s*` atom sends a `GEN *g = {&a, &b, &c, NULL}`, where a, b, c are `GEN`s of type `t_STR` (content `"xx"`), `t_INT` (equal to 1) and `t_STR` (content `"yy"`).

The format to indicate a default value (atom starts with a `D`) is "`D`*value*`,`*type*`,`", where *type* is the code for any mandatory atom (previous group), *value* is any valid GP expression which is converted according to *type*, and the ending comma is mandatory. For instance `D0,L,` stands for "this optional argument is converted to a `long`, and is `0` by default". So if the user-given argument reads `1 + 3` at this point, `4L` is sent to the function; and `0L` if the argument is omitted. The following special syntaxes are available:

`DG` optional `GEN`, send `NULL` if argument omitted.
`D&` optional `*GEN`, send `NULL` if argument omitted.
`DV` optional `*entree`, send `NULL` if argument omitted.
`DI` optional `*char`, send `NULL` if argument omitted.
`Dn` optional variable number, -1 if omitted.

• Automatic arguments:

`f` Fake `*long`. C function requires a pointer but we do not use the resulting `long`
`p` real precision (default `realprecision`)
`P` series precision (default `seriesprecision`, global variable `precdl` for the library)

• Return type: `GEN` by default, otherwise the following can appear at the start of the code string:

`i` return `int`
`l` return `long`
`v` return `void`

No more than 8 arguments can be given (syntax requirements and return types are not considered as arguments). This is currently hardcoded but can trivially be changed by modifying the definition of `argvec` in `anal.c:identifier()`. This limitation should disappear in future versions.

When the function is called under `gp`, the prototype is scanned and each time an atom corresponding to a mandatory argument is met, a user-given argument is read (`gp` outputs an error message it the argument was missing). Each time an optional atom is met, a default value is inserted if the user omits the argument. The "automatic" atoms fill in the argument list transparently, supplying the current value of the corresponding variable (or a dummy pointer).

For instance, here is how you would code the following prototypes, which do not involve default values:

```
GEN name(GEN x, GEN y, long prec)   ----> "GGp"
void name(GEN x, GEN y, long prec)  ----> "vGGp"
void name(GEN x, long y, long prec) ----> "vGLp"
long name(GEN x)                    ----> "lG"
int name(long x)                    ----> "iL"
```

If you want more examples, `gp` gives you easy access to the parser codes associated to all GP functions: just type `\h` *function*. You can then compare with the C prototypes as they stand in the `paridecl.h`.

Remark: If you need to implement complicated control statements (probably for some improved summation functions), you need to know about the **entree** type, which is not documented. Check the comment at the end of `language/init.c` and the source code in `language/sumiter.c`.

4.9.3 Coding guidelines. Code your function in a file of its own, using as a guide other functions in the PARI sources. One important thing to remember is to clean the stack before exiting your main function, since otherwise successive calls to the function clutters the stack with unnecessary garbage, and stack overflow occurs sooner. Also, if it returns a `GEN` and you want it to be accessible to `gp`, you have to make sure this `GEN` is suitable for `gerepileupto` (see Section 4.3).

If error messages or warnings are to be generated in your function, use `pari_err` and `pari_warn` respectively. Recall that `pari_err` does not return but ends with a `longjmp` statement. As well, instead of explicit `printf` / `fprintf` statements, use the following encapsulated variants:

`void` **`pariflush`**`()`: flush output stream.

`void` **`pariputc`**`(char c)`: write character `c` to the output stream.

`void` **`pariputs`**`(char *s)`: write `s` to the output stream.

`void` **`fprintferr`**`(char *s)`: write `s` to the error stream (this function is in fact much more versatile, see Section 4.7.4).

Declare all public functions in an appropriate header file, if you want to access them from C. For example, if dynamic loading is not available, you may need to modify PARI to access these functions, so put them in `paridecl.h`. The other functions should be declared `static` in your file.

Your function is now ready to be used in library mode after compilation and creation of the library. If possible, compile it as a shared library (see the `Makefile` coming with the `extgcd` example in the distribution). It is however still inaccessible from `gp`.

4.9.4 Integration with `gp` as a shared module

To tell `gp` about your function, you must do the following. First, find a name for it. It does not have to match the one used in library mode, but consistency is nice. It has to be a valid GP identifier, i.e. use only alphabetic characters, digits and the underscore character (_), the first character being alphabetic.

Then figure out the correct parser code corresponding to the function prototype, as explained above (Section 4.9.2).

Now, assuming your Operating System is supported by `install`, write a GP script like the following:

```
install(libname, code, gpname, library)
addhelp(gpname, "some help text")
```

(see Section **??** and **??**). The addhelp part is not mandatory, but very useful if you want others to use your module. `libname` is how the function is named in the library, usually the same name as one visible from C.

Read that file from your `gp` session (from your preferences file for instance, see Section **??**), and that's it. You can now use the new function *gpname* under `gp`, and we would very much like to hear about it!

4.9.5 Integration the hard way

If `install` is not available, things are more complicated: you have to hardcode your function in the `gp` binary (or install Linux). Here is what needs to be done:

You need to choose a section and add a file `functions/`*section*`/`*gpname* containing the following, keeping the notation above:

`Function:` *gpname*
`Section:` *section*
`C-Name:` *libname*
`Prototype:` *code*
`Help:` *some help text*

(If the help text does not fit on a single line, continuation lines must start by a whitespace character.) A GP2C-related `Description` field is also available to improve the code GP2C generates when compiling scripts involving your function. See the GP2C documentation for details.

At this point you can recompile `gp`, which will first rebuild the functions database.

4.9.6 Example. A complete description could look like this:

```
{
  install(bnfinit0, "GD0,L,DGp", ClassGroupInit, "libpari.so");
  addhelp(ClassGroupInit, "ClassGroupInit(P,{flag=0},{data=[]}):
    compute the necessary data for ...");
}
```

which means we have a function `ClassGroupInit` under `gp`, which calls the library function `bnfinit0` . The function has one mandatory argument, and possibly two more (two `'D'` in the code), plus the current real precision. More precisely, the first argument is a `GEN`, the second one is converted to a `long` using `itos` (`0` is passed if it is omitted), and the third one is also a `GEN`, but we pass `NULL` if no argument was supplied by the user. This matches the C prototype (from `paridecl.h`):

```
GEN bnfinit0(GEN P, long flag, GEN data, long prec)
```

This function is in fact coded in `basemath/buch2.c`, and is in this case completely identical to the GP function `bnfinit` but `gp` does not need to know about this, only that it can be found somewhere in the shared library `libpari.so`.

Important note: You see in this example that it is the function's responsibility to correctly interpret its operands: `data = NULL` is interpreted *by the function* as an empty vector. Note that since `NULL` is never a valid `GEN` pointer, this trick always enables you to distinguish between a default value and actual input: the user could explicitly supply an empty vector!

Note: If `install` is not available, we have to add a file

```
functions/number_fields/ClassGroupInit
```

containing the following:

```
Function: ClassGroupInit
Section: number_fields
C-Name: bnfinit0
Prototype: GD0,L,DGp
Help: ClassGroupInit(P,{flag=0},{tech=[]}): this routine does ...
```

Chapter 5:
Technical Reference Guide for Low-Level Functions

In this chapter, we describe all public low-level functions of the PARI library. These essentially include functions for handling all the PARI types. Higher level functions, such as arithmetic or transcendental functions, are described in Chapter 3 of the GP user's manual. A general introduction to the major concepts of PARI programming can be found in Chapter 4.

Many other undocumented functions can be found throughout the source code. These private functions are more efficient than the library wrappers, but sloppier on argument checking and damage control. Use them at your own risk!

Important advice: generic routines eventually call lower level functions. Optimize your algorithms first, not overhead and conversion costs between PARI routines. For generic operations, use generic routines first, don't waste time looking for the most specialized one available unless you identify a genuine bottleneck. The PARI source code is part of the documentation; look for inspiration there.

We let `BIL` abbreviate `BITS_IN_LONG`. The type `long` denotes a `BIL`-bit signed long integer. The type `ulong` is defined as `unsigned long`. The word *stack* always refer to the PARI stack, allocated through an initial `pari_init` call. Refer to Chapters 1–2 and 4 for general background.

5.1 Initializing the library.

The following functions enable you to start using the PARI functions in a program, and cleanup without exiting the whole program.

5.1.1 General purpose

`void` **pari_init**`(size_t size, ulong maxprime)` initialize the library, with a stack of `size` bytes and a prime table up to the maximum of `maxprime` and 2^{16}. Unless otherwise mentionned, no PARI function will function properly before such an initialization.

`void` **pari_close**`(void)` stop using the library (assuming it was initialized with `pari_init`) and frees all allocated objects.

5.1.2 Technical functions

`void` **pari_init_opts**`(size_t size, ulong maxprime, ulong opts)` as `pari_init`, more flexible. `opts` is a mask of flags among the following:

`INIT_JMPm`: install pari error handler. When an exception is raised, the program is terminated with `exit(1)`.

`INIT_SIGm`: install pari signal handler.

`INIT_DFTm`: initialize the `GP_DATA` environment structure. This one *must* be enabled once. If you close pari, then restart it, you need not reinitialize `GP_DATA`; if you do not, then old values are restored.

`void` **pari_close_opts**`(ulong init_opts)` as `pari_close`, for a library initialized with a mask of options using `pari_init_opts`. `opts` is a mask of flags among

`INIT_SIGm`: restore `SIG_DFL` default action for signals tampered with by pari signal handler.

`INIT_DFTm`: frees the `GP_DATA` environment structure.

`void` **pari_sig_init**`(void (*f)(int))` install the signal handler `f` (see `signal(2)`): the signals `SIGBUS`, `SIGFPE`, `SIGINT`, `SIGBREAK`, `SIGPIPE` and `SIGSEGV` are concerned.

5.1.3 Notions specific to the GP interpreter

An `entree` is the generic object associated to an identifier (a name) in GP's interpreter, be it a built-in or user function, or a variable. For a function, it has at least the following fields:

`char *name` : the name under which the interpreter knows us.

`ulong valence` : obsolete, set it to 1.

`void *value` : a pointer to the C function to call.

`long menu` : an integer from 1 to 11 (to which group of function help do we belong).

`char *code` : the prototype code.

`char *help` : the help text for the function.

A routine in GP is described to the analyzer by an `entree` structure. Built-in pari routines are grouped in *modules*, which are arrays of `entree` structs, the last of which satisfy `name = NULL` (sentinel).

There are currently six modules in GP: general functions (`functions_basic`), gp-specific functions (`functions_fp`), gp-specific highlevel functions (`functions_highlevel`), member functions, and two modules of obsolete functions. The function `pari_init` initializes the interpreter and declares all symbols in `functions_basic`. You may declare further functions on a case by case basis or as a whole module using

`void` **pari_add_function**`(entree *ep)` adds a single routine to the table of symbols in the interpreter. It assumes `pari_init` has been called.

`void` **pari_add_module**`(entree *mod)` adds all the routines in module `mod` to the table of symbols in the interpreter. It assumes `pari_init` has been called.

For instance, gp implements a number of private routines, which it adds to the default set via the call

```
pari_add_module(functions_gp);
pari_add_module(functions_highlevel);
```

5.2 Handling GENs.

Almost all these functions are either macros or inlined. Unless mentioned otherwise, they do not evaluate their arguments twice. Most of them are specific to a set of types, although no consistency checks are made: e.g. one may access the `sign` of a `t_PADIC`, but the result is meaningless.

5.2.1 Length conversions

`long` **ndec2nlong**`(long x)` converts a number of decimal digits to a number of words. Returns $1 + \texttt{floor}(x \times \texttt{BIL} \log_2 10)$.

`long` **ndec2prec**`(long x)` converts a number of decimal digits to a number of codewords. This is equal to $2 +$ `ndec2nlong(x)`.

`long` **prec2ndec**`(long x)` converts a number of of codewords to a number of decimal digits.

`long` **nbits2nlong**`(long x)` converts a number of bits to a number of words. Returns the smallest word count containing x bits, i.e `ceil`$(x/$`BIL`$)$.

`long` **nbits2prec**`(long x)` converts a number of bits to a number of codewords. This is equal to $2 +$ `nbits2nlong(x)`.

`long` **nchar2nlong**`(long x)` converts a number of bytes to number of words. Returns the smallest word count containing x bytes, i.e `ceil`$(x/$`sizeof(long)`$)$.

`long` **bit_accuracy**`(long x)` converts a `t_REAL` length into a number of significant bits. Returns $(x-2)$`BIL`. The macro `bit_accuracy_mul(x,y)` computes the same thing multiplied by y.

5.2.2 Read type-dependent information

`long` **typ**`(GEN x)` returns the type number of `x`. The header files included through `pari.h` define symbolic constants for the `GEN` types: `t_INT` etc. Never use their actual numerical values. E.g to determine whether `x` is a `t_INT`, simply check

```
if (typ(x) == t_INT) { }
```

The types are internally ordered and this simplifies the implementation of commutative binary operations (e.g addition, gcd). Avoid using the ordering directly, as it may change in the future; use type grouping macros instead (Section 5.2.5).

`long` **lg**`(GEN x)` returns the length of `x` in `BIL`-bit words.

`long` **lgefint**`(GEN x)` returns the effective length of the `t_INT` `x` in `BIL`-bit words.

`long` **signe**`(GEN x)` returns the sign (-1, 0 or 1) of `x`. Can be used for `t_INT`, `t_REAL`, `t_POL` and `t_SER` (for the last two types, only 0 or 1 are possible).

`long` **gsigne**`(GEN x)` same as `signe`, but also valid for `t_FRAC` (and marginally less efficient for the other types). Raise a type error if `typ(x)` is not among those three.

`long` **expi**`(GEN x)` returns the binary exponent of the real number equal to the `t_INT` `x`. This is a special case of `gexpo`.

`long` **expo**`(GEN x)` returns the binary exponent of the `t_REAL` `x`.

`long` **gexpo**`(GEN x)` same as `expo`, but also valid when `x` is not a `t_REAL` (returns the largest exponent found among the components of `x`). When `x` is an exact 0, this returns `-HIGHEXPOBIT`, which is lower than any valid exponent.

`long` **valp**`(GEN x)` returns the p-adic valuation (for a `t_PADIC`) or X-adic valuation (for a `t_SER`, taken with respect to the main variable) of `x`.

`long` **precp**`(GEN x)` returns the precision of the `t_PADIC` `x`.

`long` **varn**`(GEN x)` returns the variable number of the `t_POL` or `t_SER` `x` (between 0 and `MAXVARN`).

`long` **gvar**`(GEN x)` returns the main variable number when any variable at all occurs in the composite object `x` (the smallest variable number which occurs), and `BIGINT` otherwise.

`long` **degpol**`(GEN x)` returns the degree of `t_POL` `x`, *assuming* its leading coefficient is non-zero (an exact 0 is impossible, but an inexact 0 is allowed). By convention the degree of an exact 0 polynomial is -1. If the leading coefficient of `x` is 0, the result is undefined.

`int` **precision**`(GEN x)` If `x` is of type `t_REAL`, returns the precision of `x` (the length of `x` in `BIL`-bit words if `x` is not zero, and a reasonable quantity obtained from the exponent of `x` if `x` is numerically equal to zero). If `x` is of type `t_COMPLEX`, returns the minimum of the precisions of the real and imaginary part. Otherwise, returns 0 (which stands in fact for infinite precision).

`int` **gprecision**`(GEN x)` as `precision` for scalars; returns the lowest precision encountered among the components otherwise.

`long` **sizedigit**`(GEN x)` returns 0 if `x` is exactly 0. Otherwise, returns **gexpo**`(x)` multiplied by $\log_{10}(2)$. This gives a crude estimate for the maximal number of decimal digits of the components of `x`.

5.2.3 Eval type-dependent information. These routines convert type-dependant information to bitmask to fill the codewords of `GEN` objects (see Section 4.5). E.g for a `t_REAL` `z`:

```
z[1] = evalsigne(-1) | evalexpo(2)
```

Compatible components of a codeword for a given type can be OR-ed as above.

`ulong` **evaltyp**`(long x)` convert type `x` to bitmask (first codeword of all `GEN`s)

`long` **evallg**`(long x)` convert length `x` to bitmask (first codeword of all `GEN`s). Raise overflow error if `x` is so large that the corresponding length cannot be represented

`long` **_evallg**`(long x)` as `evallg` *without* the overflow check.

`ulong` **evalvarn**`(long x)` convert variable number `x` to bitmask (second codeword of `t_POL` and `t_SER`)

`long` **evalsigne**`(long x)` convert sign `x` (in $-1, 0, 1$) to bitmask (second codeword of `t_INT`, `t_REAL`, `t_POL`, `t_SER`)

`long` **evalprecp**`(long x)` convert p-adic (X-adic) precision `x` to bitmask (second codeword of `t_PADIC`, `t_SER`)

`long` **evalvalp**`(long x)` convert p-adic (X-adic) valuation `x` to bitmask (second codeword of `t_PADIC`, `t_SER`). Raise overflow error if `x` is so large that the corresponding valuation cannot be represented

`long` **_evalvalp**`(long x)` same as `evalvalp` *without* the overflow check.

`long` **evalexpo**`(long x)` convert exponent `x` to bitmask (second codeword of `t_REAL`). Raise overflow error if `x` is so large that the corresponding exponent cannot be represented

`long` **_evalexpo**`(long x)` same as `evalexpo` *without* the overflow check.

`long` **evallgefint**`(long x)` convert effective length `x` to bitmask (second codeword `t_INT`). This should be less or equal than the length of the `t_INT`, hence there is no overflow check for the effective length.

`long` **evallgeflist**`(long x)` convert effective length `x` to bitmask (second codeword `t_LIST`). This should be less or equal than the length of the `t_LIST`, hence there is no overflow check for the effective length.

5.2.4 Set type-dependent information. Use these macros with extreme care since usually the corresponding information is set otherwise, and the components and further codeword fields (which are left unchanged) may not be compatible with the new information.

`void` **settyp**`(GEN x, long s)` sets the type number of `x` to `s`.

`void` **setlg**`(GEN x, long s)` sets the length of `x` to `s`. This is an efficient way of truncating vectors, matrices or polynomials.

`void` **setlgefint**`(GEN x, long s)` sets the effective length of the `t_INT` `x` to `s`. The number `s` must be less than or equal to the length of `x`.

`void` **setsigne**`(GEN x, long s)` sets the sign of `x` to `s`. If `x` is a `t_INT` or `t_REAL`, `s` must be equal to -1, 0 or 1, and if `x` is a `t_POL` or `t_SER`, `s` must be equal to 0 or 1.

`void` **setexpo**`(GEN x, long s)` sets the binary exponent of the `t_REAL` `x` to `s`. The value `s` must be a 24-bit signed number.

`void` **setvalp**`(GEN x, long s)` sets the p-adic or X-adic valuation of `x` to `s`, if `x` is a `t_PADIC` or a `t_SER`, respectively.

`void` **setprecp**`(GEN x, long s)` sets the p-adic precision of the `t_PADIC` `x` to `s`.

`void` **setvarn**`(GEN x, long s)` sets the variable number of the `t_POL` or `t_SER` `x` to `s` (where $0 \leq$ `s` $\leq$ `MAXVARN`).

5.2.5 Type groups . In the following macros, `t` denotes the type of a `GEN`. Some of these macros may evaluate their argument twice. Always use them as in

```
long tx = typ(x);
if (is_intreal_t(tx)) { }
```

`int` **is_recursive_t**`(long t)` `true` iff `t` is a recursive type (the recursive types are `t_INT`, `t_REAL`, `t_STR` or `t_VECSMALL`).

`int` **is_intreal_t**`(long t)` `true` iff `t` is `t_INT` or `t_REAL`.

`int` **is_rational_t**`(long t)` `true` iff `t` is `t_INT` or `t_FRAC`.

`int` **is_vec_t**`(long t)` `true` iff `t` is `t_VEC` or `t_COL`.

`int` **is_matvec_t**`(long t)` `true` iff `t` is `t_MAT`, `t_VEC` or `t_COL`.

`int` **is_scalar_t**`(long t)` `true` iff `t` is a scalar, i.e a `t_INT`, `t_REAL`, `t_INTMOD`, `t_FRAC`, `t_COMPLEX`, `t_PADIC`, `t_QUAD`, or `t_POLMOD`.

`int` **is_extscalar_t**`(long t)` `true` iff `t` is a scalar (see `is_scalar_t`) or `t` is `t_POL`.

`int` **is_const_t**`(long t)` `true` iff `t` is a scalar which is not `t_POLMOD`.

5.2.6 Accessors and components. The first two functions return `GEN` components as copies on the stack:

`GEN` **compo**`(GEN x, long n)` creates a copy of the `n`-th true component (i.e. not counting the codewords) of the object `x`.

`GEN` **truecoeff**`(GEN x, long n)` creates a copy of the coefficient of degree `n` of `x` if `x` is a scalar, `t_POL` or `t_SER`, and otherwise of the `n`-th component of `x`.

On the contrary, the following routines return the address of a `GEN` component. No copy is made on the stack:

`GEN` **constant_term**`(GEN x)` returns the address the constant term of `t_POL x`. By convention, a 0 polynomial (whose `sign` is 0) has `gen_0` constant term.

`GEN` **leading_term**`(GEN x)` returns the address the leading term of `t_POL x`. This may be an inexact 0.

`GEN` **gel**`(GEN x, long i)` returns the address of the `x[i]` entry of `x`. (`el` stands for element.)

`GEN` **gcoeff**`(GEN x, long i, long j)` returns the address of the `x[i,j]` entry of `t_MAT x`, i.e. the coefficient at row `i` and column `j`.

`GEN` **gmael**`(GEN x, long i, long j)` returns the address of the `x[i][j]` entry of `x`. (`mael` stands for multidimensional array element.)

`GEN` **gmael2**`(GEN A, long x1, long x2)` is an alias for `gmael`. Similar macros `gmael3`, `gmael4`, `gmael5` are available.

5.3 Handling the PARI stack.

5.3.1 Allocating memory on the stack

`GEN` **cgetg**`(long n, long t)` allocates memory on the stack for an object of length `n` and type `t`, and initializes its first codeword.

`GEN` **cgeti**`(long n)` allocates memory on the stack for a `t_INT` of length `n`, and initializes its first codeword. Identical to `cgetg(n,t_INT)`.

`GEN` **cgetr**`(long n)` allocates memory on the stack for a `t_REAL` of length `n`, and initializes its first codeword. Identical to `cgetg(n,t_REAL)`.

`GEN` **cgetc**`(long n)` allocates memory on the stack for a `t_COMPLEX`, whose real and imaginary parts are `t_REAL`s of length `n`.

`GEN` **cgetp**`(GEN x)` creates space sufficient to hold the `t_PADIC x`, and sets the prime p and the p-adic precision to those of `x`, but does not copy (the p-adic unit or zero representative and the modulus of) `x`.

`GEN` **new_chunk**`(size_t n)` allocates a `GEN` with n components, *without* filling the required code words. This is the low-level constructor underlying `cgetg`, which calls `new_chunk` then sets the first code word. It works by simply returning the address `((GEN)avma) - n`, after checking that it is larger than `(GEN)bot`.

`char*` **stackmalloc**`(size_t n)` allocates memory on the stack for n chars (*not* n `GEN`s). This is faster than using `malloc`, and easier to use in most situations when temporary storage is needed.

In particular there is no need to `free` individually all variables thus allocated: a simple `avma = oldavma` might be enough. On the other hand, beware that this is not permanent independant storage, but part of the stack.

Objects allocated through these last two functions cannot be `gerepile`'d. They are not valid `GEN`s since they have no PARI type.

5.3.2 Garbage collection. See Section 4.3 for a detailed explanation and many examples.

`void` **cgiv**`(GEN x)` frees object `x` if it is the last created on the stack (otherwise nothing happens).

`GEN` **gerepile**`(pari_sp p, pari_sp q, GEN x)` general garbage collector for the stack.

`void` **gerepileall**`(pari_sp av, int n, ...)` cleans up the stack from `av` on (i.e from `avma` to `av`), preserving the `n` objects which follow in the argument list (of type `GEN*`). E.g: `gerepileall(av, 2, &x, &y)` preserves `x` and `y`.

`void` **gerepileallsp**`(pari_sp av, pari_sp ltop, int n, ...)` cleans up the stack between `av` and `ltop`, updating the `n` elements which follow `n` in the argument list (of type `GEN*`). Check that the elements of `g` have no component between `av` and `ltop`, and assumes that no garbage is present between `avma` and `ltop`. Analogous to (but faster than) `gerepileall` otherwise.

`GEN` **gerepilecopy**`(pari_sp av, GEN x)` cleans up the stack from `av` on, preserving the object `x`. Special case of `gerepileall` (case `n` = 1), except that the routine returns the preserved `GEN` instead of updating its adress through a pointer.

`void` **gerepilemany**`(pari_sp av, GEN* g[], int n)` alternative interface to `gerepileall`

`void` **gerepilemanysp**`(pari_sp av, pari_sp ltop, GEN* g[], int n)` alternative interface to `gerepileallsp`.

`void` **gerepilecoeffs**`(pari_sp av, GEN x, int n)` cleans up the stack from `av` on, preserving `x[0]`, ..., `x[n-1]` (which are `GEN`s).

`void` **gerepilecoeffssp**`(pari_sp av, pari_sp ltop, GEN x, int n)` cleans up the stack from `av` to `ltop`, preserving `x[0]`, ..., `x[n-1]` (which are `GEN`s). Same assumptions as in `gerepilemanysp`, of which this is a variant. For instance

```
z = cgetg(3, t_COMPLEX);
av = avma; garbage(); ltop = avma;
z[1] = fun1();
z[2] = fun2();
gerepilecoeffssp(av, ltop, z + 1, 2);
return z;
```

cleans up the garbage between `av` and `ltop`, and connects `z` and its two components. This is marginally more efficient than the standard

```
av = avma; garbage(); ltop = avma;
z = cgetg(3, t_COMPLEX);
z[1] = fun1();
z[2] = fun2(); return gerepile(av, ltop, z);
```

`GEN` **gerepileupto**`(pari_sp av, GEN q)` analogous to (but faster than) `gerepilecopy`. Assumes that `q` is connected and that its root was created before any component.

`GEN` **gerepileuptoint**`(pari_sp av, GEN q)` analogous to (but faster than) `gerepileupto`. Assumes further that `q` is a `t_INT`. The length and effective length of the resulting `t_INT` are equal.

`GEN` **gerepileuptoleaf**`(pari_sp av, GEN q)` analogous to (but faster than) `gerepileupto`. Assumes further that `q` is a leaf, i.e a non-recursive type (`is_recursive_t(typ(q))` is non-zero). Contrary to `gerepileuptoint`, `gerepileuptoleaf` leaves length and effective length of a `t_INT` unchanged.

`void` **stackdummy**`(pari_sp av, pari_sp ltop)` inhibits the memory area between `av` *included* and `ltop` *excluded* with respect to `gerepile`, in order to avoid a call to `gerepile(av, ltop,...)`. The stack space is not reclaimed though.

More precisely, this routine assumes that `av` is recorded earlier than `ltop`, then marks the specified stack segment as a non-recursive type of the correct length. Thus gerepile will not inspect the zone, at most copy it. To be used in the following situation:

```
av0 = avma; z = cgetg(t_VEC, 3);
gel(z,1) = HUGE(); av = avma; garbage(); ltop = avma;
gel(z,2) = HUGE(); stackdummy(av, ltop);
```

Compared to the orthodox

```
gel(z,2) = gerepile(av, ltop, gel(z,2));
```

or even more wasteful

```
z = gerepilecopy(av0, z);
```

we temporarily lose (`av`$-$`ltop`) words but save a costly `gerepile`. In principle, a garbage collection higher up the call chain should reclaim this later anyway.

Without the `stackdummy`, if the [`av`, `ltop`] zone is arbitrary (not even valid `GEN`s as could happen after direct truncation via `setlg`), we would leave dangerous data in the middle of `z`, which would be a problem for a later

```
gerepile(..., ... , z);
```

And even if it were made of valid `GEN`s, inhibiting the area makes sure `gerepile` will not inspect their components, saving time.

Another natural use in low-level routines is to "shorten" an existing `GEN z` to its first `l` -1 components:

```
setlg(z, l);
stackdummy((pari_sp)(z + lg(z)), (pari_sp)(z + l));
```

or to its last `l` components:

```
long L = lg(z) - l;
stackdummy((pari_sp)(z + L), (pari_sp)z);
z += L; setlg(z, L);
```

5.3.3 Copies and clones

`GEN` **gclone**`(GEN x)` creates a new permanent copy of the object `x` on the heap. The *clone bit* of the result is set.

`void` **gunclone**`(GEN x)` delete the clone `x` (created by `gclone`). Fatal error if `x` not a clone.

`GEN` **gcopy**`(GEN x)` creates a new copy of the object `x` on the stack.

`int` **isonstack**`(GEN x)` `true` iff `x` belongs to the stack. This is a macro whose argument is evaluated several times.

`void` **copyifstack**`(GEN x, GEN y)` sets `y = gcopy(x)` if `x` belongs to the stack, and `y = x` otherwise. This macro evaluates its arguments once, contrary to

```
y = isonstack(x)? gcopy(x): x;
```

`void` **icopyifstack**`(GEN x, GEN y)` as `copyifstack` assuming `x` is a `t_INT`.

`long` **taille**`(GEN x)` returns the total number of `BIL`-bit words occupied by the tree representing `x`.

`void` **traverseheap**`(void(*f)(GEN, void *), void *data)` this applies `f(`x`, data)` to each object x on the PARI heap, most recent first. Mostly for debugging purposes.

`GEN` **getheap**`()` a simple wrapper around `traverseheap`. Returns a two-component row vector giving the number of objects on the heap and the amount of memory they occupy in long words.

5.4 Level 0 kernel (operations on ulongs).

5.4.1 Micro-kernel. Level 0 operations simulate basic operations of the 68020 processor on which PARI was originally implemented. They need "global" `ulong` variables `overflow` (which will contain only 0 or 1) and `hiremainder` to function properly. However, for certain architectures these are replaced with local variables for efficiency; and the 'functions' mentioned below are really chunks of inlined assembler code. So, a routine using one of these lowest-level functions where the description mentions either `hiremainder` or `overflow` must declare the corresponding

```
LOCAL_HIREMAINDER;
LOCAL_OVERFLOW;
```

in a declaration block. Variables `hiremainder` and `overflow` then become available in the enclosing block. For instance a loop over the powers of an `ulong p` protected from overflows could read

```
while (pk < lim)
{
  LOCAL_HIREMAINDER;
  ...
  pk = mulll(pk, p); if (hiremainder) break;
}
```

`ulong` **addll**`(ulong x, ulong y)` adds `x` and `y`, returns the lower `BIL` bits and puts the carry bit into `overflow`.

`ulong` **addllx**`(ulong x, ulong y)` adds `overflow` to the sum of the `x` and `y`, returns the lower `BIL` bits and puts the carry bit into `overflow`.

`ulong` **subll**`(ulong x, ulong y)` subtracts `x` and `y`, returns the lower `BIL` bits and put the carry (borrow) bit into `overflow`.

`ulong` **subllx**`(ulong x, ulong y)` subtracts `overflow` from the difference of `x` and `y`, returns the lower `BIL` bits and puts the carry (borrow) bit into `overflow`.

`int` **bfffo**`(ulong x)` returns the number of leading zero bits in `x`. That is, the number of bit positions by which it would have to be shifted left until its leftmost bit first becomes equal to 1, which can be between 0 and `BIL` -1 for nonzero `x`. When `x` is 0, the result is undefined.

`ulong` **mulll**`(ulong x, ulong y)` multiplies `x` by `y`, returns the lower `BIL` bits and stores the high-order `BIL` bits into `hiremainder`.

`ulong` **addmul**`(ulong x, ulong y)` adds `hiremainder` to the product of `x` and `y`, returns the lower `BIL` bits and stores the high-order `BIL` bits into `hiremainder`.

`ulong` **divll**`(ulong x, ulong y)` returns the Euclidean quotient of (`hiremainder << BIL`) $+$ `x` by `y` and stores the remainder into `hiremainder`. An error occurs if the quotient cannot be represented by an `ulong`, i.e. if initially `hiremainder` $\geq$ `y`.

5.4.2 Modular kernel. The following routines are not part of the level 0 kernel per se, but implement modular operations on words in terms of the above. They are written so that no overflow may occur. Let $m \geq 1$ be the modulus; all operands representing classes modulo m are assumed to belong to $[0, m-1[$. The result may be wrong for a number of reasons otherwise: it may not be reduced, overflow can occur, etc.

`ulong` **Fl_add**`(ulong x, ulong y, ulong m)` returns the smallest positive representative of $x+y$ modulo m.

`ulong` **Fl_neg**`(ulong x, ulong m)` returns the smallest positive representative of $-x$ modulo m.

`ulong` **Fl_sub**`(ulong x, ulong y, ulong m)` returns the smallest positive representative of $x-y$ modulo m.

`long` **Fl_center**`(ulong x, ulong m, ulong mo2)` returns the representative in $]-m/2, m/2]$ of x modulo m. Assume $0 \leq x < m$ and `mo2` $= m>>1$.

`ulong` **Fl_mul**`(ulong x, ulong y, ulong m)` returns the smallest positive representative of xy modulo m.

`ulong` **Fl_inv**`(ulong x, ulong m)` returns the smallest positive representative of x^{-1} modulo m. If x is not invertible mod m, raise an exception.

`ulong` **Fl_div**`(ulong x, ulong y, ulong m)` returns the smallest positive representative of xy^{-1} modulo m. If y is not invertible mod m, raise an exception.

`ulong` **Fl_pow**`(ulong x, ulong n, ulong m)` returns the smallest positive representative of x^n modulo m.

`ulong` **Fl_sqrt**`(ulong x, ulong p)` returns the square root of `x` modulo `p` (smallest positive representative). Assumes `p` to be prime, and `x` to be a square modulo `p`.

`ulong` **gener_Fl**`(ulong p)` returns a primitive root modulo `p`, assuming `p` is prime.

`ulong` **gener_Fl_local**`(ulong p, GEN L)`, see `gener_Fp_local`, `L` is an `Flv`.

`long` **krouu**`(ulong x, ulong y)` returns the Kronecker symbol $(x|y)$, i.e.-1, 0 or 1. Assumes `y` is non-zero. If `y` is an odd prime, this is the Legendre symbol.

5.5 Level 1 kernel (operations on longs, integers and reals).

Note: Many functions consist of an elementary operation, immediately followed by an assignment statement. They will be introduced as in the following example:

`GEN` **gadd**[**z**]`(GEN x, GEN y[, GEN z])` followed by the explicit description of the function

```
GEN gadd(GEN x, GEN y)
```

which creates its result on the stack, returning a `GEN` pointer to it, and the parts in brackets indicate that there exists also a function

```
void gaddz(GEN x, GEN y, GEN z)
```

which assigns its result to the pre-existing object `z`, leaving the stack unchanged. All such functions are obtained using macros (see the file `paricom.h`), hence you can easily extend the list. These assignment variants are inefficient; don't use them.

5.5.1 Creation

`GEN` **cgeti**`(long n)` allocates memory on the PARI stack for a `t_INT` of length `n`, and initializes its first codeword. Identical to `cgetg(n,t_INT)`.

`GEN` **cgetr**`(long n)` allocates memory on the PARI stack for a `t_REAL` of length `n`, and initializes its first codeword. Identical to `cgetg(n,t_REAL)`.

`GEN` **cgetc**`(long n)` allocates memory on the PARI stack for a `t_COMPLEX`, whose real and imaginary parts are `t_REAL`s of length `n`.

`GEN` **real_1**`(long prec)` create a `t_REAL` equal to 1 to `prec` words of accuracy.

`GEN` **real_m1**`(long prec)` create a `t_REAL` equal to -1 to `prec` words of accuracy.

`GEN` **real_0_bit**`(long bit)` create a `t_REAL` equal to 0 with exponent $-$`bit`.

`GEN` **real_0**`(long prec)` is a shorthand for

```
real_0_bit( -bit_accuracy(prec) )
```

`GEN` **int2n**`(long n)` creates a `t_INT` equal to `1<<n` (i.e 2^n if $n \geq 0$, and 0 otherwise).

`GEN` **int2u**`(ulong n)` creates a `t_INT` equal to 2^n.

`GEN` **real2n**`(long n, long prec)` create a `t_REAL` equal to 2^n to `prec` words of accuracy.

`GEN` **stroi**`(char *s)` convert the character string `s` to a `t_INT`.

`GEN` **stror**`(char *s, long prec)` convert the character string `s` to a `t_REAL` of precision `prec`.

5.5.2 Assignment. In this section, the `z` argument in the `z`-functions must be of type `t_INT` or `t_REAL`.

`void` **mpaff**`(GEN x, GEN z)` assigns `x` into `z` (where `x` and `z` are `t_INT` or `t_REAL`). Assumes that `lg(z)` > 2.

`void` **affii**`(GEN x, GEN z)` assigns the `t_INT` `x` into the `t_INT` `z`.

`void` **affir**`(GEN x, GEN z)` assigns the `t_INT` `x` into the `t_REAL` `z`. Assumes that `lg(z)` > 2.

`void` **affiz**`(GEN x, GEN z)` assigns `t_INT` `x` into `t_INT` or `t_REAL` `z`. Assumes that `lg(z)` > 2.

`void` **affsi**`(long s, GEN z)` assigns the `long` `s` into the `t_INT` `z`. Assumes that `lg(z)` > 2.

`void` **affsr**`(long s, GEN z)` assigns the `long` `s` into the `t_REAL` `z`. Assumes that `lg(z)` > 2.

`void` **affsz**`(long s, GEN z)` assigns the `long` `s` into the `t_INT` or `t_REAL` `z`. Assumes that `lg(z)` > 2.

`void` **affui**`(ulong u, GEN z)` assigns the `ulong` `u` into the `t_INT` `z`. Assumes that `lg(z)` > 2.

`void` **affur**`(ulong u, GEN z)` assigns the `ulong` `u` into the `t_REAL` `z`. Assumes that `lg(z)` > 2.

`void` **affrr**`(GEN x, GEN z)` assigns the `t_REAL` `x` into the `t_REAL` `z`.

The function `affrs` and `affri` do not exist. So don't use them.

5.5.3 Copy

`GEN` **icopy**`(GEN x)` copy relevant words of the `t_INT` `x` on the stack: the length and effective length of the copy are equal.

`GEN` **rcopy**`(GEN x)` copy the `t_REAL` `x` on the stack.

`GEN` **mpcopy**`(GEN x)` copy the `t_INT` or `t_REAL` `x` on the stack. Contrary to `icopy`, `mpcopy` preserves the original length of a `t_INT`.

5.5.4 Conversions

`GEN` **itor**`(GEN x, long prec)` converts the `t_INT` `x` to a `t_REAL` of length `prec` and return the latter. Assumes that `prec` > 2.

`long` **itos**`(GEN x)` converts the `t_INT` `x` to a `long` if possible, otherwise raise an exception.

`long` **itos_or_0**`(GEN x)` converts the `t_INT` `x` to a `long` if possible, otherwise return 0.

`ulong` **itou**`(GEN x)` converts the `t_INT` `|x|` to an `ulong` if possible, otherwise raise an exception.

`long` **itou_or_0**`(GEN x)` converts the `t_INT` `|x|` to an `ulong` if possible, otherwise return 0.

`GEN` **stoi**`(long s)` creates the `t_INT` corresponding to the `long` `s`.

`GEN` **stor**`(long s, long prec)` converts the `long` `s` into a `t_REAL` of length `prec` and return the latter. Assumes that `prec` > 2.

`GEN` **utoi**`(ulong s)` converts the `ulong` `s` into a `t_INT` and return the latter.

`GEN` **utoipos**`(ulong s)` converts the *non-zero* `ulong` `s` into a `t_INT` and return the latter.

`GEN` **utoineg**`(ulong s)` converts the *non-zero* `ulong` `s` into a `t_INT` and return the latter.

GEN **utor**(ulong s, long prec) converts the ulong s into a t_REAL of length prec and return the latter. Assumes that prec > 2.

GEN **rtor**(GEN x, long prec) converts the t_REAL x to a t_REAL of length prec and return the latter. If prec $<$ lg(x), round properly. If prec $>$ lg(x), padd with zeroes. Assumes that prec > 2.

The following function is also available as a special case of mkintn:

GEN **u2toi**(ulong a, ulong b)

Returns the GEN equal to $2^{32}a + b$, *assuming* that $a, b < 2^{32}$. This does not depend on sizeof(long): the behaviour is as above on both 32 and 64-bit machines.

5.5.5 Integer parts

GEN **ceilr**(GEN x) smallest integer larger or equal to the t_REAL x (i.e. the ceil function).

GEN **floorr**(GEN x) largest integer smaller or equal to the t_REAL x (i.e. the floor function).

GEN **roundr**(GEN x) rounds the t_REAL x to the nearest integer (towards $+\infty$).

GEN **truncr**(GEN x) truncates the t_REAL x (not the same as floorr if x is and negative).

GEN **mpceil**[z](GEN x[, GEN z]) as ceilr except that x may be a t_INT.

GEN **ceil_safe**(GEN x), x being a real number (not necessarily a t_REAL) returns an integer which is larger than any possible incarnation of x. (Recall that a t_REAL represents an interval of possible values.)

GEN **mpfloor**[z](GEN x[, GEN z]) as floorr except that x may be a t_INT.

GEN **mpround**[z](GEN x[, GEN z]) as roundr except that x may be a t_INT.

GEN **mptrunc**[z](GEN x[, GEN z]) as truncr except that x may be a t_INT.

GEN **diviiround**(GEN x, GEN y) if x and y are t_INTs, returns the quotient x/y of x and y, rounded to the nearest integer. If x/y falls exactly halfway between two consecutive integers, then it is rounded towards $+\infty$ (as for roundr).

5.5.6 Valuation and shift

long **vals**(long s) 2-adic valuation of the long s. Returns -1 if s is equal to 0.

long **vali**(GEN x) 2-adic valuation of the t_INT x. Returns -1 if x is equal to 0.

GEN **mpshift**[z](GEN x, long n[, GEN z]) shifts the t_INT or t_REAL x by n. If n is positive, this is a left shift, i.e. multiplication by 2^n. If n is negative, it is a right shift by $-n$, which amounts to the truncation of the quotient of x by 2^{-n}.

GEN **shifti**(GEN x, long n) shifts the t_INT x by n.

GEN **shiftr**(GEN x, long n) shifts the t_REAL x by n.

long **Z_pvalrem**(GEN x, GEN p, GEN *r) applied to t_INTs $x \neq 0$ and p, $|p| > 1$, returns the highest exponent e such that p^e divides x. The quotient x/p^e is returned in *r. In particular, if p is a prime, this returns the valuation at p of x, and *r is the prime-to-p part of x.

long **Z_pval**(GEN x, GEN p) as Z_pvalrem but only returns the "valuation".

long **Z_lvalrem**(GEN x, ulong p, GEN *r) as Z_pvalrem, except that p is an ulong ($p > 1$).

`long` **Z_lval**`(GEN x, ulong p)` as `Z_pval`, except that `p` is an `ulong` (`p` > 1).

`long` **u_lvalrem**`(ulong x, ulong p, ulong *r)` as `Z_pvalrem`, except the inputs/outputs are now `ulong`s.

`long` **u_pvalrem**`(ulong x, GEN p, ulong *r)` as `Z_pvalrem`, except `x` and `r` are now `ulong`s.

`long` **u_lval**`(ulong x, ulong p)` as `Z_pval`, except the inputs/outputs are now `ulong`s.

5.5.7 Factorization

`GEN` **Z_factor**`(GEN n)` factors the `t_INT` `n`. The "primes" in the factorization are actually strong pseudoprimes.

`long` **Z_issquarefree**`(GEN x)` returns 1 if the `t_INT` `n` is square-free, and 0 otherwise.

`long` **Z_issquare**`(GEN n)` returns 1 if `t_INT` `n` is a square, and 0 otherwise. This is tested first modulo small prime powers, then `sqrtremi` is called.

`long` **Z_issquarerem**`(GEN n, GEN *sqrtn)` as `Z_issquare`. If `n` is indeed a square, set `sqrtn` to its integer square root.

`int` **isprime**`(GEN n)`, returns 1 if the `t_INT` `n` is a (fully proven) prime number and 0 otherwise.

`int` **uisprime**`(ulong p)`, returns 1 if `p` is a prime number and 0 otherwise.

`long` **Z_issquarerem**`(GEN n, GEN *sqrtn)` as `Z_issquare`. If `n` is indeed a square, set `sqrtn` to its integer square root.

`long` **uissquarerem**`(ulong n, ulong *sqrtn)` as `Z_issquarerem`, for an `ulong` operand `n`.

5.5.8 Generic unary operators. Let "*op*" be a unary operation among

op=**neg**: negation ($-$`x`).

op=**abs**: absolute value (|`x`|).

The names and prototypes of the low-level functions corresponding to *op* are as follows. The result is of the same type as `x`.

`GEN` **mp***op*`(GEN x)` creates the result of *op* applied to the `t_INT` or `t_REAL` `x`.

`GEN` *op***i**`(GEN x)` creates the result of *op* applied to the `t_INT` `x`.

`GEN` *op***r**`(GEN x)` creates the result of *op* applied to the `t_REAL` `x`.

`GEN` **mp***op***z**`(GEN x, GEN z)` assigns the result of applying *op* to the `t_INT` or `t_REAL` `x` into the `t_INT` or `t_REAL` `z`.

Remark: it has not been considered useful to include functions `void` *op*`sz(long,GEN)`, `void` *op*`iz(GEN,GEN)` and `void` *op*`rz(GEN, GEN)`.

5.5.9 Comparison operators

`int` **mpcmp**`(GEN x, GEN y)` compares the `t_INT` or `t_REAL` `x` to the `t_INT` or `t_REAL` `y`. The result is the sign of `x` − `y`.

`int` **cmpii**`(GEN x, GEN y)` compares the `t_INT` `x` to the `t_INT` `y`.

`int` **cmpir**`(GEN x, GEN y)` compares the `t_INT` `x` to the `t_REAL` `y`.

`int` **cmpis**`(GEN x, long s)` compares the `t_INT` `x` to the `long` `s`.

`int` **cmpsi**`(long s, GEN x)` compares the `long` `s` to the `t_INT` `x`.

`int` **cmpsr**`(long s, GEN x)` compares the `long` `s` to the `t_REAL` `x`.

`int` **cmpri**`(GEN x, GEN y)` compares the `t_REAL` `x` to the `t_INT` `y`.

`int` **cmprr**`(GEN x, GEN y)` compares the `t_REAL` `x` to the `t_REAL` `y`.

`int` **cmprs**`(GEN x, long s)` compares the `t_REAL` `x` to the `long` `s`.

`int` **equalii**`(GEN x, GEN y)` compares the `t_INT`s `x` and `y`. The result is 1 if `x` = `y`, 0 otherwise.

`int` **equalsi**`(long s, GEN x)`

`int` **equalis**`(GEN x, long s)` compare the `t_INT` `x` and the `long` `s`. The result is 1 if `x` = `y`, 0 otherwise.

`int` **equalui**`(ulong s, GEN x)`

`int` **equaliu**`(GEN x, ulong s)` compare the `t_INT` `x` and the `ulong` `s`. The result is 1 if |`x`| = `y`, 0 otherwise.

`int` **absi_cmp**`(GEN x, GEN y)` compares the `t_INT`s `x` and `y`. The result is the sign of |`x`| − |`y`|.

`int` **absi_equal**`(GEN x, GEN y)` compares the `t_INT`s `x` and `y`. The result is 1 if |`x`| = |`y`|, 0 otherwise.

`int` **absr_cmp**`(GEN x, GEN y)` compares the `t_REAL`s `x` and `y`. The result is the sign of |`x`| − |`y`|.

5.5.10 Generic binary operators. Let "*op*" be a binary operation among

op=**add**: addition (`x + y`). The result is a `t_REAL` unless both `x` and `y` are `t_INT`s (or longs).

op=**sub**: subtraction (`x - y`). The result is a `t_REAL` unless both `x` and `y` are `t_INT` (or longs).

op=**mul**: multiplication (`x * y`). The result is a `t_REAL` unless both `x` and `y` are `t_INT`s (or longs), *or* if `x` or `y` is an exact 0.

op=**div**: division (`x / y`). In the case where `x` and `y` are both `t_INT`s or longs, the result is the Euclidean quotient, where the remainder has the same sign as the dividend `x`. It is the ordinary division otherwise. If one of `x` or `y` is a `t_REAL`, the result is a `t_REAL` unless `x` is an exact 0. A division-by-0 error occurs if `y` is equal to 0.

op=**rem**: remainder ("`x % y`"). This operation is defined only when `x` and `y` are longs or `t_INT`. The result is the Euclidean remainder corresponding to `div`, i.e. its sign is that of the dividend `x`. The result is always a `t_INT`.

op=**mod**: true remainder (`x % y`). This operation is defined only when `x` and `y` are longs or `t_INT`s. The result is the true Euclidean remainder, i.e. non-negative and less than the absolute value of `y`.

The names and prototypes of the low-level functions corresponding to *op* are as follows. In this section, the `z` argument in the `z`-functions must be of type `t_INT` or `t_REAL`. `t_INT` is only allowed when no 'r' appears in the argument code (no `t_REAL` operand is involved).

`GEN` **mp***op*[**z**]`(GEN x, GEN y[, GEN z])` applies *op* to the `t_INT` or `t_REAL` `x` and `y`.

`GEN` *op***si**[**z**]`(long s, GEN x[, GEN z])` applies *op* to the `long` `s` and the `t_INT` `x`.

`GEN` *op***sr**[**z**]`(long s, GEN x[, GEN z])` applies *op* to the `long` `s` and the `t_REAL` `x`.

`GEN` *op***ss**[**z**]`(long s, long t[, GEN z])` applies *op* to the longs `s` and `t`.

`GEN` *op***ii**[**z**]`(GEN x, GEN y[, GEN z])` applies *op* to the `t_INT`s `x` and `y`.

`GEN` *op***ir**[**z**]`(GEN x, GEN y[, GEN z])` applies *op* to the `t_INT` `x` and the `t_REAL` `y`.

`GEN` *op***is**[**z**]`(GEN x, long s[, GEN z])` applies *op* to the `t_INT` `x` and the `long` `s`.

`GEN` *op***ri**[**z**]`(GEN x, GEN y[, GEN z])` applies *op* to the `t_REAL` `x` and the `t_INT` `y`.

`GEN` *op***rr**[**z**]`(GEN x, GEN y[, GEN z])` applies *op* to the `t_REAL`s `x` and `y`.

`GEN` *op***rs**[**z**]`(GEN x, long s[, GEN z])` applies *op* to the `t_REAL` `x` and the `long` `s`.

Some miscellaneous routines whose meaning should be clear from their names:

`GEN` **muluu**`(ulong x, ulong y)`

`GEN` **mului**`(ulong x, GEN y)`

`GEN` **muliu**`(GEN x, ulong y)`

`GEN` **sqri**`(GEN x)` squares the `t_INT` `x`

`GEN` **truedivii**`(GEN x, GEN y)` returns the true Euclidean quotient (with non-negative remainder less than $|y|$).

`GEN` **truedivis**`(GEN x, long y)` returns the true Euclidean quotient (with non-negative remainder less than $|y|$).

`GEN` **centermodii**`(GEN x, GEN y, GEN y2)`, given `t_INT`s `x`, `y`, returns z congruent to `x` modulo `y`, such that $-\mathtt{y}/2 \le z < \mathtt{y}/2$. Assumes that `y2 = shifti(y, -1)`. the representative of ssquares the `t_INT` `x`

5.5.11 Modulo to longs. The following variants of `modii` do not clutter the stack:

`long` **smodis**`(GEN x, long y)` computes the true Euclidean remainder of the `t_INT x` by the `long y`. This is the non-negative remainder, not the one whose sign is the sign of `x` as in the `div` functions.

`long` **smodsi**`(long x, GEN y)` computes the true Euclidean remainder of the `long x` by a `t_INT y`.

`long` **smodss**`(long x, long y)` computes the true Euclidean remainder of the `long x` by a `t_long y`.

`ulong` **umodiu**`(GEN x, ulong y)` computes the true Euclidean remainder of the `t_INT x` by the `ulong y`.

`ulong` **umodui**`(ulong x, GEN y)` computes the true Euclidean remainder of the `ulong x` by the `t_INT |y|`.

The routine `smodsi` does not exist, since it would not always be defined: for a *negative* `x`, its result `x + |y|` would in general not fit into a `long`. Use either `umodui` or `modsi`.

5.5.12 Exact division and divisibility

`void` **diviiexact**`(GEN x, GEN y)` returns the Euclidean quotient `x/y`, assuming `y` divides `x`. Uses Jebelean algorithm (Jebelean-Krandick bidirectional exact division is not implemented).

`void` **diviuexact**`(GEN x, ulong y)` returns the Euclidean quotient `|x|/y` (note the absolue value!), assuming `y` divides `x` and `y` is non-zero.

`int` **dvdii**`(GEN x, GEN y)` if the `t_INT y` divides the `t_INT x`, returns 1 (true), otherwise returns 0 (false).

`int` **dvdiiz**`(GEN x, GEN y, GEN z)` if the `t_INT y` divides the `t_INT x`, assigns the quotient to the `t_INT z` and returns 1 (true), otherwise returns 0 (false).

`int` **dvdisz**`(GEN x, long y, GEN z)` if the `t_long y` divides the `t_INT x`, assigns the quotient to the `t_INT z` and returns 1 (true), otherwise returns 0 (false).

`int` **dvdiuz**`(GEN x, ulong y, GEN z)` if the `t_ulong y` divides the `t_INT x`, assigns the quotient `|x|/y` to the `t_INT z` and returns 1 (true), otherwise returns 0 (false).

5.5.13 Division with remainder. The following functions return two objects, unless specifically asked for only one of them — a quotient and a remainder. The quotient is returned and the remainder is returned through the variable whose address is passed as the `r` argument. The term *true Euclidean remainder* refers to the non-negative one (`mod`), and *Euclidean remainder* by itself to the one with the same sign as the dividend (`rem`). All `GEN`s, whether returned directly or through a pointer, are created on the stack.

`GEN` **dvmdii**`(GEN x, GEN y, GEN *r)` returns the Euclidean quotient of the `t_INT x` by a `t_INT y` and puts the remainder into `*r`. If `r` is equal to `NULL`, the remainder is not created, and if `r` is equal to `ONLY_REM`, only the remainder is created and returned. In the generic case, the remainder is created after the quotient and can be disposed of individually with a `cgiv(r)`. The remainder is always of the sign of the dividend `x`. If the remainder is 0 set `r = gen_0`.

`void` **dvmdiiz**`(GEN x, GEN y, GEN z, GEN t)` assigns the Euclidean quotient of the `t_INT`s `x` and `y` into the `t_INT` or `t_REAL z`, and the Euclidean remainder into the `t_INT` or `t_REAL t`.

Analogous routines `dvmdis[z]`, `dvmdsi[z]`, `dvmdss[z]` are available, where `s` denotes a `long` argument. But the following routines are in general more flexible:

`long` **sdivss_rem**`(long s, long t, long *r)` computes the Euclidean quotient and remainder of the longs `s` and `t`. Puts the remainder into `*r`, and returns the quotient. The remainder is of the sign of the dividend `s`, and has strictly smaller absolute value than `t`.

`long` **sdivsi_rem**`(long s, GEN x, long *r)` computes the Euclidean quotient and remainder of the `long s` by the `t_INT x`. As `sdivss_rem` otherwise.

`long` **sdivsi**`(long s, GEN x)` as `sdivsi_rem`, without remainder.

`GEN` **divis_rem**`(GEN x, long s, long *r)` computes the Euclidean quotient and remainder of the `t_INT x` by the `long s`. As `sdivss_rem` otherwise.

`GEN` **diviu_rem**`(GEN x, ulong s, long *r)` computes the Euclidean quotient and remainder of the `t_INT x` by the `ulong s`. As `sdivss_rem` otherwise.

`GEN` **divsi_rem**`(long s, GEN y, long *r)` computes the Euclidean quotient and remainder of the `t_long s` by the `GEN y`. As `sdivss_rem` otherwise.

`GEN` **divss_rem**`(long x, long y, long *r)` computes the Euclidean quotient and remainder of the `t_long x` by the `long y`. As `sdivss_rem` otherwise.

`GEN` **truedvmdii**`(GEN x, GEN y, GEN *r)`, as `dvmdii` but with a non-negative remainder.

5.5.14 Square root and remainder

`GEN` **sqrtremi**`(GEN N, GEN *r)`, returns the integer square root S of the non-negative `t_INT N` (rounded towards 0) and puts the remainder R into `*r`. Precisely, $N = S^2 + R$ with $0 \leq R \leq 2S$. If `r` is equal to `NULL`, the remainder is not created. In the generic case, the remainder is created after the quotient and can be disposed of individually with `cgiv(R)`. If the remainder is 0 set `R = gen_0`.

Uses a divide and conquer algorithm (discrete variant of Newton iteration) due to Paul Zimmermann ("Karatsuba Square Root", INRIA Research Report 3805 (1999)).

`GEN` **sqrti**`(GEN N)`, returns the integer square root S of the non-negative `t_INT N` (rounded towards 0). This is identical to `sqrtremi(N, NULL)`.

5.5.15 Pseudo-random integers

`long` **random_bits**`(long k)` returns a random $0 \leq x < 2^k$. Assumes that $0 \leq k < 31$.

`long` **pari_rand31**`(long k)` as `random_bits` with $k = 31$.

`GEN` **randomi**`(GEN n)` returns a random `t_INT` between 0 and `n` $- 1$. The result is pasted from successive calls to `pari_rand31`.

5.5.16 Modular operations. In this subsection, all GENs are t_INT.

ulong **Fp_powu**(GEN x, ulong n, GEN m) raises x to the n-th power modulo p (smallest non-negative residue).

GEN **Fp_pow**(GEN x, GEN n, GEN m) returns x^n modulo p (smallest non-negative residue).

GEN **Fp_inv**(GEN a, GEN m) returns an inverse of a modulo m (smallest non-negative residue). Raise an error if a is not invertible.

GEN **Fp_invsafe**(GEN a, GEN m) as Fp_inv, but return NULL if a is not invertible.

int **invmod**(GEN a, GEN m, GEN *g), return 1 if a modulo m is invertible, else return 0 and set $g = \gcd(a, m)$.

GEN **Fp_sqrt**(GEN x, GEN p) returns a square root of x modulo p (the smallest non-negative residue), where x, p are t_INTs, and p is assumed to be prime. Return NULL if x is not a quadratic residue modulo p.

GEN **Fp_sqrtn**(GEN x, GEN n, GEN p, GEN *zn) returns an n-th root of x modulo p (smallest non-negative residue), where x, n, p are t_INTs, and p is assumed to be prime. Return NULL if x is not an n-th power residue. Otherwise, if zn is non-NULL set it to a primitive n-th root of 1.

long **kross**(long x, long y) returns the Kronecker symbol $(x|y)$, i.e.-1, 0 or 1. If y is an odd prime, this is the Legendre symbol. (Contrary to krouu, kross also supports $y = 0$)

long **krois**(GEN x, long y) returns the Kronecker symbol $(x|y)$ of t_INT x and long y. As kross otherwise.

long **krosi**(long x, GEN y) returns the Kronecker symbol $(x|y)$ of long x and t_INT y. As kross otherwise.

long **kronecker**(GEN x, GEN y) returns the Kronecker symbol $(x|y)$ of t_INTs x and y. As kross otherwise.

GEN **gener_Fp**(GEN p) returns a primitive root modulo p, assuming p is prime.

GEN **gener_Fp_local**(GEN p, GEN L), L being a vector of primes dividing $p-1$, returns an integer x which is a generator of the ℓ-Sylow of $\mathbf{F}_p^*$ for every ℓ in L. In other words, $x^{(p-1)/\ell} \neq 1$ for all such ℓ. In particular, returns Fp_gener(p) if L contains all primes dividing $p-1$.

5.5.17 Miscellaneous functions

void **addumului**(ulong a, ulong b, GEN x) return $a + b|X|$.

long **cgcd**(long x, long y), returns the GCD of the t_longs x and y.

long **cbezout**(long a,long b, long *u,long *v), returns the GCD d of a and b and sets u, v to the Bezout coefficients such that $au + bv = d$.

GEN **bezout**(GEN a,GEN b, GEN *u,GEN *v), returns the GCD d of t_INTs a and b and sets u, v to the Bezout coefficients such that $au + bv = d$.

GEN **factoru**(ulong n), returns the factorization of n. The result is a 2-component vector $[P, E]$, where P and E are t_VECSMALL containing the prime divisors of n, and the $v_p(n)$.

GEN **factoru_pow**(ulong n), returns the factorization of n. The result is a 3-component vector $[P, E, C]$, where P, E and C are t_VECSMALL containing the prime divisors of n, the $v_p(n)$ and the $p^{v_p(n)}$.

`GEN` **gcdii**`(GEN x, GEN y)`, returns the GCD of the `t_INT`s `x` and `y`.

`GEN` **lcmii**`(GEN x, GEN y)`, returns the LCM of the `t_INT`s `x` and `y`.

`long` **maxss**`(long x, long y)`, return the largest of `x` and `y`.

`long` **minss**`(long x, long y)`, return the smallest of `x` and `y`.

`GEN` **powuu**`(ulong n, ulong k)`, returns n^k.

`GEN` **powiu**`(GEN n, ulong k)`, assumes n is a `t_INT` and returns n^k.

`ulong` **upowuu**`(ulong n, ulong k)`, returns n^k modulo $2^{\texttt{BIL}}$. This is meant to be used for tiny k, where in fact n^k fits into an `ulong`.

`void` **rdivii**`(GEN x, GEN y, long prec)`, assuming `x` and `y` are both of type `t_INT`, return the quotient x/y as a `t_REAL` of precision `prec`.

`void` **rdivis**`(GEN x, long y, long prec)`, assuming `x` is of type `t_INT`, return the quotient x/y as a `t_REAL` of precision `prec`.

`void` **rdivsi**`(long x, GEN y, long prec)`, assuming `y` is of type `t_INT`, return the quotient x/y as a `t_REAL` of precision `prec`.

`void` **rdivss**`(long x, long y, long prec)`, return the quotient x/y as a `t_REAL` of precision `prec`.

5.6 Level 2 kernel (modular arithmetic).

These routines implement univariate polynomial arithmetic and linear algebra over finite fields, in fact over finite rings of the form $(\mathbf{Z}/p\mathbf{Z})[X]/(T)$, where p is not necessarily prime and $T \in (\mathbf{Z}/p\mathbf{Z})[X]$ is possibly reducible; and finite extensions thereof. All this can be emulated with `t_INTMOD` and `t_POLMOD` coefficients and using generic routines, at a considerable loss of efficiency. Also, some specialized routines are available that have no obvious generic equivalent.

5.6.1 Naming scheme. A function name is built in the following way: $A_1_\dots_A_n fun$ for an operation *fun* with n arguments of class A_1,..., A_n. A class name is given by a base ring followed by a number of code letters. Base rings are among

`Fl`: $\mathbf{Z}/l\mathbf{Z}$ where $l < 2^{\texttt{BIL}}$ is not necessarily prime. Implemented using `ulong`s

`Fp`: $\mathbf{Z}/p\mathbf{Z}$ where p is a `t_INT`, not necessarily prime. Implemented as `t_INT`s z, preferably satisfying $0 \le z < p$. More precisely, any `t_INT` can be used as an `Fp`, but reduced inputs are treated more efficiently. Outputs from `Fp`xxx routines are reduced.

`Fq`: $\mathbf{Z}[X]/(p, T(X))$, p a `t_INT`, T a `t_POL` with `Fp` coefficients or `NULL` (in which case no reduction modulo `T` is performed). Implemented as `t_POL`s z with `Fp` coefficients, $\deg(z) < \deg$ `T`.

`Z`: the integers $\mathbf{Z}$, implemented as `t_INT`s.

`z`: the integers $\mathbf{Z}$, implemented using (signed) `long`s.

`Q`: the rational numbers $\mathbf{Q}$, implemented as `t_INT`s and `t_FRAC`s.

`Rg`: a commutative ring, whose elements can be `gadd`-ed, `gmul`-ed, etc.

Possible letters are:

`X`: polynomial in X (`t_POL` in a fixed variable), e.g. `FpX` means $\mathbf{Z}/p\mathbf{Z}[X]$

`Y`: polynomial in $Y \neq X$. E.g. `FpXY` means $((\mathbf{Z}/p\mathbf{Z})[Y])[X]$

`V`: vector (`t_VEC` or `t_COL`), treated as a line vector (independantly of the actual type). E.g. `ZV` means $\mathbf{Z}^k$ for some k.

`C`: vector (`t_VEC` or `t_COL`), treated as a column vector (independantly of the actual type). The difference with `V` is purely semantic.

`M`: matrix (`t_MAT`). E.g. `QM` means a matrix with rational entries

`Q`: representative (`t_POL`) of a class in a polynomial quotient ring. E.g. an `FpXQ` belongs to $(\mathbf{Z}/p\mathbf{Z})[X]/(T(X))$, `FpXQV` means a vector of such elements, etc.

`x`, `m`, `v`, `c`, `q`: as their uppercase counterpart, but coefficient arrays are implemented using `t_VECSMALL`s, which coefficient understood as `ulong`s.

`x` (and `q`) are implemented by a `t_VECSMALL` whose first coefficient is used as a code-word and the following are the coefficients , similarly to a `t_POL`. This is known as a 'POLSMALL'.

`m` are implemented by a `t_MAT` whose components (columns) are `t_VECSMALL`s. This is know as a 'MATSMALL'.

`v` and `c` are regular `t_VECSMALL`s. Difference between the two is purely semantic.

Omitting the letter means the argument is a scalar in the base ring. Standard functions *fun* are

`add`: add

`sub`: subtract

`mul`: multiply

`sqr`: square

`div`: divide (Euclidean quotient)

`rem`: Euclidean remainder

`divrem`: return Euclidean quotient, store remainder in a pointer argument.

`gcd`: GCD

`extgcd`: return GCD, store Bezout coefficients in pointer arguments

`pow`: exponentiate

`compo`: composition

5.6.2 `ZX`**,** `ZV`**,** `ZM`. A `ZV` (resp. a `ZM`, resp. a `ZX`) is a `t_VEC` or `t_COL` (resp. `t_MAT`, resp. `t_POL`) with `t_INT` coefficients.

5.6.2.1 `ZV`

`GEN` **ZV_add**`(GEN x, GEN y)` adds `x` and `y`.

`GEN` **ZV_sub**`(GEN x, GEN y)` subtracts `x` and `y`.

5.6.2.2 ZX

GEN **ZX_renormalize**(GEN x, long l), as normalizepol, where l = lg(x), in place.

GEN **ZX_add**(GEN x,GEN y) adds x and y.

GEN **ZX_sub**(GEN x,GEN y) subtracts x and y.

GEN **ZX_neg**(GEN x,GEN p) returns $-$x.

GEN **ZX_Z_add**(GEN x,GEN y) adds the integer y to the polynomial x.

GEN **ZX_Z_mul**(GEN x,GEN y) multiplies the polynomial x by the integer y.

GEN **ZX_mul**(GEN x,GEN y) multiplies x and y.

GEN **ZX_sqr**(GEN x,GEN p) returns x^2.

GEN **ZX_caract**(GEN T, GEN A, long v) returns the characteristic polynomial of Mod(A, T), where T is a ZX, A is a ZX. More generally, A is allowed to be a QX, hence possibly has rational coefficients, *assuming* the result is a ZX, i.e. the algebraic number Mod(A,T) is integral over Z.

GEN **ZX_disc**(GEN T) returns the discriminant of the ZX T.

int **ZX_is_squarefree**(GEN T) returns 1 if the ZX T is squarefree, 0 otherwise.

GEN **ZX_resultant**(GEN A, GEN B) returns the resultant of the ZX A and B.

GEN **ZX_QX_resultant**(GEN A, GEN B) returns the resultant of the ZX A and the QX B, *assuming* the result is an integer.

GEN **ZY_ZXY_resultant**(GEN A, GEN B) under the assumption that A in $\mathbf{Z}[Y]$, B in $\mathbf{Q}[Y][X]$, and $R = \mathrm{Res}_Y(A,B) \in \mathbf{Z}[X]$, returns the resultant R.

GEN **ZY_ZXY_rnfequation**(GEN A, GEN B, long *lambda), assume A in $\mathbf{Z}[Y]$, B in $\mathbf{Q}[Y][X]$, and $R = \mathrm{Res}_Y(A,B) \in \mathbf{Z}[X]$. If lambda = NULL, returns R as in ZY_ZXY_resultant. Otherwise, lambda must point to some integer, e.g. 0 which is used as a seed. The function then finds a small $\lambda \in \mathbf{Z}$ (starting from *lambda) such that $R_\lambda(X) := \mathrm{Res}_Y(A, B(X+\lambda Y))$ is squarefree, resets *lambda to the chosen value and returns R_λ.

GEN **ZM_inv**(GEN M, GEN d) if M is a ZM and d is a t_INT such that $M' := \mathtt{d}\mathtt{M}^{-1}$ is integral, return M'. It is allowed to set d = NULL, in which case, the determinant of M is computed and used instead.

GEN **QM_inv**(GEN M, GEN d) as above, with M a QM. We still assume that M' has integer coefficients.

5.6.3 FpX. Let p an understood t_INT, to be given in the function arguments; in practice p is not assumed to be prime, but be wary. An Fp object is a t_INT belonging to $[0, \mathtt{p}-1]$, an FpX is a t_POL in a fixed variable whose coefficients are Fp objects. Unless mentionned otherwise, all outputs in this section are FpXs. All operations are understood to take place in $(\mathbf{Z}/\mathtt{p}\mathbf{Z})[X]$.

5.6.3.1 Basic operations. In what follows p is always a t_INT, not necessarily prime.

GEN **Rg_to_Fp**(GEN z, GEN p), z a scalar which can be mapped to $\mathbf{Z}/p\mathbf{Z}$: a t_INT, a t_INTMOD whose modulus is divisible by p, a t_FRAC whose denominator is coprime to p, or a t_PADIC with underlying prime p. Returns lift(z * Mod(1,p)), normalized.

GEN **RgX_to_FpX**(GEN z, GEN p), z a t_POL, returns the FpX obtained by applying Rg_to_Fp coefficientwise.

GEN **RgV_to_FpV**(GEN z, GEN p), z a t_VEC or t_COL, returns the FpV (as a t_VEC) obtained by applying Rg_to_Fp coefficientwise.

GEN **RgC_to_FpC**(GEN z, GEN p), z a t_VEC or t_COL, returns the FpC (as a t_COL) obtained by applying Rg_to_Fp coefficientwise.

GEN **FpX_to_mod**(GEN z, GEN p), z a ZX. Returns z * Mod(1,p), normalized. Hence the returned value has t_INTMOD coefficients.

GEN **FpX_red**(GEN z, GEN p), z a ZX, returns lift(z * Mod(1,p)), normalized.

GEN **FpXV_red**(GEN z, GEN p), z a t_VEC of ZX. Applies FpX_red componentwise and returns the result (and we obtain a vector of FpXs).

Now, except for p, the operands and outputs are all FpX objects. Results are undefined on other inputs.

GEN **FpX_add**(GEN x,GEN y, GEN p) adds x and y.

GEN **FpX_neg**(GEN x,GEN p) returns $-$x.

GEN **FpX_renormalize**(GEN x, long l), as normalizepol, where l = lg(x), in place.

GEN **FpX_sub**(GEN x,GEN y,GEN p) subtracts y from x.

GEN **FpX_mul**(GEN x,GEN y,GEN p) multiplies x and y.

GEN **FpX_sqr**(GEN x,GEN p) returns x^2.

GEN **FpX_divrem**(GEN x, GEN y, GEN p, GEN *pr) returns the quotient of x by y, and sets pr to the remainder.

GEN **FpX_div**(GEN x, GEN y, GEN p) returns the quotient of x by y.

GEN **FpX_div_by_X_x**(GEN A, GEN a, GEN p, GEN *r) returns the quotient of the FpX A by $(X - \mathrm{a})$, and sets r to the remainder A(a).

GEN **FpX_rem**(GEN x, GEN y, GEN p) returns the remainder x mod y

GEN **FpX_gcd**(GEN x, GEN y, GEN p) returns a (not necessarily monic) greatest common divisor of x and y.

GEN **FpX_extgcd**(GEN x, GEN y, GEN p, GEN *u, GEN *v) returns $d = \mathrm{GCD}(\mathrm{x}, \mathrm{y})$, and sets *u, *v to the Bezout coefficients such that $*\mathrm{u}\,\mathrm{x} + *\mathrm{v}\,\mathrm{y} = d$.

GEN **FpX_center**(GEN z, GEN p) returns the polynomial whose coefficient belong to the symmetric residue system (clean version of centermod, which assumes the coefficients already belong to $[0, \mathrm{p} - 1]$).

5.6.3.2 Miscellaneous operations

`GEN` **FpX_normalize**`(GEN z, GEN p)` divides the `FpX z` by its leading coefficient. If the latter is 1, `z` itself is returned, not a copy. If not, the inverse remains uncollected on the stack.

`GEN` **FpX_Fp_add**`(GEN y, GEN x, GEN p)` add the `Fp x` to the `FpX y`, possibly modifying the argument `y` (thus the operation uses constant time instead of linear linear). This function is not suitable for `gerepileupto` nor for `gerepile`.

`GEN` **FpX_Fp_mul**`(GEN y, GEN x, GEN p)` multiplies the `FpX y` by the `Fp x`.

`GEN` **FpX_rescale**`(GEN P, GEN h, GEN p)` returns $h^{\deg(P)}P(x/h)$. `P` is an `FpX` and `h` is a non-zero `Fp` (the routine would work with any non-zero `t_INT` but is not efficient in this case).

`GEN` **FpX_eval**`(GEN x, GEN y, GEN p)` evaluates the `FpX x` at the `Fp y`. The result is an `Fp`.

`GEN` **FpXV_FpC_mul**`(GEN V, GEN W, GEN p)` multiplies a line vector of`FpX` by a column vector of `Fp` (scalar product). The result is an `FpX`.

`GEN` **FpXV_prod**`(GEN V, GEN p)`, `V` being a vector of `FpX`, returns their product.

`GEN` **FpV_roots_to_pol**`(GEN V, GEN p, long v)`, `V` being a vector of `INT`s, returns the monic `FpX` $\prod_i$(`pol_x`[`v`] − `V`[`i`]).

`GEN` **FpX_chinese_coprime**`(GEN x,GEN y, GEN Tx,GEN Ty, GEN Tz, GEN p)` returns an `FpX`, congruent to `x` mod `Tx` and to `y` mod `Ty`. Assumes `Tx` and `Ty` are coprime, and `Tz = Tx * Ty` or `NULL` (in which case it is computed within).

`GEN` **FpV_polint**`(GEN x, GEN y, GEN p)` returns the `FpX` interpolation polynomial with value `y[i]` at `x[i]`. Assumes lengths are the same, components are `t_INT`s, and the `x[i]` are distinct modulo `p`.

`long` **FpX_is_squarefree**`(GEN f, GEN p)` returns 1 if the `FpX f` is squarefree, 0 otherwise.

`long` **FpX_is_irred**`(GEN f, GEN p)` returns 1 if the `FpX f` is irreducible, 0 otherwise. Assumes that `p` is prime. If `f` has few factors, `FpX_nbfact(f,p) == 1` is much faster.

`long` **FpX_is_totally_split**`(GEN f, GEN p)` returns 1 if the `FpX f` splits into a product of distinct linear factors, 0 otherwise. Assumes that `p` is prime.

`GEN` **FpX_factor**`(GEN f, GEN p)`, factors the `FpX f`. Assumes that `p` is prime. The returned value `v` has two components: `v[1]` is a vector of distinct irreducible (`FpX`) factors, and `v[2]` is a `t_VECSMALL` of corresponding exponents. The order of the factors is deterministic (the computation is not).

`long` **FpX_nbfact**`(GEN f, GEN p)`, assuming the `FpX` f is squarefree, returns the number of its irreducible factors. Assumes that `p` is prime.

`long` **FpX_degfact**`(GEN f, GEN p)`, as `FpX_factor`, but the degrees of the irreducible factors are returned instead of the factors themselves (as a `t_VECSMALL`). Assumes that `p` is prime.

`long` **FpX_nbroots**`(GEN f, GEN p)` returns the number of distinct roots in $\mathbf{Z}/p\mathbf{Z}$ of the `FpX f`. Assumes that `p` is prime.

`GEN` **FpX_roots**`(GEN f, GEN p)` returns the roots in $\mathbf{Z}/p\mathbf{Z}$ of the `FpX f` (without multiplicity, as a vector of `Fp`s). Assumes that `p` is prime.

`GEN` **FpX_rand**`(long d, long v, GEN p)` returns a random `FpX` in variable `v`, of degree less than `d`.

GEN **FpX_resultant**(GEN x, GEN y, GEN p) returns the resultant of x and y, both FpX. The result is a t_INT belonging to $[0, p-1]$.

GEN **FpY_FpXY_resultant**(GEN a, GEN b, GEN p), a a t_POL of t_INTs (say in variable Y), b a t_POL (say in variable X) whose coefficients are either t_POLs in $\mathbf{Z}[Y]$ or t_INTs. Returns $\mathrm{Res}_Y(a, b)$, which is an FpX. The function assumes that Y has lower priority than X.

5.6.4 FpXQ, Fq. Let p a t_INT and T an FpX for p, both to be given in the function arguments; an FpXQ object is an FpX whose degree is strictly less than the degree of T. An Fq is either an FpXQ or an Fp. Both represent a class in $(\mathbf{Z}/p\mathbf{Z})[X]/(T)$, in which all operations below take place. In addition, Fq routines also allow T = NULL, in which case no reduction mod T is performed on the result.

For efficiency, the routines in this section may leave small unused objects behind on the stack (their output is still suitable for gerepileupto). Besides T and p, arguments are either FpXQ or Fq depending on the function name. (All Fq routines accept FpXQs by definition, not the other way round.)

GEN **Rg_to_FpXQ**(GEN z, GEN T, GEN p), z a GEN which can be mapped to $\mathbf{F}_p[X]/(T)$: anything Rg_to_Fp can be applied to, a t_POL to which RgX_to_FpX can be applied to, a t_POLMOD whose modulus is divisible by T (once mapped to a FpX), a suitable t_RFRAC. Returns z as an FpXQ, normalized.

GEN **RgX_to_FpXQX**(GEN z, GEN T, GEN p), z a t_POL, returns the FpXQ obtained by applying Rg_to_FpXQ coefficientwise.

GEN **RgX_to_FqX**(GEN z, GEN T, GEN p), z a t_POL, returns the FpXQ obtained by applying Rg_to_FpXQ coefficientwise and simplifying scalars to t_INTs.

GEN **Fq_red**(GEN x, GEN T, GEN p), x a ZX or t_INT, reduce it to an Fq (T = NULL is allowed iff x is a t_INT).

GEN **FqX_red**(GEN x, GEN T, GEN p), x a t_POL whose coefficients are ZXs or t_INTs, reduce them to Fqs. (If T = NULL, as FpXX_red(x, p).)

GEN **FqV_red**(GEN x, GEN T, GEN p), x a vector of ZXs or t_INTs, reduce them to Fqs. (If T = NULL, only reduce components mod p to FpXs or Fps.)

GEN **FpXQ_mul**(GEN y, GEN x, GEN T,GEN p)

GEN **FpXQ_sqr**(GEN y, GEN T, GEN p)

GEN **FpXQ_div**(GEN x, GEN y, GEN T,GEN p)

GEN **FpXQ_inv**(GEN x, GEN T, GEN p) computes the inverse of x

GEN **FpXQ_invsafe**(GEN x,GEN T,GEN p), as FpXQ_inv, returning NULL if x is not invertible.

GEN **FpXQ_pow**(GEN x, GEN n, GEN T, GEN p) computes x^n.

GEN **Fq_add**(GEN x, GEN y, GEN T/*unused*/, GEN p)

GEN **Fq_sub**(GEN x, GEN y, GEN T/*unused*/, GEN p)

GEN **Fq_mul**(GEN x, GEN y, GEN T, GEN p)

GEN **Fq_neg**(GEN x, GEN T, GEN p)

GEN **Fq_neg_inv**(GEN x, GEN T, GEN p) computes $-x^{-1}$

GEN **Fq_inv**(GEN x, GEN pol, GEN p) computes x^{-1}, raising an error if x is not invertible.

GEN **Fq_invsafe**(GEN x, GEN pol, GEN p) as Fq_inv, but returns NULL if x is not invertible.

GEN **Fq_pow**(GEN x, GEN n, GEN pol, GEN p) returns x^n.

GEN **FpXQ_charpoly**(GEN x, GEN T, GEN p) returns the characteristic polynomial of x

GEN **FpXQ_minpoly**(GEN x, GEN T, GEN p) returns the minimal polynomial of x

GEN **FpXQ_powers**(GEN x, long n, GEN T, GEN p) returns $[x^0, \dots, x^n]$ as a t_VEC of FpXQs.

GEN **FpX_FpXQ_compo**(GEN f,GEN x,GEN T,GEN p) returns f(x).

GEN **FpX_FpXQV_compo**(GEN f,GEN V,GEN T,GEN p) returns f(x), assuming that V was computed by FpXQ_powers(x, n, T, p).

5.6.5 FpXX. Contrary to what the name implies, an FpXQX is a t_POL whose coefficients are either t_INTs or t_FpXs. This reduce memory overhead at the expense of consistency.

GEN **FpXX_add**(GEN x, GEN y, GEN p) adds x and y.

GEN **FpXX_red**(GEN z, GEN p), z a t_POL whose coefficients are either ZXs or t_INTs. Returns the t_POL equal to z with all components reduced modulo p.

GEN **FpXX_renormalize**(GEN x, long l), as normalizepol, where l = lg(x), in place.

5.6.6 FpXQX, FqX. Contrary to what the name implies, an FpXQX is a t_POL whose coefficients are Fqs. So the only difference between FqX and FpXQX routines is that T = NULL is not allowed in the latter. (It was thought more useful to allow t_INT components than to enforce strict consistency, which would not imply any efficiency gain.)

5.6.6.1 Basic operations

GEN **FqX_mul**(GEN x, GEN y, GEN T, GEN p)

GEN **FqX_Fq_mul**(GEN P, GEN U, GEN T, GEN p) multiplies the FqX y by the Fq x.

GEN **FqX_normalize**(GEN z, GEN T, GEN p) divides the FqX z by its leading term.

GEN **FqX_sqr**(GEN x, GEN T, GEN p)

GEN **FqX_divrem**(GEN x, GEN y, GEN T, GEN p, GEN *z)

GEN **FqX_div**(GEN x, GEN y, GEN T, GEN p)

GEN **FqX_rem**(GEN x, GEN y, GEN T, GEN p)

GEN **FqX_gcd**(GEN P, GEN Q, GEN T, GEN p)

GEN **FpXQX_red**(GEN z, GEN T, GEN p) z a t_POL whose coefficients are ZXs or t_INTs, reduce them to FpXQs.

GEN **FpXQX_mul**(GEN x, GEN y, GEN T, GEN p)

GEN **FpXQX_sqr**(GEN x, GEN T, GEN p)

GEN **FpXQX_divrem**(GEN x, GEN y, GEN T, GEN p, GEN *pr)

GEN **FpXQX_gcd**(GEN x, GEN y, GEN T, GEN p)

GEN **FpXQX_extgcd**(GEN x, GEN y, GEN T, GEN p, GEN *ptu, GEN *ptv)

GEN **FpXQYQ_pow**(GEN x, GEN n, GEN S, GEN T, GEN p), x and T being FpXQXs, returns x^n modulo S.

GEN **FpXQXV_prod**(GEN V, GEN T, GEN p), V being a vector of FpXQX, returns their product.

GEN **FqV_roots_to_pol**(GEN V, GEN T, GEN p, long v), V being a vector of Fqs, returns the monic FqX $\prod_i$(pol_x[v] − V[i]).

5.6.6.2 Miscellaneous operations

GEN **init_Fq**(GEN p, long n, long v) returns an irreducible polynomial of degree n over $\mathbf{F}_p$, in variable v.

long **FqX_is_squarefree**(GEN P, GEN T, GEN p)

GEN **FqX_factor**(GEN x, GEN T, GEN p) same output convention as FpX_factor. Assumes p is prime and T irreducible in $\mathbf{F}_p[X]$.

GEN **FpX_factorff_irred**(GEN P, GEN T, GEN p). Assumes p prime and T irreducible in $\mathbf{F}_p[X]$. P being an *irreducible* FpX, factors it over the finite field $\mathbf{F}_p[Y]/(T(Y))$ and returns the vector of irreducible FqXs factors (the exponents, being all equal to 1, are not included).

GEN **FpX_ffisom**(GEN P, GEN Q, GEN p). Assumes p prime, P, Q are ZXs, both irreducible mod p, and $\deg(P) \mid \deg Q$. Outputs a monomorphism between $\mathbf{F}_p[X]/(P)$ and $\mathbf{F}_p[X]/(Q)$, as a polynomial R such that Q | P(R) in $\mathbf{F}_p[X]$. If P and Q have the same degree, it is of course an isomorphism.

void **FpX_ffintersect**(GEN P, GEN Q, long n, GEN p, GEN *SP,GEN *SQ, GEN MA,GEN MB) Assumes p is prime, P, Q are ZXs, both irreducible mod p, and n divides both the degree of P and Q. Compute SP and SQ such that the subfield of $\mathbf{F}_p[X]/(P)$ generated by SP and the subfield of $\mathbf{F}_p[X]/(Q)$ generated by SQ are isomorphic of degree n. The polynomials P and Q do not need to be of the same variable. If MA (resp. MB) is not NULL, it must be the matrix of the Frobenius map in $\mathbf{F}_p[X]/(P)$ (resp. $\mathbf{F}_p[X]/(Q)$).

GEN **FpXQ_ffisom_inv**(GEN S, GEN T, GEN p). Assumes p is prime, T a ZX, which is irreducible modulo p, S a ZX representing an automorphism of $\mathbf{F}_q := \mathbf{F}_p[X]/$(T). (S($X$) is the image of X by the automorphism.) Returns the inverse automorphism of S, in the same format, i.e. an FpX H such that H(S) $\equiv X$ modulo (T, p).

long **FqX_nbfact**(GEN u, GEN T, GEN p). Assumes p is prime and T irreducible in $\mathbf{F}_p[X]$.

long **FqX_nbroots**(GEN f, GEN T, GEN p) Assumes p is prime and T irreducible in $\mathbf{F}_p[X]$.

5.6.7 FpV, FpM, FqM. A ZV (resp. a ZM) is a t_VEC or t_COL (resp. t_MAT) with t_INT coefficients. An FpV or FpM, with respect to a given t_INT p, is the same with Fp coordinates; operations are understood over $\mathbf{Z}/p\mathbf{Z}$. An FqM is a matrix with Fq coefficients (with respect to given T, p), not necessarily reduced (i.e arbitrary t_INTs and ZXs in the same variable as T).

5.6.7.1 Basic operations

GEN **FpC_to_mod**(GEN z, GEN p), z a ZC. Returns Col(z) * Mod(1,p), hence a t_COL with t_INTMOD coefficients.

GEN **FpV_to_mod**(GEN z, GEN p), z a ZV. Returns Vec(z) * Mod(1,p), hence a t_VEC with t_INTMOD coefficients.

GEN **FpM_to_mod**(GEN z, GEN p), z a ZM. Returns z * Mod(1,p), hence with t_INTMOD coefficients.

GEN **FpC_red**(GEN z, GEN p), z a ZC. Returns lift(Col(z) * Mod(1,p)), hence a t_COL.

GEN **FpV_red**(GEN z, GEN p), z a ZV. Returns lift(Vec(z) * Mod(1,p)), hence a t_VEC

GEN **FpM_red**(GEN z, GEN p), z a ZM. Returns lift(z * Mod(1,p)), which is an FpM.

GEN **FpC_Fp_mul**(GEN x, GEN y, GEN p) multiplies the ZC x (seen as a column vector) by the t_INT y and reduce modulo p to obtain an FpC.

GEN **FpC_FpV_mul**(GEN x, GEN y, GEN p) multiplies the ZC x (seen as a column vector) by the ZV y (seen as a row vector, assumed to have compatible dimensions), and reduce modulo p to obtain an FpM.

GEN **FpM_mul**(GEN x, GEN y, GEN p) multiplies the two ZMs x and y (assumed to have compatible dimensions), and reduce modulo p to obtain an FpM.

GEN **FpM_FpC_mul**(GEN x, GEN y, GEN p) multiplies the ZM x by the ZC y (seen as a column vector, assumed to have compatible dimensions), and reduce modulo p to obtain an FpC.

GEN **FpV_FpC_mul**(GEN x, GEN y, GEN p) multiplies the ZV x (seen as a row vector) by the ZC y (seen as a column vector, assumed to have compatible dimensions), and reduce modulo p to obtain an Fp.

5.6.7.2 Fp-linear algebra. The implementations are not asymptotically efficient ($O(n^3)$ standard algorithms).

GEN **FpM_deplin**(GEN x, GEN p) returns a non-trivial kernel vector, or NULL if none exist.

GEN **FpM_gauss**(GEN a, GEN b, GEN p) as gauss

GEN **FpM_image**(GEN x, GEN p) as image

GEN **FpM_intersect**(GEN x, GEN y, GEN p) as intersect

GEN **FpM_inv**(GEN x, GEN p) returns the inverse of x, or NULL if x is not invertible.

GEN **FpM_invimage**(GEN m, GEN v, GEN p) as inverseimage

GEN **FpM_ker**(GEN x, GEN p) as ker

long **FpM_rank**(GEN x, GEN p) as rank

GEN **FpM_indexrank**(GEN x, GEN p) as indexrank but returns a t_VECSMALL

GEN **FpM_suppl**(GEN x, GEN p) as suppl

5.6.7.3 Fq-linear algebra

GEN **FqM_gauss**(GEN a, GEN b, GEN T, GEN p) as gauss

GEN **FqM_ker**(GEN x, GEN T, GEN p) as ker

GEN **FqM_suppl**(GEN x, GEN T, GEN p) as suppl

5.6.8 `Flx` Let `p` an understood `ulong`, assumed to be prime, to be given the the function arguments; an `Fl` is an `ulong` belonging to $[0, \mathtt{p}-1]$, an `Flx z` is a `t_VECSMALL` representing a polynomial with small integer coefficients. Specifically `z[0]` is the usual codeword, `z[1] = evalvarn(`v`)` for some variable v, then the coefficients by increasing degree. An `FlxX` is a `t_POL` whose coefficients are `Flx`s.

In the following, an argument called `sv` is of the form `evalvarn`(v) for some variable number v.

5.6.8.1 Basic operations

`ulong` **Rg_to_Fl**`(GEN z, ulong p)`, `z` which can be mapped to $\mathbf{Z}/p\mathbf{Z}$: a `t_INT`, a `t_INTMOD` whose modulus is divisible by p, a `t_FRAC` whose denominator is coprime to p, or a `t_PADIC` with underlying prime p. Returns `lift(z * Mod(1,p))`, normalized, as an `Fl`.

`GEN` **Flx_red**`(GEN z, ulong p)` converts from `zx` with non-negative coefficients to `Flx` (by reducing them mod `p`).

`GEN` **Flx_add**`(GEN x, GEN y, ulong p)`

`GEN` **Flx_neg**`(GEN x, ulong p)`

`GEN` **Flx_neg_inplace**`(GEN x, ulong p)`, same as `Flx_neg`, in place (`x` is destroyed).

`GEN` **Flx_sub**`(GEN x, GEN y, ulong p)`

`GEN` **Flx_mul**`(GEN x, GEN y, ulong p)`

`GEN` **Flx_sqr**`(GEN x, ulong p)`

`GEN` **Flx_divrem**`(GEN x, GEN y, ulong p, GEN *pr)`

`GEN` **Flx_div**`(GEN x, GEN y, ulong p)`

`GEN` **Flx_rem**`(GEN x, GEN y, ulong p)`

`GEN` **Flx_deriv**`(GEN z, ulong p)`

`GEN` **Flx_gcd**`(GEN a, GEN b, ulong p)` returns a (not necessarily monic) greatest common divisor of x and y.

`GEN` **Flx_gcd_i**`(GEN a, GEN b, ulong p)`, same as `Flx_gcd` without collecting garbage.

`GEN` **Flx_extgcd**`(GEN a, GEN b, ulong p, GEN *ptu, GEN *ptv)`

`GEN` **Flx_pow**`(GEN x, long n, ulong p)`

5.6.8.2 Miscellaneous operations

`GEN` **Flx_normalize**`(GEN z, ulong p)`, as `FpX_normalize`.

`GEN` **Flx_Fl_mul**`(GEN y, ulong x, ulong p)`

`GEN` **Flx_recip**`(GEN x)`, returns the reciprocal polynomial

`ulong` **Flx_resultant**`(GEN a, GEN b, ulong p)`, returns the resultant of `a` and `b`

`ulong` **Flx_extresultant**`(GEN a, GEN b, ulong p, GEN *ptU, GEN *ptV)` returns the resultant and sets Bezout coefficients (if the resultant is 0, the latter are not set).

`GEN` **Flx_invmontgomery**`(GEN T, ulong p)`, returns the Montgomery inverse of `T`, i.e. `truncate(x / polrecip(T)+O(x^n)`. Assumes $\mathtt{T}(0) \neq 0$.

GEN **Flx_rem_montgomery**(GEN x, GEN mg, GEN T, ulong p), returns x modulo T, where mg is the Montgomery inverse of T.

GEN **Flx_renormalize**(GEN x, long l), as FpX_renormalize, where l = lg(x), in place.

GEN **Flx_shift**(GEN T, long n), returns T multiplied by x^n.

long **Flx_valuation**(GEN x) returns the valuation of x, i.e. the multiplicity of the 0 root.

GEN **FlxYqQ_pow**(GEN x, GEN n, GEN S, GEN T, ulong p), as FpXQYQ_pow.

GEN **Flx_div_by_X_x**(GEN A, ulong a, ulong p, ulong *rem), returns the Euclidean quotient of the Flx A by $X - a$, and sets rem to the remainder A(a).

ulong **Flx_eval**(GEN x, ulong y, ulong p), as FpX_eval.

GEN **FlxV_Flc_mul**(GEN V, GEN W, ulong p), as FpXV_FpC_mul.

int **Flx_is_squarefree**(GEN z, ulong p)

long **Flx_nbfact**(GEN z, ulong p), as FpX_nbfact.

long **Flx_nbroots**(GEN f, ulong p), as FpX_nbroots.

GEN **Flv_polint**(GEN x, GEN y, ulong p, long sv) as FpV_polint, returning an Flx in variable v.

GEN **Flv_roots_to_pol**(GEN a, ulong p, long sv) as FpV_roots_to_pol returning an Flx in variable v.

5.6.9 Flxq. See FpXQ operations.

GEN **Flxq_mul**(GEN y, GEN x, GEN pol, ulong p)

GEN **Flxq_sqr**(GEN y, GEN pol, ulong p)

GEN **Flxq_inv**(GEN x, GEN T, ulong p)

GEN **Flxq_invsafe**(GEN x, GEN T, ulong p)

GEN **Flxq_pow**(GEN x, GEN n, GEN pol, ulong p)

GEN **Flxq_powers**(GEN x, long l, GEN T, ulong p)

GEN **FlxqV_roots_to_pol**(GEN V, GEN T, ulong p, long v) as FqV_roots_to_pol returning an FlxqX in variable v.

5.6.10 FlxX. See FpXX operations.

GEN **FlxX_add**(GEN P, GEN Q, ulong p)

GEN **FlxX_renormalize**(GEN x, long l), as normalizepol, where l = lg(x), in place.

GEN **FlxX_shift**(GEN a, long n)

5.6.11 `FlxqX`. See `FpXQX` operations.

`GEN` **FlxqX_mul**`(GEN x, GEN y, GEN T, ulong p)`

`GEN` **FlxqX_Flxq_mul**`(GEN P, GEN U, GEN T, ulong p)`

`GEN` **FlxqX_normalize**`(GEN z, GEN T, ulong p)`

`GEN` **FlxqX_sqr**`(GEN x, GEN T, ulong p)`

`GEN` **FlxqX_divrem**`(GEN x, GEN y, GEN T, ulong p, GEN *pr)`

`GEN` **FlxqX_red**`(GEN z, GEN T, ulong p)`

`GEN` **FlxqXV_prod**`(GEN V, GEN T, ulong p)`

`GEN` **FlxqXQ_pow**`(GEN x, GEN n, GEN S, GEN T, ulong p)`

5.6.12 `Flv`, `Flm`. See `FpV`, `FpM` operations.

`GEN` **Flm_Flc_mul**`(GEN x, GEN y, ulong p)`

`GEN` **Flm_deplin**`(GEN x, ulong p)`

`GEN` **Flm_gauss**`(GEN a, GEN b, ulong p)`

`GEN` **Flm_indexrank**`(GEN x, ulong p)`

`GEN` **Flm_inv**`(GEN x, ulong p)`

`GEN` **Flm_ker**`(GEN x, ulong p)`

`GEN` **Flm_ker_sp**`(GEN x, ulong p, long deplin)`, as `Flm_ker`, in place (destroys `x`).

`GEN` **Flm_mul**`(GEN x, GEN y, ulong p)`

5.6.13 `FlxqV`, `FlxqM`. See `FqV`, `FqM` operations.

`GEN` **FlxqM_ker**`(GEN x, GEN T, ulong p)`

5.6.14 `QX`.

`GEN` **QXQ_inv**`(GEN A, GEN B)` returns the inverse of `A` modulo `B` where `A` and `B` are `QX`s.

5.6.15 `RgX`.

`GEN` **RgX_add**`(GEN x,GEN y)` adds `x` and `y`.

`GEN` **RgX_sub**`(GEN x,GEN y)` subtracts `x` and `y`.

`GEN` **RgX_neg**`(GEN x,GEN p)` returns $-$`x`.

The functions above are currently implemented through the generic routines, but it might change in the future.

`GEN` **RgX_mul**`(GEN x, GEN y)` multiplies the two `t_POL` (in the same variable) `x` and `y`. Uses Karatsuba algorithm.

`GEN` **RgX_mulspec**`(GEN a, GEN b, long na, long nb)`. Internal routine: `a` and `b` are arrays of coefficients representing polynomials $\sum_{i=0}^{\mathtt{na}} \mathtt{a}[i]X^i$ and $\sum_{i=0}^{\mathtt{nb}} \mathtt{b}[i]X^i$. Returns their product (as a true `GEN`).

GEN **RgX_sqr**(GEN x) squares the t_POL x. Uses Karatsuba algorithm.

GEN **RgX_sqrspec**(GEN a, long na). Internal routine: a is an array of coefficients representing polynomial $\sum_{i=0}^{\mathtt{na}} \mathtt{a}[i]X^i$. Return its square (as a true GEN).

GEN **RgX_divrem**(GEN x, GEN y, GEN *r)

GEN **RgX_div**(GEN x, GEN y, GEN *r)

GEN **RgX_div_by_X_x**(GEN A, GEN a, GEN *r) returns the quotient of the RgX A by $(X - \mathtt{a})$, and sets r to the remainder A(a).

GEN **RgX_rem**(GEN x, GEN y, GEN *r)

GEN **RgX_mulXn**(GEN x, long n) returns $\mathtt{x} * t^n$. This may be a t_FRAC if $n < 0$ and the valuation of x is not large enough.

GEN **RgX_shift**(GEN x, long n) returns $\mathtt{x} * t^n$ if $n \geq 0$, and $\mathtt{x} \backslash t^{-n}$ otherwise.

GEN **RgX_shift_shallow**(GEN x, long n) as RgX_shift, but shallow (coefficients are not copied). This is not suitable for gerepile or gerepileupto.

GEN **RgX_extgcd**(GEN x, GEN y, GEN *u, GEN *v) returns $d = \mathrm{GCD}(\mathtt{x}, \mathtt{y})$, and sets *u, *v to the Bezout coefficients such that $*\mathtt{u}\mathtt{x} + *\mathtt{v}\mathtt{y} = d$.

GEN **RgXQ_mul**(GEN y, GEN x, GEN T)

GEN **RgXQ_norm**(GEN x, GEN T) returns the norm of Mod(x, T).

GEN **RgXQ_sqr**(GEN x, GEN T)

GEN **RgXQ_powers**(GEN x, long n, GEN T, GEN p) returns $[\mathtt{x}^0, \ldots, \mathtt{x}^{\mathtt{n}}]$ as a t_VEC of RgXQs.

GEN **RgXQC_red**(GEN z, GEN T) z a vector whose coefficients are RgXs (arbitrary GENs in fact), reduce them to RgXQs (applying grem coefficientwise) in a t_COL.

GEN **RgXQV_red**(GEN z, GEN T) z a t_POL whose coefficients are RgXs (arbitrary GENs in fact), reduce them to RgXQs (applying grem coefficientwise) in a t_VEC.

GEN **RgXQX_red**(GEN z, GEN T) z a t_POL whose coefficients are RgXs (arbitrary GENs in fact), reduce them to RgXQs (applying grem coefficientwise).

GEN **RgXQX_mul**(GEN x, GEN y, GEN T)

GEN **RgX_Rg_mul**(GEN y, GEN x) multiplies the RgX y by the scalar x.

GEN **RgX_Rg_div**(GEN y, GEN x) divides the RgX y by the scalar x.

GEN **RgXQX_RgXQ_mul**(GEN x, GEN y, GEN T) multiplies the RgXQX y by the scalar (RgXQ) x.

GEN **RgXQX_sqr**(GEN x, GEN T)

GEN **RgXQX_divrem**(GEN x, GEN y, GEN T, GEN *pr)

GEN **RgXQX_div**(GEN x, GEN y, GEN T, GEN *r)

GEN **RgXQX_rem**(GEN x, GEN y, GEN T, GEN *r)

GEN **RgX_rescale**(GEN P, GEN h) returns $h^{\deg(P)}P(x/h)$. P is an RgX and h is non-zero. (Leaves small objects on the stack. Suitable but inefficient for gerepileupto.)

GEN **RgX_unscale**(GEN P, GEN h) returns $P(hx)$. (Leaves small objects on the stack. Suitable but inefficient for gerepileupto.)

GEN **RgXV_unscale**(GEN v, GEN h)

5.6.16 Conversions involving single precision objects

5.6.16.1 To single precision

GEN **ZX_to_Flx**(GEN x, ulong p) reduce ZX x modulo p (yielding an Flx).

GEN **ZV_to_Flv**(GEN x, ulong p) reduce ZV x modulo p (yielding an Flv).

GEN **ZXV_to_FlxV**(GEN v, ulong p), as ZX_to_Flx, repeatedly called on the vector's coefficients.

GEN **ZXX_to_FlxX**(GEN B, ulong p, long v), as ZX_to_Flx, repeatedly called on the polynomial's coefficients.

GEN **ZXXV_to_FlxXV**(GEN V, ulong p, long v), as ZXX_to_FlxX, repeatedly called on the vector's coefficients.

GEN **ZM_to_Flm**(GEN x, ulong p) reduce ZM x modulo p (yielding an Flm).

GEN **ZV_to_zv**(GEN z), converts coefficients using itos

GEN **ZV_to_nv**(GEN z), converts coefficients using itou

GEN **ZM_to_zm**(GEN z), converts coefficients using itos

GEN **FqC_to_FlxC**(GEN x, GEN T, GEN p), converts coefficients in Fq to coefficient in Flx, result being a column vector.

GEN **FqV_to_FlxV**(GEN x, GEN T, GEN p), converts coefficients in Fq to coefficient in Flx, result being a line vector.

GEN **FqM_to_FlxM**(GEN x, GEN T, GEN p), converts coefficients in Fq to coefficient in Flx.

5.6.16.2 From single precision

GEN **Flx_to_ZX**(GEN z), converts to ZX (t_POL of non-negative t_INTs in this case)

GEN **Flx_to_ZX_inplace**(GEN z), same as Flx_to_ZX, in place (z is destroyed).

GEN **FlxX_to_ZXX**(GEN B), converts an FlxX to a polynomial with ZX or t_INT coefficients (repeated calls to Flx_to_ZX).

GEN **FlxC_to_ZXC**(GEN x), converts a vector of Flx to a column vector of polynomials with t_INT coefficients (repeated calls to Flx_to_ZX).

GEN **FlxM_to_ZXM**(GEN z), converts a matrix of Flx to a matrix of polynomials with t_INT coefficients (repeated calls to Flx_to_ZX).

GEN **zx_to_ZX**(GEN z), as Flx_to_ZX, without assuming coefficients are non-negative.

GEN **Flc_to_ZC**(GEN z), converts to ZC (t_COL of non-negative t_INTs in this case)

GEN **Flv_to_ZV**(GEN z), converts to ZV (t_VEC of non-negative t_INTs in this case)

GEN **Flm_to_ZM**(GEN z), converts to ZM (t_MAT with non-negative t_INTs coefficients in this case)

GEN **zc_to_ZC**(GEN z) as Flc_to_ZC, without assuming coefficients are non-negative.

GEN **zv_to_ZV**(GEN z) as Flv_to_ZV, without assuming coefficients are non-negative.

GEN **zm_to_ZM**(GEN z) as Flm_to_ZM, without assuming coefficients are non-negative.

5.6.16.3 Mixed precision linear algebra Assumes dimensions are compatible. Multiply a multiprecision object by a single-precision one.

`GEN` **RgM_zc_mul**`(GEN x, GEN y)`

`GEN` **RgM_zm_mul**`(GEN x, GEN y)`

`GEN` **RgV_zc_mul**`(GEN x, GEN y)`

`GEN` **RgV_zm_mul**`(GEN x, GEN y)`

`GEN` **ZM_zc_mul**`(GEN x, GEN y)`

`GEN` **ZM_zm_mul**`(GEN x, GEN y)`

5.6.16.4 Miscellaneous

`GEN` **zero_Flx**`(long sv)` returns a zero `Flx` in variable v.

`GEN` **zero_zx**`(long sv)` as `zero_Flx`

`GEN` **polx_Flx**`(long sv)` returns the variable v as degree 1 `Flx`.

`GEN` **polx_zx**`(long sv)` as `polx_Flx`

`GEN` **Fl_to_Flx**`(ulong x, long sv)` converts a `unsigned long` to a scalar `Flx` in shifted variable sv.

`GEN` **Z_to_Flx**`(GEN x, ulong p, long v)` converts a `t_INT` to a scalar polynomial in variable v.

`GEN` **Flx_to_Flv**`(GEN x, long n)` converts from `Flx` to `Flv` with `n` components (assumed larger than the number of coefficients of `x`).

`GEN` **zx_to_zv**`(GEN x, long n)` as `Flx_to_Flv`.

`GEN` **Flv_to_Flx**`(GEN x, long sv)` converts from vector (coefficient array) to (normalized) polynomial in variable v.

`GEN` **zv_to_zx**`(GEN x, long n)` as `Flv_to_Flx`.

`GEN` **matid_Flm**`(long n)` returns an `Flm` which is an $n \times n$ identity matrix.

`GEN` **Flm_to_FlxV**`(GEN x, long sv)` converts the colums of `Flm x` to an array of `Flx` (repeated calls to `Flv_to_Flx`).

`GEN` **zm_to_zxV**`(GEN x, long n)` as `Flm_to_FlxV`.

`GEN` **Flm_to_FlxX**`(GEN x, long sv,long w)` converts the colums of `Flm x` to the coefficient of an `FlxX`, and normalize the result.

`GEN` **FlxV_to_Flm**`(GEN v, long n)` reverse `Flm_to_FlxV`, to obtain an `Flm` with `n` rows (repeated calls to `Flx_to_Flv`).

`GEN` **FlxX_to_Flm**`(GEN v, long n)` reverse `Flm_to_FlxX`, to obtain an `Flm` with `n` rows (repeated calls to `Flx_to_Flv`).

5.7 Operations on general PARI objects.

5.7.1 Assignment

`void` **gaffsg**`(long s, GEN x)` assigns the `long s` into the object `x`.

`void` **gaffect**`(GEN x, GEN y)` assigns the object `x` into the object `y`.

5.7.2 Conversions

5.7.2.1 Scalars

`double` **rtodbl**`(GEN x)` applied to a `t_REAL x`, converts `x` into a `double` if possible.

`GEN` **dbltor**`(double x)` converts the `double x` into a `t_REAL`.

`double` **gtodouble**`(GEN x)` if `x` is a real number (not necessarily a `t_REAL`), converts `x` into a `double` if possible.

`long` **gtolong**`(GEN x)` if `x` is an integer (not necessarily a `t_INT`), converts `x` into a `long` if possible.

`GEN` **fractor**`(GEN x, long l)` applied to a `t_FRAC x`, converts `x` into a `t_REAL` of length `prec`.

`GEN` **quadtoc**`(GEN x, long l)` applied to a `t_QUAD x`, converts `x` into a `t_REAL` or `t_COMPLEX` depending on the sign of the discriminant of `x`, to precision `l` `BIL`-bit words.line brk at hyphen here [GN]

`GEN` **ctofp**`(GEN x, long prec)` converts the `t_COMPLEX x` to a a complex whose real and imaginary parts are `t_REAL` of length `prec`, using `gtofp`;

`GEN` **gtofp**`(GEN x, long prec)` converts the complex number `x` (`t_INT`, `t_REAL`, `t_FRAC`, `t_QUAD` or `t_COMPLEX`) to either a `t_REAL` or `t_COMPLEX` whose components are `t_REAL` of length `prec`.

`GEN` **gcvtop**`(GEN x, GEN p, long l)` converts `x` into a `t_PADIC p`-adic number of precision `l`.

`GEN` **gprec**`(GEN x, long l)` returns a copy of x whose precision is changed to l digits. The precision change is done recursively on all components of x. Digits means *decimal*, p-adic and X-adic digits for `t_REAL`, `t_SER`, `t_PADIC` components, respectively.

`GEN` **gprec_w**`(GEN x, long l)` returns a shallow copy of x whose `t_REAL` components have their precision changed to l *words*. This is often more useful than `gprec`. Shallow copy means that unaffected components are not copied; in particular, this funciton is not suitable for `gerepileupto`.

`GEN` **gprec_wtrunc**`(GEN x, long l)` returns a shallow copy of x whose `t_REAL` components have their precision *truncated* to l *words*. Contrary to `gprec_w`, this function may never increase the precision of x. Shallow copy means that unaffected components are not copied; in particular, this funciton is not suitable for `gerepileupto`.

5.7.2.2 Modular objects

`GEN` **gmodulo**`(GEN x, GEN y)` creates the object **Mod**`(x,y)` on the PARI stack, where `x` and `y` are either both `t_INT`s, and the result is a `t_INTMOD`, or `x` is a scalar or a `t_POL` and `y` a `t_POL`, and the result is a `t_POLMOD`.

`GEN` **gmodulgs**`(GEN x, long y)` same as **gmodulo** except `y` is a `long`.

`GEN` **gmodulss**`(long x, long y)` same as **gmodulo** except both `x` and `y` are `long`s.

5.7.2.3 Between polynomials and coefficient arrays

`GEN` **gtopoly**`(GEN x, long v)` converts or truncates the object `x` into a `t_POL` with main variable number `v`. A common application would be the conversion of coefficient vectors (coefficients are given by decreasing degree). E.g. `[2,3]` goes to `2*v + 3`

`GEN` **gtopolyrev**`(GEN x, long v)` converts or truncates the object `x` into a `t_POL` with main variable number `v`, but vectors are converted in reverse order compared to `gtopoly` (coefficients are given by increasing degree). E.g. `[2,3]` goes to `3*v + 2`. In other words the vector represents a polynomial in the basis $(1, v, v^2, v^3, \ldots)$.

`GEN` **normalizepol**`(GEN x)` applied to an unnormalized `t_POL` `x` (with all coefficients correctly set except that `leading_term(x)` might be zero), normalizes `x` correctly in place and returns `x`. For internal use.

The following routines do *not* copy coefficients on the stack (they only move pointers around), hence are very fast but not suitable for `gerepile` calls. Recall that an `RgV` (resp. an `RgX`, resp. an `RgM`) is a `t_VEC` or `t_COL` (resp. a `t_POL`, resp. a `t_MAT`) with arbitrary components. Similarly, an `RgXV` is a `t_VEC` or `t_COL` with `RgX` components, etc.

`GEN` **RgV_to_RgX**`(GEN x, long v)` converts the `RgV` `x` to a (normalized) polynomial in variable `v` (as `gtopolyrev`, without copy).

`GEN` **RgX_to_RgV**`(GEN x, long N)` converts the `t_POL` `x` to a `t_COL` `v` with `N` components. Other types than `t_POL` are allowed for `x`, which is then considered as a constant polynomial. Coefficients of `x` are listed by increasing degree, so that `y[i]` is the coefficient of the term of degree $i-1$ in `x`.

`GEN` **RgM_to_RgXV**`(GEN x, long v)` converts the `RgM` `x` to a `t_VEC` of `RgX`, by repeated calls to `RgV_to_RgX`.

`GEN` **RgXV_to_RgM**`(GEN v, long N)` converts the vector of `RgX` `v` to a `t_MAT` with `N` rows, by repeated calls to `RgX_to_RgV`.

`GEN` **RgM_to_RgXX**`(GEN x, long v,long w)` converts the `RgM` `x` into a `t_POL` in variable `v`, whose coefficients are `t_POL`s in variable `w`. This is a shortcut for

```
RgV_to_RgX( RgM_to_RgXV(x, w), v );
```

There are no consistency checks with respect to variable priorities: the above is an invalid object if `varncmp(v, w)` ≥ 0.

`GEN` **RgXX_to_RgM**`(GEN x, long N)` converts the `t_POL` `x` with `RgX` (or constant) coefficients to a matrix with `N` rows.

`GEN` **RgXY_swap**`(GEN P, long n, long w)` converts the bivariate polynomial `P`(u, v) (a `t_POL` with `t_POL` coefficients) to $P($`pol_x[w]`$, u)$, assuming `n` is an upper bound for $\deg_v($`P`$)$.

`GEN` **greffe**`(GEN x, long l, int use_stack)` applied to a `t_POL` `x`, creates a `t_SER` of length `l` starting with `x`, but without actually copying the coefficients, just the pointers. If `use_stack` is 0, this is created through malloc, and must be freed after use. Intended for internal use only.

`GEN` **gtoser**`(GEN x, long v)` converts the object `x` into a `t_SER` with main variable number `v`.

`GEN` **gtocol**`(GEN x)` converts the object `x` into a `t_COL`

`GEN` **gtomat**`(GEN x)` converts the object `x` into a `t_MAT`.

`GEN` **gtovec**`(GEN x)` converts the object `x` into a `t_VEC`.

GEN **gtovecsmall**(GEN x) converts the object x into a t_VECSMALL.

GEN **normalize**(GEN x) applied to an unnormalized t_SER x (i.e. type t_SER with all coefficients correctly set except that x[2] might be zero), normalizes x correctly in place. Returns x. For internal use.

5.7.3 Clean Constructors

GEN **zeropadic**(GEN p, long n) creates a 0 t_PADIC equal to $O(p^n)$.

GEN **zeroser**(long v, long n) creates a 0 t_SER in variable v equal to $O(X^n)$.

GEN **scalarser**(GEN x, long v, long prec) creates a constant t_SER in variable v and precision prec, whose constant coefficient is (a copy of) x, in other words $x + O(v^{prec})$. Assumes that x is non-zero.

GEN **zeropol**(long v) creates a 0 t_POL in variable v.

GEN **scalarpol**(GEN x, long v) creates a constant t_POL in variable v, whose constant coefficient is (a copy of) x.

GEN **zerocol**(long n) creates a t_COL with n components set to gen_0.

GEN **zerovec**(long n) creates a t_VEC with n components set to gen_0.

GEN **col_ei**(long n, long i) creates a t_COL with n components set to gen_0, but the i-th one which us set to gen_1 (i-th vector in the canonical basis).

GEN **vec_ei**(long n, long i) creates a t_VEC with n components set to gen_0, but the i-th one which us set to gen_1 (i-th vector in the canonical basis).

GEN **zeromat**(long m, long n) creates a t_MAT with m x n components set to gen_0. Note that the result allocates a *single* column, so modifying an entry in one column modifies it in all columns. To fully allocate a matrix initialized with zero entries, use zeromatcopy.

GEN **zeromatcopy**(long m, long n) creates a t_MAT with m x n components set to gen_0. Note that

See also next section for analogs of the following functions:

GEN **mkcolcopy**(GEN x) creates a 1-dimensional t_COL containing x.

GEN **mkmatcopy**(GEN x) creates a 1-by-1 t_MAT containing x.

GEN **mkveccopy**(GEN x) creates a 1-dimensional t_VEC containing x.

GEN **mkvec2copy**(GEN x, GEN y) creates a 2-dimensional t_VEC equal to [x,y].

GEN **mkvecs**(long x) creates a 1-dimensional t_VEC containing stoi(x).

GEN **mkvec2s**(long x, long y) creates a 2-dimensional t_VEC containing [stoi(x), stoi(y)].

GEN **mkvec3s**(long x, long y, long z) creates a 3-dimensional t_VEC containing [stoi(x), stoi(y), stoi(z)].

GEN **mkvecsmall**(long x) creates a 1-dimensional t_VECSMALL containing x.

GEN **mkvecsmall2**(long x, long y) creates a 2-dimensional t_VECSMALL containing [x, y].

GEN **mkvecsmall3**(long x, long y, long z) creates a 3-dimensional t_VECSMALL containing [x, y, z].

5.7.4 Unclean Constructors

Contrary to the policy of general PARI functions, the functions in this subsection do *not* copy their arguments, nor do they produce an object a priori suitable for `gerepileupto`. In particular, they are faster than their clean equivalent (which may not exist). *If* you restrict their arguments to universal objects (e.g `gen_0`), then the above warning does not apply.

`GEN` **mkcomplex**`(GEN x, GEN y)` creates the `t_COMPLEX` $x + iy$.

`GEN` **mkfrac**`(GEN x, GEN y)` creates the `t_FRAC` x/y. Assumes that $y > 1$ and $(x, y) = 1$.

`GEN` **mkrfrac**`(GEN x, GEN y)` creates the `t_RFRAC` x/y. Assumes that y is a `t_POL`, x a compatible type whose variable has lower or same priority, with $(x, y) = 1$.

`GEN` **mkcol**`(GEN x)` creates a 1-dimensional `t_COL` containing `x`.

`GEN` **mkintmod**`(GEN x, GEN y)` creates the `t_INTMOD Mod(x, y)`. The input must be `t_INT`s satisfying $0 \leq x < y$.

`GEN` **mkpolmod**`(GEN x, GEN y)` creates the `t_POLMOD Mod(x, y)`. The input must satisfy $\deg x < \deg y$ with respect to the main variable of the `t_POL` y. x may be a scalar.

`GEN` **mkmat**`(GEN x)` creates a 1-by-1 `t_MAT` containing `x`.

`GEN` **mkvec**`(GEN x)` creates a 1-dimensional `t_VEC` containing `x`.

`GEN` **mkvec2**`(GEN x, GEN y)` creates a 2-dimensional `t_VEC` equal to `[x,y]`.

`GEN` **mkvec3**`(GEN x, GEN y, GEN z)` creates a 3-dimensional `t_VEC` equal to `[x,y,z]`.

`GEN` **mkvec4**`(GEN x, GEN y, GEN z, GEN t)` creates a 4-dimensional `t_VEC` equal to `[x,y,z,t]`.

`GEN` **mkintn**`(long n, ...)` returns the non-negative `t_INT` whose development in base 2^{32} is given by the following n words (`unsigned long`). It is assumed that all such arguments are less than 2^{32} (the actual `sizeof(long)` is irrelevant, the behaviour is also as above on 64-bit machines).

```
mkintn(3, a2, a1, a0);
```

returns $a_2 2^{64} + a_1 2^{32} + a_0$.

`GEN` **mkpoln**`(long n, ...)` Returns the `t_POL` whose n coefficients (`GEN`) follow, in order of decreasing degree.

```
mkpoln(3, gen_1, gen_2, gen_0);
```

returns the polynomial $X^2 + 2X$ (in variable 0, use `setvarn` if you want other variable numbers). Beware that n is the number of coefficients, hence *one more* than the degree.

`GEN` **mkvecn**`(long n, ...)` returns the `t_VEC` whose n coefficients (`GEN`) follow.

`GEN` **mkcoln**`(long n, ...)` returns the `t_COL` whose n coefficients (`GEN`) follow.

5.7.5 Integer parts

`GEN` **gfloor**`(GEN x)` creates the floor of `x`, i.e. the (true) integral part.

`GEN` **gfrac**`(GEN x)` creates the fractional part of `x`, i.e. `x` minus the floor of `x`.

`GEN` **gceil**`(GEN x)` creates the ceiling of `x`.

`GEN` **ground**`(GEN x)` rounds towards $+\infty$ the components of `x` to the nearest integers.

`GEN` **grndtoi**`(GEN x, long *e)` same as `ground`, but in addition sets `*e` to the binary exponent of $x - \texttt{ground}(x)$. If this is positive, all significant bits are lost. This kind of situation raises an error message in **ground** but not in **grndtoi**.

`GEN` **gtrunc**`(GEN x)` truncates `x`. This is the false integer part if `x` is a real number (i.e. the unique integer closest to `x` among those between 0 and `x`). If `x` is a `t_SER`, it is truncated to a `t_POL`; if `x` is a `t_RFRAC`, this takes the polynomial part.

`GEN` **gcvtoi**`(GEN x, long *e)` same as **grndtoi** except that rounding is replaced by truncation.

5.7.6 Valuation and shift

`GEN` **gshift**`[z](GEN x, long n[, GEN z])` yields the result of shifting (the components of) `x` left by `n` (if `n` is non-negative) or right by $-$`n` (if `n` is negative). Applies only to `t_INT` and vectors/matrices of such. For other types, it is simply multiplication by $2^{\texttt{n}}$.

`GEN` **gmul2n**`[z](GEN x, long n[, GEN z])` yields the product of `x` and $2^{\texttt{n}}$. This is different from `gshift` when `n` is negative and `x` is a `t_INT`: **gshift** truncates, while **gmul2n** creates a fraction if necessary.

`long` **ggval**`(GEN x, GEN p)` returns the greatest exponent e such that $\texttt{p}^e$ divides `x`, when this makes sense.

`long` **gval**`(GEN x, long v)` returns the highest power of the variable number `v` dividing the `t_POL` `x`.

`long` **polvaluation**`(GEN P, GEN *z)` returns the valuation v of the `t_POL` `P` with respect to its main variable X. Check whether coefficients are 0 using `gcmp0`. If `z` is non-`NULL`, set it to $\texttt{P}/X^v$.

`long` **polvaluation_inexact**`(GEN P, GEN *z)` as `polvaluation` but use `isexactzero` instead of `gcmp0`.

`long` **ZX_valuation**`(GEN P, GEN *z)` as `polvaluation`, but assumes `P` has `t_INT` coefficients.

5.7.7 Comparison operators

`int` **isexactzero**`(GEN x)` returns 1 (true) if `x` is exactly equal to 0, 0 (false) otherwise. Note that many PARI functions return a pointer to `gen_0` when they are aware that the result they return is an exact zero, so it is almost always faster to test for pointer equality first, and call `isexactzero` (or `gcmp0`) only when the first test fails.

`int` **isinexact**`(GEN x)` returns 0 (false) if `x` has an inexact component, and 1 (true) otherwise.

`int` **isint**`(GEN x, GEN *n)` returns 0 (false) if `x` does not round to an integer. Otherwise, returns 1 (true) and set `n` to the rounded value.

`int` **issmall**`(GEN x, long *n)` returns 0 (false) if `x` does not round to a small integer (suitable for `itos`). Otherwise, returns 1 (true) and set `n` to the rounded value.

`int` **gcmp0**`(GEN x)` returns 1 (true) if `x` is equal to 0, 0 (false) otherwise.

`int` **gcmp1**`(GEN x)` returns 1 (true) if `x` is equal to 1, 0 (false) otherwise.

`int` **gcmp_1**`(GEN x)` returns 1 (true) if `x` is equal to -1, 0 (false) otherwise.

`long` **gcmp**`(GEN x, GEN y)` comparison of `x` with `y` (returns the sign of `x - y`).

`long` **gcmpsg**`(long s, GEN x)` comparison of the `long` `s` with `x`.

`long` **gcmpgs**`(GEN x, long s)` comparison of `x` with the `long` `s`.

`long` **lexcmp**`(GEN x, GEN y)` comparison of `x` with `y` for the lexicographic ordering.

`long` **gequal**`(GEN x, GEN y)` returns 1 (true) if `x` is equal to `y`, 0 otherwise. A priori, this makes sense only if `x` and `y` have the same type. When the types are different, a `true` result means that `x - y` was successfully computed and found equal to 0 (by `gcmp0`). In particular

```
gequal(cgetg(1, t_VEC), gen_0)
```

is true, and the relation is not transitive. E.g. an empty `t_COL` and an empty `t_VEC` are not equal but are both equal to `gen_0`.

`long` **gequalsg**`(long s, GEN x)` returns 1 (true) if the `long` `s` is equal to `x`, 0 otherwise.

`long` **gequalgs**`(GEN x, long s)` returns 1 (true) if `x` is equal to the `long` `s`, 0 otherwise.

`long` **iscomplex**`(GEN x)` returns 1 (true) if `x` is a complex number (of component types embeddable into the reals) but is not itself real, 0 if `x` is a real (not necessarily of type `t_REAL`), or raises an error if `x` is not embeddable into the complex numbers.

`long` **ismonome**`(GEN x)` returns 1 (true) if `x` is a non-zero monomial in its main variable, 0 otherwise.

5.7.8 Generic unary operators

`GEN` **gneg**[**z**]`(GEN x[, GEN z])` yields $-$`x`.

`GEN` **gabs**[**z**]`(GEN x[, GEN z])` yields $|$`x`$|$.

`GEN` **gsqr**`(GEN x)` creates the square of `x`.

`GEN` **ginv**`(GEN x)` creates the inverse of `x`.

5.7.9 Divisibility, Euclidean division

`GEN` **gdivexact**`(GEN x, GEN y)` returns the quotient `x`/`y`, assuming `y` divides `x`.

`int` **gdvd**`(GEN x, GEN y)` returns 1 (true) if `y` divides `x`, 0 otherwise.

`GEN` **gdiventres**`(GEN x, GEN y)` creates a 2-component vertical vector whose components are the true Euclidean quotient and remainder of `x` and `y`.

`GEN` **gdivent**[**z**]`(GEN x, GEN y[, GEN z])` yields the true Euclidean quotient of `x` and the `t_INT` or `t_POL` `y`.

`GEN` **gdiventsg**[**z**]`(long s, GEN y[, GEN z])`, as `gdivent` except that `x` is a `long`.

`GEN` **gdiventgs**[**z**]`(GEN x, long s[, GEN z])`, as `gdivent` except that `y` is a `long`.

GEN **gmod**[**z**](GEN x, GEN y[, GEN z]) yields the true remainder of x modulo the t_INT or t_POL y. A t_REAL or t_FRAC y is also allowed, in which case the remainder is the unique real r such that $0 \leq r < |\mathtt{y}|$ and $\mathtt{y} = q\mathtt{x} + r$ for some (in fact unique) integer q.

GEN **gmodsg**[**z**](long s, GEN y[, GEN z]) as gmod, except x is a long.

GEN **gmodgs**[**z**](GEN x, long s[, GEN z]) as gmod, except y is a long.

GEN **gdivmod**(GEN x, GEN y, GEN *r) If r is not equal to NULL or ONLY_REM, creates the (false) Euclidean quotient of x and y, and puts (the address of) the remainder into *r. If r is equal to NULL, do not create the remainder, and if r is equal to ONLY_REM, create and output only the remainder. The remainder is created after the quotient and can be disposed of individually with a cgiv(r).

GEN **poldivrem**(GEN x, GEN y, GEN *r) same as **gdivmod** but specifically for t_POLs x and y, not necessarily in the same variable. Either of x and y may also be scalars (treated as polynomials of degree 0)

GEN **gdeuc**(GEN x, GEN y) creates the Euclidean quotient of the t_POLs x and y. Either of x and y may also be scalars (treated as polynomials of degree 0)

GEN **grem**(GEN x, GEN y) creates the Euclidean remainder of the t_POL x divided by the t_POL y.

GEN **gdivround**(GEN x, GEN y) if x and y are t_INT, as diviiround. Operate componentwise if x is a t_COL, t_VEC or t_MAT. Otherwise as **gdivent**.

GEN **centermod_i**(GEN x, GEN y, GEN y2), as centermodii, componentwise.

GEN **centermod**(GEN x, GEN y), as centermod_i, except that y2 is computed (and left on the stack for efficiency).

GEN **ginvmod**(GEN x, GEN y) creates the inverse of x modulo y when it exists. y must be of type t_INT (in which case x is of type t_INT) or t_POL (in which case x is either a scalar type or a t_POL).

5.7.10 GCD, content and primitive part

GEN **subres**(GEN x, GEN y) creates the resultant of the t_POLs x and y computed using the subresultant algorithm. Either of x and y may also be scalars (treated as polynomials of degree 0)

GEN **ggcd**(GEN x, GEN y) creates the GCD of x and y.

GEN **glcm**(GEN x, GEN y) creates the LCM of x and y.

GEN **gbezout**(GEN x,GEN y, GEN *u,GEN *v) creates the GCD of x and y, and puts (the addresses of) objects u and v such that $u\mathtt{x} + v\mathtt{y} = \gcd(\mathtt{x}, \mathtt{y})$ into *u and *v.

GEN **bezoutpol**(GEN a,GEN b, GEN *u,GEN *v), returns the GCD d of t_INTs a and b and sets u, v to the Bezout coefficients such that $\mathtt{au} + \mathtt{bv} = d$.

GEN **content**(GEN x) creates the GCD of all the components of x.

GEN **primitive_part**(GEN x, GEN *c), sets c to content(x) and returns the primitive part x / c.

GEN **primpart**(GEN x) as primitive_part but the content is lost. (For efficiency, the content remains on the stack.)

5.7.11 Generic binary operators. Let "*op*" be a binary operation among

op=**add**: addition (`x + y`).

op=**sub**: subtraction (`x - y`).

op=**mul**: multiplication (`x * y`).

op=**div**: division (`x / y`).

op=**max**: maximum (`max(x, y)`)

op=**min**: minimum (`min(x, y)`)

The names and prototypes of the functions corresponding to *op* are as follows:

`GEN` **g***op*[**z**]`(GEN x, GEN y[, GEN z])`

`GEN` **g***op***gs**[**z**]`(GEN x, long s[, GEN z])`

`GEN` **g***op***sg**[**z**]`(long s, GEN y[, GEN z])`

`GEN` **gpow**`(GEN x, GEN y, long l)` creates x^y. If `y` is a `t_INT`, return `powgi(x,y)` (the precision `l` is not taken into account). Otherwise, the result is $\exp(y * \log(x))$ computed to precision `l`.

`GEN` **gpowgs**`(GEN x, long n)` creates x^n using binary powering.

`GEN` **powgi**`(GEN x, GEN y)` creates x^y, where `y` is a `t_INT`, using left-shift binary powering.

`GEN` **gsubst**`(GEN x, long v, GEN y)` substitutes the object `y` into `x` for the variable number `v`.

5.7.12 Miscellaneous functions

`const char*` **type_name**`(long t)` given a type number `t` this routine returns a string containing its symbolic name. E.g `type_name(t_INT)` returns `"t_INT"`. The return value is read-only.

5.8 Further type specific functions.

5.8.1 Vectors and Matrices See Section 5.7.3 and Section 5.7.4 for various useful constructors. Coefficients are accessed and set using `gel`, `gcoeff`, see Section 5.2.6. There are many internal functions to extract or manipulate subvectors or submatrices but, like the accessors above, none of them are suitable for `gerepileupto`. Worse, there are no type verification, nor bound checking, so use at your own risk.

Note. In the function names below, i stands for *interval* and p for *permutation*.

`GEN` **shallowcopy**`(GEN x)` returns a `t_GEN` whose components are the components of x (no copy is made). The result may now be used to compute in place without destroying x. This is essentially equivalent to

```
GEN y = cgetg(lg(x), typ(x));
for (i = 1; i < lg(x); i++) y[i] = x[i];
return y;
```

except that `t_POLMOD` (resp. `t_MAT`) are treated specially since a dummy copy of the representative (resp. all columns) is also made.

`GEN` **shallowtrans**`(GEN x)` returns the transpose of x, *without* copying its components, i. e., it returns a `GEN` whose components are (physically) the components of x. This is the internal function underlying `gtrans`.

`GEN` **shallowconcat**`(GEN x, GEN y)` concatenate x and y, *without* copying compoents, i. e., it returns a `GEN` whose components are (physically) the comonents of x and y.

`GEN` **vconcat**`(GEN A, GEN B)` concatenate vertically the two `t_MAT` A and B of compatible dimensions. A `NULL` pointer is accepted for an empty matrix. See `shallowconcat`.

`GEN` **row**`(GEN A, long i)` return $A[i,]$, the i-th row of the `t_MAT` A.

`GEN` **row_i**`(GEN A, long i, long j1, long j2)` return part of the i-th row of `t_MAT` A: $A[i, j_1]$, $A[i, j_1 + 1] \ldots, A[i, j_2]$. Assume $j_1 \leq j_2$.

`GEN` **rowslice**`(GEN A, long i1, long i2)` return the `t_MAT` formed by the i_1-th through i_2-th rows of `t_MAT` A. Assume $i_1 \leq i_2$.

`GEN` **rowpermute**`(GEN A, GEN p)`, p being a `t_VECSMALL` representing a list $[p_1, \ldots, p_n]$ of rows of `t_MAT` A, returns the matrix whose rows are $A[p_1,], \ldots, A[p_n,]$.

`GEN` **rowslicepermute**`(GEN A, GEN p, long x1, long x2)`, short for

```
rowslice(rowpermute(A,p), x1, x2)
```

(more efficient).

`GEN` **vecslice**`(GEN A, long j1, long j2)`, return $A[j_1], \ldots, A[j_2]$. If A is a `t_MAT`, these correspond to *columns* of A. The object returned has the same type as A (`t_VEC`, `t_COL` or `t_MAT`). Assume $j_1 \leq j_2$.

`GEN` **vecpermute**`(GEN A, GEN p)` p is a `t_VECSMALL` representing a list $[p_1, \ldots, p_n]$ of indices. Returns a `GEN` which has the same type as A (`t_VEC`, `t_COL` or `t_MAT`), and whose components are $A[p_1], \ldots, A[p_n]$. If A is a `t_MAT`, these are the *columns* of A.

`GEN` **vecslicepermute**`(GEN A, GEN p, long y1, long y2)` short for

```
vecslice(vecpermute(A,p), y1, y2)
```

(more efficient).

5.8.2 Low-level vectors and columns functions

Theses functions handle `t_VEC` as an abstract container type of `GEN`s. No specific meaning is attached to the content.

They accept both `t_VEC` and `t_COL` as input, but `col` functions always return `t_COL` and `vec` functions alway return `t_VEC`.

Note. All the functions below are shallow.

`GEN` **const_col**`(long n, long c)` returns a `t_COL` of `n` components equal to `c`.

`GEN` **const_vec**`(long n, long c)` returns a `t_VEC` of `n` components equal to `c`.

`int` **vec_isconst**`(GEN v)` Returns 1 if all the components of `v` are equal, else returns 0.

`int` **vec_is1to1**`(GEN v)` Returns 1 if the components of `v` are pair-wise distinct, i.e. if $i \mapsto v[i]$ is a 1-to-1 mapping, else returns 0.

`GEN` **vec_shorten**`(GEN v, long n)` shortens the vector `v` to `n` components.

`GEN` **vec_lengthen**`(GEN v, long n)` lengthens the vector `v` to `n` components. The extra components are not initialised.

5.8.3 Function to handle `t_VECSMALL`

Theses functions handle `t_VECSMALL` as an abstract container type of small signed integers. No specific meaning is attached to the content.

`GEN` **const_vecsmall**`(long n, long c)` returns a `t_VECSMALL` of `n` components equal to `c`.

`GEN` **vec_to_vecsmall**`(GEN z)` identical to `ZV_to_zv(z)`.

`GEN` **vecsmall_to_vec**`(GEN z)` identical to `zv_to_ZV(z)`.

`GEN` **vecsmall_to_col**`(GEN z)` identical to `zv_to_ZC(z)`.

`GEN` **vecsmall_copy**`(GEN x)` makes a copy of `x` on the stack.

`GEN` **vecsmall_shorten**`(GEN v, long n)` shortens the `t_VECSMALL` `v` to `n` components.

`GEN` **vecsmall_lengthen**`(GEN v, long n)` lengthens the `t_VECSMALL` `v` to `n` components. The extra components are not initialised.

`GEN` **vecsmall_indexsort**`(GEN x)` performs an indirect sort of the components of the `t_VECSMALL` `x` and return a permutation stored in a `t_VECSMALL`.

`void` **vecsmall_sort**`(GEN v)` sorts the `t_VECSMALL` `v` in place.

`GEN` **vecsmall_uniq**`(GEN v)` given a sorted `t_VECSMALL` `v`, return the vector of unique occurences.

`int` **vecsmall_lexcmp**`(GEN x, GEN y)` compares two `t_VECSMALL` lexically

`int` **vecsmall_prefixcmp**`(GEN x, GEN y)` truncate the longest `t_VECSMALL` to the length of the shortest and compares them lexicographically.

`GEN` **vecsmall_prepend**`(GEN V, long s)` prepend `s` to the `t_VECSMALL` `V`.

`GEN` **vecsmall_append**`(GEN V, long s)` append `s` to the `t_VECSMALL` `V`.

`GEN` **vecsmall_concat**`(GEN u, GEN v)` concat the `t_VECSMALL` `u` and `v`.

`long` **vecsmall_coincidence**`(GEN u, GEN v)` returns the numbers of indices where `u` and `v` agree.

`long` **vecsmall_pack**`(GEN v, long base, long mod)` handles the `t_VECSMALL` `v` as the digit of a number in base `base` and return this number modulo `mod`. This can be used as an hash function.

5.8.4 Functions to handle bits-vectors Theses functions manipulate vectors of bits (stored in `t_VECSMALL`). Bits are numbered from 0.

`GEN` **bitvec_alloc**`(long n)` allocates a bits-vector suitable for `n` bits.

`GEN` **bitvec_shorten**`(GEN bitvec, long n)` shortens a bits-vector `bitvec` to `n` bits.

`long` **bitvec_test**`(GEN bitvec, long b)` returns the bit of index `b` of `bitvec`.

`void` **bitvec_set**`(GEN bitvec, long b)` (in place) sets the bit of index `b` of `bitvec`.

`void` **bitvec_clear**`(GEN bitvec, long b)` (in place) clears the bit of index `b` of `bitvec`.

5.8.5 Functions to handle vectors of `t_VECSMALL` Theses functions manipulate vectors of `t_VECSMALL` (vecvecsmall).

`GEN` **vecvecsmall_sort**`(GEN x)` sorts lexicographically the components of the vector `x`.

`GEN` **vecvecsmall_indexsort**`(GEN x)` performs an indirect lexicographic sorting of the components of the vector `x` and return a permutation stored in a `t_VECSMALL`.

`long` **vecvecsmall_search**`(GEN x, GEN y, long flag)` `x` being a sorted vecvecsmall and `y` a `t_VECSMALL`, search `y` inside `x`. `fla` has the same meaning as for `setsearch`.

Appendix A:
A Sample program and Makefile

We assume that you have installed the PARI library and include files as explained in Appendix A or in the installation guide. If you chose differently any of the directory names, change them accordingly in the Makefiles.

If the program example that we have given is in the file `extgcd.c`, then a sample Makefile might look as follows. Note that the actual file `examples/Makefile` is more elaborate and you should have a look at it if you intend to use `install()` on custom made functions, see Section **??**.

```
CC = cc
INCDIR = /usr/pkg/include
LIBDIR = /usr/pkg/lib
CFLAGS = -O -I$(INCDIR) -L$(LIBDIR)

all:  extgcd

extgcd:  extgcd.c
      $(CC) $(CFLAGS) -o extgcd extgcd.c -lpari -lm
```

We then give the listing of the program `examples/extgcd.c` seen in detail in Section 4.8.

```
#include <pari/pari.h>
/*
GP;install("extgcd", "GG&&", "gcdex", "./libextgcd.so");
*/

/* return d = gcd(a,b), sets u, v such that au + bv = gcd(a,b) */
GEN
extgcd(GEN A, GEN B, GEN *U, GEN *V)
{
  pari_sp av = avma;
  GEN ux = gen_1, vx = gen_0, a = A, b = B;
  if (typ(a) != t_INT || typ(b) != t_INT) pari_err(typeer, "extgcd");
  if (signe(a) < 0) { a = negi(a); ux = negi(ux); }
  while (!gcmp0(b))
  {
    GEN r, q = dvmdii(a, b, &r), v = vx;

    vx = subii(ux, mulii(q, vx));
    ux = v;
    a = b; b = r;
  }
  *U = ux;
  *V = diviiexact( subii(a, mulii(A,ux)), B );
  gerepileall(av, 3, &a, U, V); return a;
}

int
```

```
main()
{
  GEN x, y, d, u, v;
  pari_init(1000000,2);
  printf("x = "); x = gp_read_stream(stdin);
  printf("y = "); y = gp_read_stream(stdin);
  d = extgcd(x, y, &u, &v);
  pariprintf("gcd = %Z\nu = %Z\nv = %Z\n", d,u,v);
  return 0;
}
```

Appendix B:
Summary of Available Constants

In this appendix we give the list of predefined constants available in the PARI library. All of them are in the heap and *not* on the PARI stack. We start by recalling the universal objects introduced in Section 4.1:

```
t_INT: gen_0, gen_1, gen_m1, gen_2
t_FRAC: ghalf
t_COMPLEX: gi
t_POL: pol_1[..], pol_x[..]
```

Only polynomials in the variables `0` and `MAXVARN` are defined initially. Use `fetch_var()` (see Section 4.6.2.2) to create new ones.

The other objects are not initialized by default:

`bern`(i). This is the $2i$-th Bernoulli number ($B_0 = 1$, $B_2 = 1/6$, $B_4 = -1/30$, etc...). To initialize them, use the function:

`void` **mpbern**`(long n, long prec)`

This creates the even numbered Bernoulli numbers up to B_{2n-2} *as real numbers* of precision `prec`. They can then be used with the macro `bern(i)`. Note that this is not a function but simply an abbreviation, hence care must be taken that `i` is inside the right bounds (i.e. $0 \le$ `i` $\le n-1$) before using it, since no checking is done by PARI itself.

`geuler`. This is Euler's constant. It is initialized by the first call to `mpeuler` (see Section **??**).

`gpi`. This is the number π. It is initialized by the first call to `mppi` (see Section **??**).

The use of both `geuler` and `gpi` is deprecated since it is always possible that some library function increases the precision of the constant *after* you've computed it, hence modifying the computation accuracy without your asking for it and increasing your running times for no good reason. You should always use `mpeuler` and `mppi` (note that only the first call will actually compute the constant, unless a higher precision is required).

In addition, some single or double-precision real numbers (like `PI`) are predefined, and their list is in the file `paricom.h`.

Finally, one has access to a table of (differences of) primes through the pointer `diffptr`. This is used as follows: when

`void` **pari_init**`(size_t size, ulong maxprime)`

is called, this table is initialized with the successive differences of primes up to (just a little beyond) `maxprime` (see Section 4.1). The prime table will occupy roughly `maxprime`/ log(`maxprime`) bytes in memory, so be sensible when choosing `maxprime` (it is 500000 by default under `gp`). In any case, the implementation requires that `maxprime` $< 2^{\mathtt{BIL}} - 2048$, whatever memory is available.

The largest prime computable using this table is available as the output of

`ulong` **maxprime**`()`

After the following initializations (the names p and ptr are arbitrary of course)

```
byteptr ptr = diffptr;
ulong p = 0;
```

calling the macro `NEXT_PRIME_VIADIFF_CHECK(p, ptr)` repeatedly will assign the successive prime numbers to p. Overrunning the prime table boundary will raise the error `primer1`, which will just print the error message:

```
*** not enough precomputed primes
```

and then abort the computations. The alternative macro `NEXT_PRIME_VIADIFF` operates in the same way, but will omit that check, and is slightly faster. It should be used in the following way:

```
byteptr ptr = diffptr;
ulong p = 0;
if (maxprime() < goal) pari_err(primer1); /* not enough primes */
while (p <= goal) /* run through all primes up to goal */
{
  NEXT_PRIME_VIADIFF(p, ptr);
  ...
}
```

Here, we use the general error handling function `pari_err` (see Section 4.7.3), with the codeword `primer1`, raising the "not enough primes" error.

You can use the function `initprimes` from the file `arith2.c` to compute a new table on the fly and assign it to `diffptr` or to a similar variable of your own. Beware that before changing `diffptr`, you should really free the (`malloc`ed) precomputed table first, and then all pointers into the old table will become invalid.

PARI currently guarantees that the first 6547 primes, up to and including 65557, are present in the table, even if you set `maxprime` to zero. in the `pari_init` call.

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`SomeWord` is a PARI-GP keyword.
SomeWord is a generic index entry.

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