

Pari-GP reference card

(PARI-GP version 2.19.0)

Note: optional arguments are surrounded by braces {}.

To start the calculator, type its name in the terminal: **gp**

To exit **gp**, type **quit**, **\q**, or **<C-D>** at prompt.

Help

describe function	?function
extended description	??keyword
list of relevant help topics	???pattern
name of GP-1.39 function f in GP-2.*	whatnow(f)

Input/Output

previous result, the result before	%, %`, %`` , etc.
n -th result since startup	% n
separate multiple statements on line	;
extend statement on additional lines	\
extend statements on several lines	{ seq_1 ; seq_2 ;}
comment	/* ... */
one-line comment, rest of line ignored	\\ ...

Metacommands & Defaults

set default d to val	default($\{d\}$, $\{val\}$)
toggle timer on/off	#
print time for last result	##
print defaults	\d
set debug level to n	\g n
set memory debug level to n	\gm n
set n significant digits / bits	\p n , \pb n
set n terms in series	\ps n
quit GP	\q
print the list of PARI types	\t
print the list of user-defined functions	\u
read file into GP	\r <i>filename</i>
set debuglevel for domain D to n	setdebug(D , n)

Debugger / break loop

get out of break loop	break or <C-D>
go up/down n frames	dbg_up($\{n\}$), dbg_down
set break point	breakpoint()
examine object o	dbg_x(o)
current error data	dbg_err()
number of objects on heap and their size	getheap()
total size of objects on PARI stack	getstack()

PARI Types & Input Formats

t_INT . Integers; hex, binary	± 31 ; $\pm 0x1F$, $\pm 0b101$
t_REAL . Reals	± 3.14 , 6.022 E23
t_INTMOD . Integers modulo m	Mod(n , m)
t_FRAC . Rational Numbers	n/m
t_FFELT . Elt in finite field $\mathbf{F}_q$	ffgen(q , 't)
t_COMPLEX . Complex Numbers	$x + y * I$
t_PADIC . p -adic Numbers	$x + O(p^k)$
t_QUAD . Quadratic Numbers	$x + y * \text{quadgen}(D, \{ 'w \})$
t_POLMOD . Polynomials modulo g	Mod(f , g)
t_POL . Polynomials	$a * x^n + \dots + b$
t_SER . Power Series	$f + O(x^k)$
t_RFRAC . Rational Functions	f/g
t_QFB . Binary quadratic form	Qfb(a , b , c)
t_VEC/t_COL . Row/Column Vectors	$[x, y, z]$, $[x, y, z] \sim$
t_VEC integer range	$[1..10]$

t_VECSMALL . Vector of small ints	Vecsmall($[x, y, z]$)
t_MAT . Matrices	$[a, b; c, d]$
t_LIST . Lists	List($[x, y, z]$)
t_STR . Strings	"abc"
t_INFINITY . $\pm\infty$	+oo, -oo

Reserved Variable Names

$\pi \approx 3.14$, $\gamma \approx 0.57$, $C \approx 0.91$, $I = \sqrt{-1}$	Pi, Euler, Catalan, I
Landau's big-oh notation	O

Information about an Object, Precision

PARI type of object x	type(x)
length of x / size of x in memory	# x , sizebyte(x)
real precision / bit precision of x	precision(x), bitprecision(x)
p -adic, series prec. of x	padicprec(x, p), serprec(x, v)
current dynamic precision	getlocalprec, getlocalbitprec

Operators

basic operations	+, - , *, / , ^ , sqr
$i \leftarrow i+1$, $i \leftarrow i-1$, $i \leftarrow i*j$, ...	i++, i--, i*=j,...
Euclidean quotient, remainder	$x \backslash y$, $x \backslash y$, $x \% y$, divrem(x, y)
shift x left or right n bits	$x << n$, $x >> n$ or shift($x, \pm n$)
multiply by 2^n	shiftmul(x, n)
comparison operators	<=, <, >=, >, ==, !=, ==, lex, cmp
boolean operators (or, and, not)	, &&, !
bit operations	bitand, bitneg, bitor, bitxor, bitnegimply
in place bit operations	bitclear, bitflip, bitset
maximum/minimum of x and y	max(x, y), min(x, y)
sign of x (gives $-1, 0, 1$)	sign(x)
binary exponent of x	exponent(x)
derivative of f , 2nd derivative, etc.	f' , f'' , ...
differential operator	diffop($f, v, d, \{n = 1\}$)
quote operator (formal variable)	' x
assignment	x = <i>value</i>
simultaneous assignment $x \leftarrow v[1]$, $y \leftarrow v[2]$	[x , y] = v

Select Components

Caveat: components start at index $n = 1$.

n -th component of x	component(x, n)
n -th component of vector/list x	$x[n]$
components $a, a + 1, \dots, b$ of vector x	$x[a..b]$
(m, n) -th component of matrix x	$x[m, n]$
row m or column n of matrix x	$x[m,]$, $x[, n]$
numerator/denominator of x	numerator(x), denominator(x)

Random Numbers

random integer/prime in $[0, N[$	random(N), randomprime(N)
get/set random seed	getrand, setrand(s)

Conversions

to vector, matrix, vec. of small ints	Col/Vec, Mat, Vecsmall
to list, set, map, string	List, Set, Map, Str
create $(x \bmod y)$	Mod(x, y)
make x a polynomial of v	Pol($x, \{v\}$)
variants of Pol <i>et al.</i> , in reverse order	Polrev, Vecrev, Colrev
make x a power series of v	Ser($x, \{v\}$)
convert x to simplest possible type	simplify(x)
object x with real precision n	precision(x, n)
object x with bit precision n	bitprecision(x, n)
b -bit fingerprint of x	fingerprint($x, \{b = 64\}$)
set precision to p digits in dynamic scope	localprec(p)
set precision to p bits in dynamic scope	localbitprec(p)

Character strings

convert to TeX representation	strtex(x)
string from bytes / from format+args	strchr, sprintf
split string / join strings	strsplit, strjoin
convert time t ms. to h, m, s, ms format	strtime(t)
Conjugates and Lifts	
conjugate of a number x	conj(x)
norm of x , product with conjugate	norm(x)
L^p norm of x (L^∞ if no p)	normlp($x, \{p\}$)
square of L^2 norm of x	norml2(x)
lift of x from Mods and p -adics	lift, centerlift(x)
recursive lift of all components of x	liftall(x)
lift all t_INT and t_PADIC ($\rightarrow$ t_INT)	liftint
lift all t_POLMOD ($\rightarrow$ t_POL)	liftpol

Lists, Sets & Maps

Sets (= row vector with strictly increasing entries w.r.t. **cmp**)

intersection of sets x and y	setintersect(x, y)
set of elements in x not belonging to y	setminus(x, y)
symmetric difference $x \Delta y$	setdelta(x, y)
union of sets x and y	setunion(x, y)
does y belong to the set x	setsearch($x, y, \{flag\}$)
set of all $f(x, y)$, $x \in X$, $y \in Y$	setbinop(f, X, Y)
is x a set ?	setisset(x)

Lists. create empty list: $L = \text{List}()$

append x to list L	listput($L, x, \{i\}$)
remove i -th component from list L	listpop($L, \{i\}$)
insert x in list L at position i	listinsert(L, x, i)
sort the list L in place	listsort($L, \{flag\}$)

Maps. create empty dictionary: $M = \text{Map}()$

attach value v to key k	mapput(M, k, v)
recover value attach to key k or error	mapget(M, k)
is key k in the dict? (set v to $M(k)$)	mapisdefined($M, k, \{\&v\}$)
evaluate f at $M(k)$	mapapply(M, k, f)
remove k from map domain	mapdelete(M, k)

GP Programming

User functions and closures

x, y are formal parameters; y defaults to Pi if parameter omitted;
 z, t are local variables (lexical scope), z initialized to 1.

fun(**x**, **y**=Pi) = **my**(**z**=1, **t**); *seq*
fun = (**x**, **y**=Pi) -> **my**(**z**=1, **t**); *seq*

attach help message h to s	addhelp(s, h)
undefine symbol s (also kills help)	kill(s)
Control Statements (X : formal parameter in expression seq)	
if $a \neq 0$, evaluate seq_1 , else seq_2	if($a, \{seq_1\}, \{seq_2\}$)
eval. seq for $a \leq X \leq b$	for($X = a, b, seq$)
...for $X \in v$	foreach(v, X, seq)
...for primes $a \leq X \leq b$	forprime($X = a, b, seq$)
...for primes $\equiv a \pmod{q}$	forprimestep($X = a, b, q, seq$)
...for composites $a \leq X \leq b$	forcomposite($X = a, b, seq$)
...for $a \leq X \leq b$ stepping s	forstep($X = a, b, s, seq$)
...for X dividing n	fordiv(n, X, seq)
... $X = [n, factor(n)]$, $a \leq n \leq b$	forfactored($X = a, b, seq$)
...as above, n squarefree	forsquarefree($X = a, b, seq$)
... $X = [d, factor(d)]$, $d \mid n$	fordivfactored(n, X, seq)
multivariable for , lex ordering	forvec($X = v, seq$)

loop over partitions of n
... permutations of S
... subsets of $\{1, \dots, n\}$
... k -subsets of $\{1, \dots, n\}$
... vectors $v, q(v) \leq B; q > 0$
... $H < G$ finite abelian group
evaluate seq until $a \neq 0$
while $a \neq 0$, evaluate seq
exit n innermost enclosing loops
start new iteration of n -th enclosing loop
return x from current subroutine

Exceptions, warnings
raise an exception / warning
type of error message E
try seq_1 , evaluate seq_2 on error

Functions with closure arguments / results
number of arguments of f
select from v according to f
apply f to all entries in v
evaluate $f(a_1, \dots, a_n)$
evaluate $f(\dots f(f(a_1, a_2), a_3) \dots, a_n)$
calling function as closure

Sums & Products
sum $X = a$ to $X = b$, initialized at x
sum entries of vector v
product of all vector entries
sum $expr$ over divisors of n
... assuming $expr$ multiplicative
product $a \leq X \leq b$, initialized at x
product over primes $a \leq X \leq b$

Sorting
sort x by k -th component
min. m of x ($m = x[i]$), max.
does y belong to x , sorted wrt. f
 $\prod g^x \rightarrow$ factorization ($\Rightarrow$ sorted, unique g)

Input/Output
print with/without $\backslash n$, TeX format
pretty print matrix
print fields with separator
formatted printing
write $args$ to file
write x in binary format
read file into GP
... return as vector of lines
... return as vector of strings
read a string from keyboard

Files and file descriptors
File descriptors allow efficient small consecutive reads or writes from or to a given file. The argument n below is always a descriptor, attached to a file in **r**(ead), **w**(rite) or **a**(ppend) mode.
get descriptor n for file $path$ in given $mode$
... from shell cmd output (pipe)
close descriptor
commit pending write operations
read logical line from file
... raw line from file
write $s \backslash n$ to file
... write s to file

forpart($p = n, seq$)
forperm(S, p, seq)
forsubset(n, p, seq)
forsubset($[n, k], p, seq$)
forqvec(v, q, b, seq)
forsubgroup($H = G$)
until(a, seq)
while(a, seq)
break($\{n\}$)
next($\{n\}$)
return($\{x\}$)

error(), **warning**()
errname(E)
iferr(seq_1, E, seq_2)

arity(f)
select(f, v)
apply(f, v)
call(f, a)
fold(f, a)
self()

sum($X = a, b, expr, \{x\}$)
vecsum(v)
vecprod(v)
sumdiv($n, X, expr$)
sumdivmult($n, X, expr$)
prod($X = a, b, expr, \{x\}$)
prodeuler($X = a, b, expr$)

vecsrt($x, \{k\}, \{fl = 0\}$)
vecmin($x, \{&i\}$), **vecmax**
vecsearch($x, y, \{f\}$)
matreduce(m)

print, **print1**, **printtex**
printp
printsep($sep, \dots$), **printsep1**
printf()
write, **writel**, **writetex**($file, args$)
writebin($file, x$)
read($\{file\}$)
readvec($\{file\}$)
readstr($\{file\}$)
input()

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Timers
CPU time in ms and reset timer
CPU time in ms since gp startup
time in ms since UNIX Epoch
timeout command after s seconds

Interface with system
allocates a new stack of s bytes
alias old to new
install function from library
execute system command a
... and feed result to GP
... returning GP string
get \$VAR from environment
expand env. variable in string

gettime()
getabstime()
getwalltime()
alarm($s, expr$)

allocatemem($\{s\}$)
alias(new, old)
install($f, code, \{gpf\}, \{lib\}$)
system(a)
extern(a)
externstr(a)
getenv("VAR")
strexand(x)

Parallel evaluation

These functions evaluate their arguments in parallel (pthreads or MPI); args. must not access global variables (use **export** for this) and must be free of side effects. Enabled if threading engine is not *single* in gp header.

evaluate f on $x[1], \dots, x[n]$
evaluate closures $f[1], \dots, f[n]$
parallel **select**
parallel **sum**
parallel **vector**
parallel **matrix**
eval f for $i = a, \dots, b$
... for each element x in v
... for p prime in $[a, b]$
... for $p = a \bmod q$
... for $i = a, a + s, \dots, b$
... multivariate
export x to parallel world
... all dynamic variables
frees single or all exported values

parapply(f, x)
pareval(f)
parselect($f, A, \{flag\}$)
parsum($i = a, b, expr$)
parvector($n, i, \{expr\}$)
parmatrix($n, i, j, \{expr\}$)
parfor($i = a, \{b\}, f, \{r\}, \{f_2\}$)
parforeach($v, x, f, \{r\}, \{f_2\}$)
parforprime($p = a, \{b\}, f, \{r\}, \{f_2\}$)
parforprimestep($p = a, \{b\}, q, f, \{r\}, \{f_2\}$)
parforstep($i = a, \{b\}, s, f, \{r\}, \{f_2\}$)
parforvec($X = v, f, \{r\}, \{f_2\}, \{flag\}$)
export(x)
exportall()
unexport(x), **unexportall**()

Linear Algebra

dimensions of matrix x
multiply two matrices
... assuming result is diagonal
concatenation of x and y
extract components of x
transpose of vector or matrix x
adjoint of the matrix x
eigenvectors/values of matrix x
characteristic/minimal polynomial of x
trace/determinant of matrix x
permanent of matrix x
Frobenius form of x
QR decomposition
apply **matqr**'s transform to v

matsize(x)
 $x * y$
matmultodiagonal(x, y)
concat($x, \{y\}$)
vecextract($x, y, \{z\}$)
 $x \sim$, **mattranspose**(x)
matadjoint(x)
mateigen(x)
charpoly(x), **minpoly**(x)
trace(x), **matdet**(x)
matpermanent(x)
matfrobenius(x)
matqr(x)
mathouseholder(Q, v)

Constructors & Special Matrices

$\{g(x) : x \in v \text{ s.t. } f(x)\}$
 $\{x : x \in v \text{ s.t. } f(x)\}$
 $\{g(x) : x \in v\}$
row vec. of $expr$ eval'd at $1 \leq i \leq n$
col. vec. of $expr$ eval'd at $1 \leq i \leq n$
vector of small ints

[g(x) | x <- v, f(x)]
[x | x <- v, f(x)]
[g(x) | x <- v]
vector($n, \{i\}, \{expr\}$)
vectorv($n, \{i\}, \{expr\}$)
vectorsmall($n, \{i\}, \{expr\}$)

$[c, c \cdot x, \dots, c \cdot x^n]$
 $[1, 2^x, \dots, n^x]$
matrix $1 \leq i \leq m, 1 \leq j \leq n$
define matrix by blocks
diagonal matrix with diagonal x
is x diagonal?
 $x \cdot \mathbf{matdiagonal}(d)$
 $n \times n$ identity matrix
Hessenberg form of square matrix x
 $n \times n$ Hilbert matrix $H_{ij} = (i + j - 1)^{-1}$
 $n \times n$ Pascal triangle
companion matrix to polynomial x
Sylvester matrix of x and y

powers($x, n, \{c = 1\}$)
dirpowers(n, x)
matrix($m, n, \{i\}, \{j\}, \{expr\}$)
matconcat(B)
matdiagonal(x)
matisdiagonal(x)
matmuldiagonal(x, d)
matid(n)
mathess(x)
mathilbert(n)
matpascal($n - 1$)
matcompanion(x)
polsylvestermatrix(x, y)

Gaussian elimination

kernel of matrix x
intersection of column spaces of x and y
solve $MX = B$ (M invertible)
one sol of $M * X = B$
basis for image of matrix x
columns of x *not* in **matimage**
supplement columns of x to get basis
rows, cols to extract invertible matrix
rank of the matrix x
solve $MX = B \bmod D$
Image, kernel, inverse and determinant modulo D : **matimagemod**, **matkernelmod**, **matinvmod** , **matdetmod**.

matker($x, \{flag\}$)
matintersect(x, y)
matsolve(M, B)
matinverseimage(M, B)
matimage(x)
matimagecompl(x)
mat supplement(x)
matindexrank(x)
matrank(x)
matsolvemod(M, D, B)

Lattices & Quadratic Forms

Quadratic forms

evaluate ${}^t x Q y$
evaluate ${}^t x Q x$
signature of quad form ${}^t y * x * y$
decomp into squares of ${}^t y * x * y$
eigenvalues/vectors for real symmetric x
Cholesky decomposition of x

qfeval($\{Q = id\}, x, y$)
qfeval($\{Q = id\}, x$)
qfsign(x)
qfgaussred(x)
qfjacobi(x)
qfcholesky(x)

HNF and SNF

upper triangular Hermite Normal Form
HNF of x where d is a multiple of $\det(x)$
reduce x modulo H in HNF
multiple of $\det(x)$
HNF of $(x \mid \mathbf{diagonal}(D))$
elementary divisors of x
 q -rank from elementary divisors
write $A = QH + R$, H in HNF
elementary divisors of $\mathbf{Z}[a]/(f'(a))$
integer kernel of x
Z-module $\leftrightarrow$ **Q**-vector space

mathnf(x)
mathnfmod(x, d)
matmodhnf(x, H)
matdetint(x)
mathnfmodid(x, D)
matsnf(x)
snfrank(v, q)
mathmodhnf($A, H, \{&Q\}$)
poldisreduced(f)
matkerint(x)
matrixqz(x, p)

Lattices

LLL-algorithm applied to columns of x
... for Gram matrix of lattice
find up to m sols of **qfeval**(x, y) $\leq b$
... up to m closest vectors to t
 $v, v[i] :=$ number of y s.t. **qfeval**(x, y) = i
perfection rank of x
find isomorphism between q and Q

qflll($x, \{flag\}$)
qflllgram($x, \{flag\}$)
qfminim(x, b, m)
qfcvp(x, t, m)
qfrep($x, B, \{flag\}$)
qfperfection(x)
qfisom(q, Q)

```

precompute for isomorphism test with  $q$       qfisominit( $q$ )
automorphism group of  $q$                      qfauto( $q$ )
convert qfauto for GAP/Magma                 qfautoexport( $G, \{flag\}$ )
orbits of  $V$  under  $G \subset \mathrm{GL}(V)$            qforbits( $G, V$ )

```

Polynomials & Rational Functions

```

all defined polynomial variables             variables()
get var. of highest priority (higher than  $v$ ) varhigher( $name, \{v\}$ )
... of lowest priority (lower than  $v$ )        varlower( $name, \{v\}$ )

```

Coefficients, variables and basic operators

```

degree of  $f$                                 poldegree( $f$ )
coef. of degree  $n$  of  $f$ , leading coef.      polcoef( $f, n$ ), pollead
main variable / all variables in  $f$           variable( $f$ ), variables( $f$ )
replace  $x$  by  $y$  in  $f$                          subst( $f, x, y$ )
evaluate  $f$  replacing vars by their value    eval( $f$ )
replace polynomial expr.  $T(x)$  by  $y$  in  $f$     substpol( $f, T, y$ )
replace  $x_1, \dots, x_n$  by  $y_1, \dots, y_n$  in  $f$  substvec( $f, x, y$ )
 $f \in A[x]$ ; reciprocal polynomial  $x^{\deg f} f\left(\frac{1}{x}\right)$  polrecip( $f$ )
gcd of coefficients of  $f$                     content( $f$ )
derivative of  $f$  w.r.t.  $x$                    deriv( $f, \{x\}$ )
...  $n$ -th derivative of  $f$                    derivn( $f, n, \{x\}$ )
formal integral of  $f$  w.r.t.  $x$                in formal( $f, \{x\}$ )
formal sum of  $f$  w.r.t.  $x$                    sumformal( $f, \{x\}$ )

```

Constructors & Special Polynomials

```

interpolation polynomial at  $(x[1], y[1]), \dots, (x[n], y[n])$ , evaluated
at  $t$ , with error estimate  $e$                  polinterpolate( $x, \{y\}, \{t\}, \{&e\}$ )
monic polynomial from roots  $r$                polfromroots( $r$ )
 $T_n/U_n, H_n$                                polchebyshev( $n$ ), polhermite( $n$ )
 $P_n, L_n^{(\alpha)}$                            pollegendre( $n$ ), pollaguerre( $n, a$ )
 $n$ -th cyclotomic polynomial  $\Phi_n$              polcyclo( $n$ )
return  $n$  if  $f = \Phi_n$ , else 0                 poliscyclo( $f$ )
is  $f$  a product of cyclotomic polynomials?    poliscycloprod( $f$ )
Zagier's polynomial of index  $(n, m)$           polzagier( $n, m$ )

```

Resultant, elimination

```

discriminant of polynomial  $f$                 poldisc( $f$ )
find factors of poldisc( $f$ )                   poldiscfactors( $f$ )
resultant  $R = \mathrm{Res}_v(f, g)$               polresultant( $f, g, \{v\}$ )
 $[u, v, R], xu + yv = \mathrm{Res}_v(f, g)$           polresultantext( $x, y, \{v\}$ )
solve Thue equation  $f(x, y) = a$               thue( $t, a, \{sol\}$ )
initialize  $t$  for Thue equation solver         thueinit( $f$ )

```

Roots and Factorization (Complex/Real)

```

complex roots of  $f$                            polroots( $f$ )
bound complex roots of  $f$                      polrootsbound( $f$ )
number of real roots of  $f$  (in  $[a, b]$ )          polsturm( $f, \{[a, b]\}$ )
real roots of  $f$  (in  $[a, b]$ )                   polrootsreal( $f, \{[a, b]\}$ )
complex embeddings of  $t$ .POLMOD  $z$              conjvec( $z$ )

```

Roots and Factorization (Finite fields)

```

factor  $f$  mod  $p$ , roots                        factormod( $f, p$ ), polrootsmod
factor  $f$  over  $\mathbf{F}_p[x]/(T)$ , roots             factormod( $f, [T, p]$ ), polrootsmod
squarefree factorization of  $f$  in  $\mathbf{F}_q[x]$          factormodSQF( $f, \{D\}$ )
distinct degree factorization of  $f$  in  $\mathbf{F}_q[x]$      factormodDDF( $f, \{D\}$ )
factor  $n$ -th cyclotomic pol.  $\Phi_n$  mod  $p$         factormodcyclo( $n, p$ )

```

Roots and Factorization (p -adic fields)

```

factor  $f$  over  $\mathbf{Q}_p$ , roots                     factorpadic( $f, p, r$ ), polrootspadic
 $p$ -adic root of  $f$  congruent to  $a$  mod  $p$         padicappr( $f, a$ )
Newton polygon of  $f$  for prime  $p$                newtonpoly( $f, p$ )
Hensel lift  $A/lc(A) = \prod_i B[i] \bmod p^e$       polhensellift( $A, B, p, e$ )

```

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```

 $T = \prod (x - z_i) \mapsto \prod (x - \omega(z_i)) \in \mathbf{Z}_p[x]$       polteichmuller( $T, p, e$ )
extensions of  $\mathbf{Q}_p$  of degree  $N$                  padicfields( $p, N$ )
Roots and Factorization (Miscellaneous)
symmetric powers of roots of  $f$  up to  $n$          polysym( $f, n$ )
Graeffe transform of  $f$ ,  $g(x^2) = f(x)f(-x)$       polgraeffe( $f$ )
factor  $f$  over coefficient field                 factor( $f$ )
cyclotomic factors of  $f \in \mathbf{Q}[X]$                polcyclofactors( $f$ )

```

Finite Fields

```

A finite field is encoded by any element (t_FFELT).
find irreducible  $T \in \mathbf{F}_p[x]$ ,  $\deg T = n$          ffinit( $p, n, \{x\}$ )
Create  $t$  in  $\mathbf{F}_q \simeq \mathbf{F}_p[t]/(T)$                  t = ffgen( $T, 't$ )
... indirectly, with implicit  $T$                 t = ffgen( $q, 't$ ); T = t.mod
map  $m$  from  $\mathbf{F}_q \ni a$  to  $\mathbf{F}_{q^k} \ni b$              m = ffebed( $a, b$ )
build  $K = \mathbf{F}_q[x]/(P)$  extending  $\mathbf{F}_q \ni a$ ,         ffextend( $a, P$ )
evaluate map  $m$  on  $x$                            ffeval( $m, x$ )
inverse map of  $m$                                 ffinvmap( $m$ )
compose maps  $m \circ n$                            ffcompomap( $m, n$ )
 $x$  as polmod over codomain of map  $m$              ffevalprel( $m, x$ )
 $F^n$  over  $\mathbf{F}_q \ni a$                              fffrobenius( $a, n$ )
#{monic irred.  $T \in \mathbf{F}_q[x]$ ,  $\deg T = n$ }          ffnbirred( $q, n$ )

```

Formal & p -adic Series

```

truncate power series or  $p$ -adic number          truncate( $x$ )
valuation of  $x$  at  $p$                            valuation( $x, p$ )
Dirichlet and Power Series
Taylor expansion around 0 of  $f$  w.r.t.  $x$          taylor( $f, x$ )
Laurent series of closure  $F$  up to  $x^k$           laurentseries( $f, k$ )
 $\sum a_k b_k t^k$  from  $\sum a_k t^k$  and  $\sum b_k t^k$       serconvol( $a, b$ )
 $f = \sum a_k t^k$  from  $\sum (a_k/k!) t^k$              serlaplace( $f$ )
reverse power series  $F$  so  $F(f(x)) = x$           serreverse( $f$ )
remove terms of degree  $< n$  in  $f$                 serchop( $f, n$ )
Dirichlet series multiplication / division       dirmul, dirdiv( $x, y$ )
Dirichlet Euler product ( $b$  terms)              direuler( $p = a, b, expr$ )

```

Transcendental and p -adic Functions

```

real, imaginary part of  $x$                       real( $x$ ), imag( $x$ )
absolute value, argument of  $x$                  abs( $x$ ), arg( $x$ )
square/ $n$ th root of  $x$                          sqrt( $x$ ), sqrtn( $x, n, \{&z\}$ )
all  $n$ -th roots of 1                           rootsof1( $n$ )
FFT of  $[f_0, \dots, f_{n-1}]$                    w = fftinit( $n$ ), fft/fftinw( $w, f$ )
trig functions                                sin, cos, tan, cotan, sinc
inverse trig functions                        asin, acos, atan
hyperbolic functions                         sinh, cosh, tanh, cotanh
inverse hyperbolic functions                 asinh, acosh, atanh
log( $x$ ), log(1 +  $x$ ),  $e^x$ ,  $e^x - 1$              log, loglp, exp, expm1
Euler  $\Gamma$  function, log  $\Gamma$ ,  $\Gamma'/\Gamma$          gamma, lngamma, psi
half-integer gamma function  $\Gamma(n + 1/2)$         gammah( $n$ )
Riemann's zeta  $\zeta(s) = \sum n^{-s}$                zeta( $s$ )
 $\sum_{1 \leq n \leq N} n^s$                          dirpowerssum( $N, s$ )
Hurwitz's  $\zeta(s, x) = \sum (n + x)^{-s}$           zetahurwitz( $s, x$ )
Lerch  $\Phi(z, s, x) = \sum z^n (n + x)^{-s}$          lerchphi( $z, s, x$ )
Lerch  $L(s, x, t) = \Phi(e^{2\pi i t}, s, x)$        lerchzeta( $s, x, t$ )
multiple zeta value (MZV),  $\zeta(s_1, \dots, s_k)$  zetamult( $s, \{T\}$ )
all MZVs for weight  $\sum s_i = n$                 zetamultall( $n$ )
convert MZV id to  $[s_1, \dots, s_k]$             zetamultconvert( $f, \{flag\}$ )
MZV dual sequence                           zetamultdual( $s$ )
multiple polylog  $Li_{s_1, \dots, s_k}(z_1, \dots, z_k)$  polylogmult( $s, z$ )

```

```

incomplete  $\Gamma$  function ( $y = \Gamma(s)$ )           incgam( $s, x, \{y\}$ )
complementary incomplete  $\Gamma$                    incgamc( $s, x$ )
 $\int_x^\infty e^{-t} dt/t$ ,  $(2/\sqrt{\pi}) \int_x^\infty e^{-t^2} dt$  eint1, erfc
elliptic integral of 1st and 2nd kind          ellK( $k$ ), ellE( $k$ )
dilogarithm of  $x$                              dilog( $x$ )
 $m$ -th polylogarithm of  $x$                       polylog( $m, x, \{flag\}$ )
 $U$ -confluent hypergeometric function          hyperu( $a, b, u$ )
Hypergeometric  ${}_pF_q(A, B; z)$                  hypergeom( $A, B, z$ )
Bessel  $J_n(x)$ ,  $J_{n+1/2}(x)$                    besselj( $n, x$ ), besseljh( $n, x$ )
Bessel  $I_\nu$ ,  $K_\nu$ ,  $H_\nu^1$ ,  $H_\nu^2$ ,  $Y_\nu$              (bessel)i, k, h1, h2, y
 $k$ -th zero of  $J_\nu(x)$                            besseljzero( $nu, \{k = 1\}$ )
 $k$ -th zero of  $Y_\nu(x)$                            besselyzero( $nu, \{k = 1\}$ )
Airy functions  $A_i(x)$ ,  $B_i(x)$                  airy( $x$ )
Lambert  $W$ :  $x$  s.t.  $xe^x = y$                   lambertw( $y$ )
Teichmuller character of  $p$ -adic  $x$              teichmuller( $x$ )

```

Iterations, Sums & Products

Numerical integration for meromorphic functions

```

Behaviour at endpoint for Double Exponential (DE) methods: either a scalar ( $a \in \mathbf{C}$ , regular) or  $\pm\infty$  (decreasing at least as  $x^{-2}$ ) or
 $(x - a)^{-\alpha}$  singularity                      [a, a]
exponential decrease  $e^{-\alpha|x|}$               [ $\pm\infty, a$ ],  $\alpha > 0$ 
slow decrease  $|x|^\alpha$                         ...  $\alpha < -1$ 
oscillating as  $\cos(kx)$                         $\alpha = kI$ ,  $k > 0$ 
oscillating as  $\sin(kx)$                         $\alpha = -kI$ ,  $k > 0$ 

```

```

numerical integration                          intnum( $x = a, b, f, \{T\}$ )
weights  $T$  for intnum                          intnuminit( $a, b, \{m\}$ )
weights  $T$  incl. kernel  $K$                     intfuncinit( $t = a, b, K, \{m\}$ )
integrate  $(2i\pi)^{-1} f$  on circle  $|z - a| = R$  intcirc( $x = a, R, f, \{T\}$ )

```

Other integration methods

```

 $n$ -point Gauss-Legendre                      intnumgauss( $x = a, b, f, \{n\}$ )
weights for  $n$ -point Gauss-Legendre          intnumgaussinit( $\{n\}$ )
quasi-periodic function, period  $2H$           intnumosc( $x = a, f, H$ )
Romberg (low accuracy)                      intnumromb( $x = a, b, f, \{flag\}$ )

```

Numerical summation

```

sum of series  $f(n)$ ,  $n \geq a$  (low accuracy)    suminf( $n = a, expr$ )
sum of alternating/positive series            sumalt, sumpos
sum of series using Euler-Maclaurin           sumnum( $n = a, f, \{T\}$ )
... Sidi summation                          sumnumsidi( $n = a, f$ )
 $\sum_{n \geq a} F(n)$ ,  $F$  rational function          sumnumrat( $F, a$ )
...  $\sum_{p \geq a} F(p^s)$                         sumeulerrat( $F, \{s = 1\}, \{a = 2\}$ )
weights for sumnum,  $a$  as in DE               sumnuminit( $\{\infty, a\}$ )
sum of series by Monien summation             sumnummonien( $n = a, f, \{T\}$ )
weights for sumnummonien                     sumnummonieninit( $\{\infty, a\}$ )
sum of series using Abel-Plana                sumnumap( $n = a, f, \{T\}$ )
weights for sumnumap,  $a$  as in DE             sumnumapinit( $\{\infty, a\}$ )
sum of series using Lagrange                  sumnumlagrange( $n = a, f, \{T\}$ )
weights for sumnumlagrange                   sumnumlagrangeinit

```

Products

```

product  $a \leq X \leq b$ , initialized at  $x$       prod( $X = a, b, expr, \{x\}$ )
product over primes  $a \leq X \leq b$            prodeuler( $X = a, b, expr$ )
infinite product  $a \leq X \leq \infty$           prodinf( $X = a, expr$ )
 $\prod_{n \geq a} F(n)$ ,  $F$  rational function          prodnumrat( $F, a$ )
 $\prod_{p \geq a} F(p^s)$                           prodeulerrat( $F, \{s = 1\}, \{a = 2\}$ )

```

Other numerical methods

real root of f in $[a, b]$; bracketed root	<code>solve($X = a, b, f$)</code>
...interval splitting, step s	<code>solvestep($X = a, b, s, f, \{flag = 0\}$)</code>
limit of $f(t)$, $t \rightarrow \infty$	<code>limitnum($f, \{\alpha\}$)</code>
asymptotic expansion of f (rational)	<code>asypnum($f, \{\alpha\}$)</code>
... $N + 1$ terms as floats	<code>asypnumraw($f, N, \{\alpha\}$)</code>
numerical derivation w.r.t x : $f'(a)$	<code>derivnum($x = a, f$)</code>
evaluate continued fraction F at t	<code>contfraceval($F, t, \{L\}$)</code>
power series to cont. fraction (L terms)	<code>contfracinit($S, \{L\}$)</code>
Padé approximant (deg. denom. $\leq B$)	<code>bestapprPade($S, \{B\}$)</code>

Elementary Arithmetic Functions

vector of binary digits of $ x $	<code>binary(x)</code>
bit number n of integer x	<code>bittest(x, n)</code>
Hamming weight of integer x	<code>hammingweight(x)</code>
digits of integer x in base B	<code>digits($x, \{B = 10\}$)</code>
sum of digits of integer x in base B	<code>sumdigits($x, \{B = 10\}$)</code>
integer from digits	<code>fromdigits($v, \{B = 10\}$)</code>
ceiling/floor/fractional part	<code>ceil, floor, frac</code>
round x to nearest integer	<code>round($x, \{\&e\}$)</code>
truncate x	<code>truncate($x, \{\&e\}$)</code>
gcd/LCM of x and y	<code>gcd(x, y), lcm(x, y)</code>
gcd of entries of a vector/matrix	<code>content(x)</code>

Primes and Factorization

extra prime table	<code>addprimes()</code>
add primes in v to prime table	<code>addprimes(v)</code>
remove primes from prime table	<code>removeprimes(v)</code>
Chebyshev $\pi(x)$, n -th prime p_n	<code>primepi(x), prime(n)</code>
vector of first n primes	<code>primes(n)</code>
smallest prime $\geq x$	<code>nextprime(x)</code>
largest prime $\leq x$	<code>precprime(x)</code>
factorization of x	<code>factor($x, \{lim\}$)</code>
...selecting specific algorithms	<code>factorint($x, \{flag = 0\}$)</code>
$n = df^2$, d squarefree/fundamental	<code>core($n, \{fl\}$), coredisc</code>
certificate for (prime) N	<code>primecert(N)</code>
verifies a certificate c	<code>primecertisvalid(c)</code>
convert certificate to Magma/PRIMO	<code>primecertexport</code>
recover x from its factorization	<code>factorback($f, \{e\}$)</code>
$x \in \mathbf{Z}$, $ x \leq X$, $\gcd(N, P(x)) \geq N$	<code>zncoppersmith($P, N, X, \{B\}$)</code>
divisors of N in residue class r mod s	<code>divisorslensstra(N, r, s)</code>

Divisors and multiplicative functions

number of prime divisors $\omega(n)$ / $\Omega(n)$	<code>omega(n), bigomega</code>
divisors of n / number of divisors $\tau(n)$	<code>divisors(n), numdiv</code>
sum of (k -th powers of) divisors of n	<code>sigma($n, \{k\}$)</code>
Möbius μ -function	<code>moebius(x)</code>
Ramanujan's τ -function	<code>ramanujantau(x)</code>

Combinatorics

factorial of x	<code>x!</code> or <code>factorial(x)</code>
binomial coefficient $\binom{x}{k}$	<code>binomial($x, \{k\}$)</code>
Bernoulli number B_n as real/rational	<code>bernreal(n), bernfrac</code>
$[B_0, B_2, \dots B_{2k}]$	<code>bernvec(k)</code>
Bernoulli polynomial $B_n(x)$	<code>bernpol($n, \{x\}$)</code>
Euler numbers	<code>eulerfrac, eulerreal, eulervec</code>
Euler polynomial $E_n(x)$	<code>eulerpol($n, \{x\}$)</code>
Eulerian polynomial $A_n(x)$	<code>eulerianpol</code>
Fibonacci number F_n	<code>fibonacci(n)</code>
Harmonic number $H_{n,r} = 1^{-r} + \dots + n^{-r}$	<code>harmonic(n, r)</code>
Stirling numbers $s(n, k)$ and $S(n, k)$	<code>stirling($n, k, \{flag\}$)</code>

Pari-GP reference card

(PARI-GP version 2.19.0)

number of partitions of n	<code>numbpart(n)</code>
k -th permutation on n letters	<code>numtoperm(n, k)</code>
...index k of permutation v	<code>permtotnum(v)</code>
order of permutation p	<code>permorder(p)</code>
signature of permutation p	<code>permsign(p)</code>
cyclic decomposition of permutation p	<code>permcycles(p)</code>

Multiplicative groups $(\mathbf{Z}/N\mathbf{Z})^*$, $\mathbf{F}_q^*$

Euler ϕ -function	<code>eulerphi(x)</code>
multiplicative order of x (divides ϕ)	<code>znorder($x, \{o\}$), fforder</code>
primitive root mod q / x .mod	<code>znprimroot(q), fprimroot(x)</code>
structure of $(\mathbf{Z}/n\mathbf{Z})^*$	<code>znstar(n)</code>
discrete logarithm of x in base g	<code>znlog($x, g, \{o\}$), fflag</code>
Kronecker-Legendre symbol $(\frac{x}{y})$	<code>kronecker(x, y)</code>
quadratic Hilbert symbol (at p)	<code>hilbert($x, y, \{p\}$)</code>

Euclidean algorithm, continued fractions

CRT: solve $z \equiv x$ and $z \equiv y$	<code>chinese(x, y)</code>
minimal u, v so $xu + yv = \gcd(x, y)$	<code>gcdext(x, y)</code>
half-gcd algorithm	<code>halfgcd(x, y)</code>
continued fraction of x	<code>contfrac($x, \{b\}, \{lmax\}$)</code>
last convergent of continued fraction x	<code>contfracpnqn(x)</code>
rational approximation to x (den. $\leq B$)	<code>bestappr($x, \{B\}$)</code>
recognize $x \in \mathbf{C}$ as polmod mod $T \in \mathbf{Z}[X]$	<code>bestapprnf(x, T)</code>

Miscellaneous

integer square / n -th root of x	<code>sqrtnint(x), sqrtsint(x, n)</code>
largest integer e s.t. $b^e \leq b$, $e = \lfloor \log_b(x) \rfloor$	<code>logint($x, b, \{\&z\}$)</code>

Characters

Let $\chi = [d_1, \dots, d_k]$ represent an abelian group $G = \oplus (\mathbf{Z}/d_j\mathbf{Z}) \cdot g_j$ or any structure G affording a `.cyc` method; e.g. `znstar( $q, 1$ )` for Dirichlet characters. A character χ is coded by $[c_1, \dots, c_k]$ such that $\chi(g_j) = e(n_j/d_j)$.
 $\chi \cdot \psi$; χ^{-1} ; $\chi \cdot \psi^{-1}$; χ^k `charmul, charconj, chardiv, charpow`
order of χ `charorder( $cyc, \chi$ )`
kernel of χ `charker( $cyc, \chi$ )`
 $\chi(x)$, G a GP group structure `chareval( $G, \chi, x, \{z\}$ )`
Galois orbits of characters `chargalois( $G$ )`

Dirichlet Characters

initialize $G = (\mathbf{Z}/q\mathbf{Z})^*$ `G = znstar( $q, 1$ )`
convert datum D to $[G, \chi]$ `znchar( $D$ )`
is χ odd? `zncharisodd( $G, \chi$ )`
real $\chi \rightarrow$ Kronecker symbol $(D/.)$ `znchartokronecker( $G, \chi$ )`
conductor of χ `zncharconductor( $G, \chi$ )`
 $[G_0, \chi_0]$ primitive attached to χ `znchartoprimitive( $G, \chi$ )`
induce $\chi \in \hat{G}$ to $\mathbf{Z}/N\mathbf{Z}$ `zncharinduce( $G, \chi, N$ )`
 χp `znchardecompose( $G, \chi, p$ )`
 $\prod_p |(Q, N) \chi p$ `znchardecompose( $G, \chi, Q$ )`
complex Gauss sum $G_a(\chi)$ `znchargauss( $G, \chi$ )`

Conrey labelling

Conrey label $m \in (\mathbf{Z}/q\mathbf{Z})^* \rightarrow$ character `znconreychar( $G, m$ )`
character $\rightarrow$ Conrey label `znconreyexp( $G, \chi$ )`
log on Conrey generators `znconreylog( $G, m$ )`
conductor of χ (χ_0 primitive) `znconreyconductor( $G, \chi, \{\chi_0\}$ )`

True-False Tests

is x the disc. of a quadratic field?	<code>isfundamental(x)</code>
is x a prime?	<code>isprime(x)</code>
is x a strong pseudo-prime?	<code>ispseudoprime(x)</code>
is x square-free?	<code>issquarefree(x)</code>
is x a square?	<code>issquare($x, \{\&n\}$)</code>
is x a perfect power?	<code>ispower($x, \{k\}, \{\&n\}$)</code>
is x a perfect power of a prime? ($x = p^n$)	<code>isprimepower($x, \&n$)</code>
... of a pseudoprime?	<code>ispseudoprimepower($x, \&n$)</code>
is x powerful?	<code>ispowerful(x)</code>
is x a totient? ($x = \varphi(n)$)	<code>istotient($x, \{\&n\}$)</code>
is x a polygonal number? ($x = P(s, n)$)	<code>ispolygonal($x, s, \{\&n\}$)</code>
is pol irreducible?	<code>polisirreducible(pol)</code>

Graphic Functions

crude graph of $expr$ between a and b `plot( $X = a, b, expr$ )`
High-resolution plot (immediate plot)
plot $expr$ between a and b `plotoh( $X = a, b, expr, \{flag\}, \{n\}$ )`
plot points given by lists lx, ly `plotthraw( $lx, ly, \{flag\}$ )`
terminal dimensions `plotsizes()`
Rectwindow functions
init window w , with size x, y `plotinit( $w, x, y$ )`
erase window w `plotkill( $w$ )`
copy w to w_2 with offset (dx, dy) `plotcopy( $w, w_2, dx, dy$ )`
scale contents of w `plotclip( $w$ )`
scale coordinates in w `plotscale( $w, x_1, x_2, y_1, y_2$ )`
`plotoh` in w `plotrecth( $w, X = a, b, expr, \{flag\}, \{n\}$ )`
`plotthraw` in w `plotrectthraw( $w, data, \{flag\}$ )`
draw window w_1 at $(x_1, y_1), \dots$ `plotdraw( $[[w_1, x_1, y_1], \dots]$ )`

Low-level Rectwindow Functions

set current drawing color in w to c `plotcolor( $w, c$ )`
current position of cursor in w `plotcursor( $w$ )`
write s at cursor's position `plotstring( $w, s$ )`
move cursor to (x, y) `plotmove( $w, x, y$ )`
move cursor to $(x + dx, y + dy)$ `plotrmove( $w, dx, dy$ )`
draw a box to (x_2, y_2) `plotbox( $w, x_2, y_2$ )`
draw a box to $(x + dx, y + dy)$ `plotrbox( $w, dx, dy$ )`
draw polygon `plotlines( $w, lx, ly, \{flag\}$ )`
draw points `plotpoints( $w, lx, ly$ )`
draw ellipse `plotarc( $w, lx, ly, \{flag\}$ )`
draw line to $(x + dx, y + dy)$ `plotrline( $w, dx, dy$ )`
draw point $(x + dx, y + dy)$ `plotrpoint( $w, dx, dy$ )`

Convert to Postscript or Scalable Vector Graphics

The format f is either "ps" or "svg".
as `plotoh` `plotexport( $f, X = a, b, expr, \{flag\}, \{n\}$ )`
as `plotthraw` `plotthrawexport( $f, lx, ly, \{flag\}$ )`
as `plotdraw` `plotexport( $f, [[w_1, x_1, y_1], \dots]$ )`

Based on an earlier version by Joseph H. Silverman
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