
gmpy2 Documentation

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gmpy2 is a C-coded Python extension module that supports multiple-precision arithmetic. It is the successor to the original gmpy module (supported only the GMP library). gmpy2 adds support for the MPFR (correctly rounded real floating-point arithmetic) and MPC (correctly rounded complex floating-point arithmetic) libraries.

The following libraries are supported:

- GMP for integer and rational arithmetic (<https://gmplib.org>)
- MPFR (<https://www.mpfr.org>)
- MPC (<https://www.multiprecision.org/mpc/>)
- Generalized Lucas sequences and primality tests are based on the following code:
 - mpz_lucas: <https://sourceforge.net/projects/mpzluucas/>
 - mpz_prp: <https://sourceforge.net/projects/mpzprp/>

CONTENTS

1.1 Overview

The `mpz` and `mpq` types support arbitrary precision integers and rationals via the GMP library. These types should be drop-in replacements for Python's `int`'s and `Fraction`'s, but are significantly faster for large values. The cutover point for performance varies, but can be as low as 20 to 40 digits. All the special integer functions in the GMP are supported.

Warning: gmpy2 can crash the Python interpreter in case of memory allocation failure. To mitigate this feature of memory management in the GMP library, you should estimate the size of all results and prevent calculations that can exhaust available memory.

The `mpfr` and `mpc` types provide support for correctly rounded multiple precision real and complex arithmetic via the MPFR and MPC libraries. The `context` type is used to control precision, rounding modes, and exceptional conditions. For example, division by zero can either return an Infinity or raise an exception. It is possible to specify different precision and rounding modes for both the real and imaginary components of an `mpc`. The default precision is 53 bits — just same as for Python's `float` and `complex` types.

Operator overloading is fully supported. Conversion from native Python types is optimized for performance.

1.2 Installation

gmpy2 requires CPython 3.7 or above. Pre-compiled binary wheels are available on PyPI. You can install latest release with pip:

```
pip install gmpy2
```

or some specific version with:

```
pip install gmpy2==2.1.5
```

1.2.1 From Sources

If pre-compiled binary wheels aren't available for your platform, the pip will fallback to installation from sources. In this case you will need to have required libraries (GMP, MPFR and MPC) already installed on your system, along with the include files for those libraries. On Debian you can install them system-wide with:

```
sudo apt install libgmp-dev libmpfr-dev libmpc-dev
```

Tip: On Windows we recommend using [MSYS2](#) to build the gmpy2 from sources. To install required dependencies before, run:

```
pacman -S gcc gmp-devel mpfr-devel mpc-devel python-setuptools python-pip
```

If you are a developer or like to get the latest updates as they come, be sure to install from the git repository and include required extra dependencies, for example the optional "tests" list, which include packages required for testing:

```
git clone git://github.com/aleaxit/gmpy.git
cd gmpy
pip install -e .[tests]
```

Next you may want to run full set of unit tests to make sure everything works:

```
pytest test/
```

1.3 Tutorial

Start by importing the contents of the package with:

```
>>> from gmpy2 import *
```

Note: The use of `from gmpy2 import *` is not recommended in real code. The names in gmpy2 have been chosen to avoid conflict with Python's builtin names but gmpy2 does use names that may conflict with other modules or variable names. In normal usage you'll probably only want to import the classes and functions that you actually need.

Lets look first on some examples of arbitrary precision arithmetic with integer and rational types:

```
>>> mpz(99) * 43
mpz(4257)
>>> pow(mpz(99), 37, 59)
mpz(18)
>>> isqrt(99)
mpz(9)
>>> isqrt_rem(99)
(mpz(9), mpz(18))
>>> gcd(123, 27)
mpz(3)
>>> lcm(123, 27)
mpz(1107)
>>> (mpz(123) + 12) / 5
```

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```
mpfr('27.0')
>>> (mpz(123) + 12) // 5
mpz(27)
>>> (mpz(123) + 12) / 5.0
mpfr('27.0')
>>> mpz('123') + 1
mpz(124)
>>> 10 - mpz(1)
mpz(9)
>>> is_prime(17)
True
>>> mpz('1_000_000')
mpz(1000000)
>>> mpq(3, 7)/7
mpq(3,49)
>>> mpq(45, 3) * mpq(11, 8)
mpq(165,8)
>>> mpq(1, 7) * 11
mpq(11,7)
```

```
>>> mpfr('1.2')
mpfr('1.2')
>>> mpfr(float('1.2'))
mpfr('1.2')
>>> ctx = get_context()
>>> ctx.precision
53
>>> ctx.precision = 100
>>> mpfr('1.2')
mpfr('1.2000000000000000000000000000000000000000006',100)
>>> mpfr(float('1.2'))
mpfr('1.1999999999999999999999999999999999999999994',100)
>>> ctx.precision = 53
>>> ctx.round = RoundUp
>>> const_pi()
mpfr('3.1415926535897936')
>>> ctx.round = RoundToNearest
>>> const_pi()
mpfr('3.1415926535897931')
```

```
>>> ctx.divzero
False
>>> mpfr(1)/0
mpfr('inf')
```

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```
>>> ctx.trap_divzero = True
>>> mpfr(1)/0
Traceback (most recent call last):
...
gmpy2.DivisionByZeroError: division by zero
>>> ctx.divzero
True
```

Exceptions are normally raised in Python when the result of a real operation is not defined over the reals; for example, `math.sqrt(-2)` will raise a `ValueError` exception. The default context in gmpy2 implements similar behavior, but by setting `allow_complex` flag, complex results will be returned.

```
>>> sqrt(mpfr(-2))
mpfr('nan')
>>> ctx.allow_complex = True
>>> sqrt(mpfr(-2))
mpc('0.0+1.4142135623730951j')
```

Contexts can also be used as context managers in conjunction with Python’s `with` statement to temporarily change the current context settings for a block of code.

```
>>> print(const_pi())
3.1415926535897931
>>> with context(precision=100) as ctx:
...     print(const_pi())
...     ctx.precision += 20
...     print(const_pi())
...
3.1415926535897932384626433832793
3.1415926535897932384626433832795028847
>>> print(const_pi())
3.1415926535897931
```

It’s possible to set different precision settings for real and imaginary components.

```
>>> ctx = get_context()
>>> ctx.real_prec = 60
>>> ctx.imag_prec = 70
>>> sqrt(mpc('1+2j'))
mpc('1.272019649514068965+0.78615137775742328606947j', (60,70))
```

All gmpy2 numeric types support Python’s “new style” string formatting available in [formatted string literals](#) or with `str.format()`; see [Format Specification Mini-Language](#) for a description of the standard formatting syntax. The precision value optionally can be followed by the rounding mode type (‘U’ to round toward plus infinity, ‘D’ to round toward minus infinity, ‘Y’ to round away from zero, ‘Z’ to round toward zero and ‘N’ - round to the nearest value.

```
>>> a = mpfr("1.23456")
>>> "{0:15.3f}".format(a)
'          1.235'
>>> "{0:15.3Uf}".format(a)
'          1.235'
>>> "{0:15.3Df}".format(a)
'          1.234'
```

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```
>>> "{0:.3Df}".format(a)
'1.234'
>>> "{0:+.3Df}".format(a)
'+1.234'
```

1.4 Integers

1.4.1 mpz type

class gmpy2.mpz(*n=0, /*)

class gmpy2.mpz(*s, /, base=0*)

Return an immutable integer constructed from a numeric value *n* (truncating *n* to its integer part) or a string *s* made of digits in the given base. Every input, that is accepted by the `int` type constructor is also accepted.

The base may vary from 2 to 62, or if base is 0, then binary, octal, or hexadecimal strings are recognized by leading '0b', '0o', or '0x' characters (case is ignored), otherwise the string is assumed to be decimal. For bases up to 36, digits case is ignored. For bases 37 to 62, upper-case letter represent the usual 10..35 range, while lower-case letter represent 36..61. Optionally the string can be preceded by '+' or '-'. White space and underscore is simply ignored.

__format__(*fmt*) → `str`

Return a Python string by formatting `mpz` 'x' using the format string 'fmt'. A valid format string consists of:

optional alignment code:

'<' -> left shifted in field '>' -> right shifted in field '^' -> centered in field

optional leading sign code:

'+' -> always display leading sign '-' -> only display minus sign ' ' -> minus for negative values, space for positive values

optional base indicator

'#' -> precede binary, octal, or hex with 0b, 0o or 0x

optional width

optional conversion code:

'd' -> decimal format 'b' -> binary format 'o' -> octal format 'x' -> hex format 'X' -> upper-case hex format

The default format is 'd'.

as_integer_ratio() → `tuple[mpz, mpz]`

Return a pair of integers, whose ratio is exactly equal to the original number. The ratio is in lowest terms and has a positive denominator.

bit_clear(*n, /*) → `mpz`

Return a copy of *x* with the *n*-th bit cleared.

bit_count() → `int`

Return the number of 1-bits set in `abs(x)`.

bit_flip(*n*, /) → *mpz*

Return a copy of *x* with the *n*-th bit inverted.

bit_length() → *int*

Return the number of significant bits in the radix-2 representation of *x*. Note: *mpz*(0).*bit_length*() returns 0.

bit_scan0(*n*=0, /) → *int* | *None*

Return the index of the first 0-bit of *x* with index ≥ *n*. *n* ≥ 0. If there are no more 0-bits in *x* at or above index *n* (which can only happen for *x*<0, assuming an infinitely long 2's complement format), then *None* is returned.

bit_scan1(*n*=0, /) → *int* | *None*

Return the index of the first 1-bit of *x* with index ≥ *n*. *n* ≥ 0. If there are no more 1-bits in *x* at or above index *n* (which can only happen for *x*≥0, assuming an infinitely long 2's complement format), then *None* is returned.

bit_set(*n*, /) → *mpz*

Return a copy of *x* with the *n*-th bit set.

bit_test(*n*, /) → *bool*

Return the value of the *n*-th bit of *x*.

conjugate() → *mpz*

Return the conjugate of *x* (which is just a new reference to *x* since *x* is not a complex number).

digits(*base*=10, /) → *str*

Return Python string representing *x* in the given base. Values for base can range between 2 to 62. A leading '-' is present if *x*<0 but no leading '+' is present if *x*≥0.

from_bytes(*bytes*, *byteorder*='big', *, *signed*=False) → *mpz*

Return the integer represented by the given array of bytes.

bytes

Holds the array of bytes to convert. The argument must either support the buffer protocol or be an iterable object producing bytes. *bytes* and *bytearray* are examples of built-in objects that support the buffer protocol.

byteorder

The byte order used to represent the integer. If *byteorder* is 'big', the most significant byte is at the beginning of the byte array. If *byteorder* is 'little', the most significant byte is at the end of the byte array. To request the native byte order of the host system, use *sys.byteorder* as the byte order value.

signed

Indicates whether two's complement is used to represent the integer.

is_congruent(*y*, *m*, /) → *bool*

Returns *True* if *x* is congruent to *y* modulo *m*, else return *False*.

is_divisible(*d*, /) → *bool*

Returns *True* if *x* is divisible by *d*, else return *False*.

is_even() → *bool*

Return *True* if *x* is even, *False* otherwise.

is_odd() → *bool*

Return *True* if *x* is odd, *False* otherwise.

is_power() → bool

Return **True** if x is a perfect power (there exists a y and an n > 1, such that x=y**n), else return **False**.

is_prime(n=25, /) → bool

Return **True** if x is *probably* prime, else **False** if x is definitely composite. x is checked for small divisors and up to n Miller-Rabin tests are performed.

is_probab_prime(n=25, /) → int

Return 2 if x is definitely prime, 1 if x is probably prime, or return 0 if x is definitely non-prime. x is checked for small divisors and up to n Miller-Rabin tests are performed. Reasonable values of n are between 15 and 50.

is_square() → bool

Returns **True** if x is a perfect square, else return **False**.

num_digits(base=10, /) → int

Return length of string representing the absolute value of x in the given base. Values for base can range between 2 and 62. The value returned may be 1 too large.

to_bytes(length=1, byteorder='big', *, signed=False) → bytes

Return an array of bytes representing an integer.

length

Length of bytes object to use. An **OverflowError** is raised if the integer is not representable with the given number of bytes.

byteorder

The byte order used to represent the integer. If byteorder is 'big', the most significant byte is at the beginning of the byte array. If byteorder is 'little', the most significant byte is at the end of the byte array. To request the native byte order of the host system, use **sys.byteorder** as the byte order value.

signed

Determines whether two's complement is used to represent the integer. If signed is **False** and a negative integer is given, an **OverflowError** is raised.

denominator

the denominator of a rational number in lowest terms

imag

the imaginary part of a complex number

numerator

the numerator of a rational number in lowest terms

real

the real part of a complex number

1.4.2 mpz Functions

`gmpy2.bincoef(n, k, /) → mpz`

Return the binomial coefficient ('n choose k'). $k \geq 0$.

`gmpy2.bit_clear(x, n, /) → mpz`

Return a copy of x with the n-th bit cleared.

`gmpy2.bit_count(x, /) → int`

Return the number of 1-bits set in `abs(x)`.

`gmpy2.bit_flip(x, n, /) → mpz`

Return a copy of x with the n-th bit inverted.

`gmpy2.bit_length(x, /) → int`

Return the number of significant bits in the radix-2 representation of x. Note: `bit_length(0)` returns 0.

`gmpy2.bit_mask(n, /) → mpz`

Return an `mpz` exactly n bits in length with all bits set.

`gmpy2.bit_scan0(x, n=0, /) → int | None`

Return the index of the first 0-bit of x with index $\geq n$. $n \geq 0$. If there are no more 0-bits in x at or above index n (which can only happen for $x < 0$, assuming an infinitely long 2's complement format), then `None` is returned.

`gmpy2.bit_scan1(x, n=0, /) → int | None`

Return the index of the first 1-bit of x with index $\geq n$. $n \geq 0$. If there are no more 1-bits in x at or above index n (which can only happen for $x \geq 0$, assuming an infinitely long 2's complement format), then `None` is returned.

`gmpy2.bit_set(x, n, /) → mpz`

Return a copy of x with the n-th bit set.

`gmpy2.bit_test(x, n, /) → bool`

Return the value of the n-th bit of x.

`gmpy2.c_div(x, y, /) → mpz`

Return the quotient of x divided by y. The quotient is rounded towards +Inf (ceiling rounding). x and y must be integers.

`gmpy2.c_div_2exp(x, n, /) → mpz`

Returns the quotient of x divided by $2^{**}n$. The quotient is rounded towards +Inf (ceiling rounding). x must be an integer. n must be > 0 .

`gmpy2.c_divmod(x, y, /) → tuple[mpz, mpz]`

Return the quotient and remainder of x divided by y. The quotient is rounded towards +Inf (ceiling rounding) and the remainder will have the opposite sign of y. x and y must be integers.

`gmpy2.c_divmod_2exp(x, n, /) → tuple[mpz, mpz]`

Return the quotient and remainder of x divided by $2^{**}n$. The quotient is rounded towards +Inf (ceiling rounding) and the remainder will be negative. x must be an integer. n must be > 0 .

`gmpy2.c_mod(x, y, /) → mpz`

Return the remainder of x divided by y. The remainder will have the opposite sign of y. x and y must be integers.

`gmpy2.c_mod_2exp(x, n, /) → mpz`

Return the remainder of x divided by $2^{**}n$. The remainder will be negative. x must be an integer. n must be > 0 .

`gmpy2.comb(n, k, /) → mpz`

Return the number of combinations of ‘n things, taking k at a time’. $k \geq 0$. Same as `bincoef(n, k)`

`gmpy2.divexact(x, y, /) → mpz`

Return the quotient of x divided by y. Faster than standard division but requires the remainder is zero!

`gmpy2.divm(a, b, m, /) → mpz`

Return x such that $b*x \equiv a \pmod{m}$. Raises a `ZeroDivisionError` exception if no such value x exists.

`gmpy2.double_fac(n, /) → mpz`

Return the exact double factorial ($n!!$) of n. The double factorial is defined as $n*(n-2)*(n-4)\dots$

`gmpy2.f_div(x, y, /) → mpz`

Return the quotient of x divided by y. The quotient is rounded towards -Inf (floor rounding). x and y must be integers.

`gmpy2.f_div_2exp(x, n, /) → mpz`

Return the quotient of x divided by $2**n$. The quotient is rounded towards -Inf (floor rounding). x must be an integer. n must be >0 .

`gmpy2.f_divmod(x, y, /) → tuple[mpz, mpz]`

Return the quotient and remainder of x divided by y. The quotient is rounded towards -Inf (floor rounding) and the remainder will have the same sign as y. x and y must be integers.

`gmpy2.f_divmod_2exp(x, n, /) → tuple[mpz, mpz]`

Return quotient and remainder after dividing x by $2**n$. The quotient is rounded towards -Inf (floor rounding) and the remainder will be positive. x must be an integer. n must be >0 .

`gmpy2.f_mod(x, y, /) → mpz`

Return the remainder of x divided by y. The remainder will have the same sign as y. x and y must be integers.

`gmpy2.f_mod_2exp(x, n, /) → mpz`

Return remainder of x divided by $2**n$. The remainder will be positive. x must be an integer. n must be >0 .

`gmpy2.fac(n, /) → mpz`

Return the exact factorial of n.

See `factorial(n)` to get the floating-point approximation.

`gmpy2.fib(n, /) → mpz`

Return the n-th Fibonacci number.

`gmpy2.fib2(n, /) → tuple[mpz, mpz]`

Return a 2-tuple with the (n-1)-th and n-th Fibonacci numbers.

`gmpy2.gcd(*integers, /) → mpz`

Return the greatest common divisor of integers.

`gmpy2.gcdext(a, b, /) → tuple[mpz, mpz, mpz]`

Return a 3-element tuple (g,s,t) such that $g = \gcd(a,b)$ and $g = a*s + b*t$.

`gmpy2.hamdist(x, y, /) → int`

Return the Hamming distance (number of bit-positions where the bits differ) between integers x and y.

`gmpy2.invert(x, m, /) → mpz`

Return y such that $x*y \equiv 1 \pmod{m}$. Raises `ZeroDivisionError` if no inverse exists.

`gmpy2.iroot(x, n, /) → tuple[mpz, bool]`

Return the integer n-th root of x and boolean value that is `True` iff the root is exact. $x \geq 0$. $n > 0$.

`gmpy2.iroot_rem(x, n, /) → tuple[mpz, mpz]`

Return a 2-element tuple (y,r), such that y is the integer n-th root of x and $x = y^n + r$. $x \geq 0$. $n > 0$.

`gmpy2.is_congruent(x, y, m, /) → bool`

Returns `True` if x is congruent to y modulo m, else return `False`.

`gmpy2.is_divisible(x, d, /) → bool`

Returns `True` if x is divisible by d, else return `False`.

`gmpy2.is_even(x, /) → bool`

Return `True` if x is even, `False` otherwise.

`gmpy2.is_odd(x, /) → bool`

Return `True` if x is odd, `False` otherwise.

`gmpy2.is_power(x, /) → bool`

Return `True` if x is a perfect power (there exists a y and an $n > 1$, such that $x = y^n$), else return `False`.

`gmpy2.is_prime(x, n=25, /) → bool`

Return `True` if x is *probably* prime, else `False` if x is definitely composite. x is checked for small divisors and up to n Miller-Rabin tests are performed.

`gmpy2.is_probab_prime(x, n=25, /) → int`

Return 2 if x is definitely prime, 1 if x is probably prime, or return 0 if x is definitely non-prime. x is checked for small divisors and up to n Miller-Rabin tests are performed. Reasonable values of n are between 15 and 50.

`gmpy2.is_square(x, /) → bool`

Returns `True` if x is a perfect square, else return `False`.

`gmpy2.isqrt(x, /) → mpz`

Return the integer square root of a non-negative integer x.

`gmpy2.isqrt_rem(x, /)`

Return a 2-element tuple (s,t) such that $s = \text{isqrt}(x)$ and $t = x - s^2$. $x \geq 0$.

`gmpy2.jacobi(x, y, /) → mpz`

Return the Jacobi symbol (x|y). y must be odd and > 0 .

`gmpy2.kronecker(x, y, /) → mpz`

Return the Kronecker-Jacobi symbol (x|y).

`gmpy2.lcm(*integers, /) → mpz`

Return the lowest common multiple of integers.

`gmpy2.legendre(x, y, /) → mpz`

Return the Legendre symbol (x|y). y is assumed to be an odd prime.

`gmpy2.lucas(n, /) → mpz`

Return the n-th Lucas number.

`gmpy2.lucas2(n, /) → tuple[mpz, mpz]`

Return a 2-tuple with the (n-1)-th and n-th Lucas numbers.

`gmpy2.mpz_random(random_state, int, /) → mpz`

Return uniformly distributed random integer between 0 and n-1.

`gmpy2.mpz_rrandomb(random_state, bit_count, /) → mpz`

Return a random integer between 0 and $2^{**}bit_count-1$ with long sequences of zeros and one in its binary representation.

`gmpy2.mpz_urandomb(random_state, bit_count, /) → mpz`

Return uniformly distributed random integer between 0 and $2^{**}bit_count-1$.

`gmpy2.multi_fac(n, m, /) → mpz`

Return the exact m-multi factorial of n. The m-multifactorial is defined as $n*(n-m)*(n-2m)\dots$

`gmpy2.next_prime(x, /) → mpz`

Return the next *probable* prime number $> x$.

`gmpy2.num_digits(x, base=10, /) → int`

Return length of string representing the absolute value of x in the given base. Values for base can range between 2 and 62. The value returned may be 1 too large.

`gmpy2.pack(lst, n, /) → mpz`

Pack a list of integers *lst* into a single *mpz* by concatenating each integer element of *lst* after padding to length *n* bits. Raises an error if any integer is negative or greater than *n* bits in length.

`gmpy2.popcount(x, /) → int`

Return the number of 1-bits set in *x*. If $x < 0$, the number of 1-bits is infinite so -1 is returned in that case.

`gmpy2.powmod(x, y, m, /) → mpz`

Return $(x**y) \bmod m$. Same as the three argument version of Python's built-in *pow*, but converts all three arguments to *mpz*.

`gmpy2.powmod_exp_list(base, exp_lst, mod, /) → list[mpz, ...]`

Returns $\text{list}(\text{powmod}(\text{base}, i, \text{mod}) \text{ for } i \text{ in } \text{exp_lst})$. Will always release the GIL. (Experimental in gmpy2 2.1.x).

`gmpy2.powmod_base_list(base_lst, exp, mod, /) → list[mpz, ...]`

Returns $\text{list}(\text{powmod}(i, \text{exp}, \text{mod}) \text{ for } i \text{ in } \text{base_lst})$. Will always release the GIL. (Experimental in gmpy2 2.1.x).

`gmpy2.powmod_sec(x, y, m, /) → mpz`

Return $(x**y) \bmod m$. Calculates $x ** y \bmod m$ but using a constant time algorithm to reduce the risk of side channel attacks. *y* must be an integer > 0 . *m* must be an odd integer.

`gmpy2.prev_prime(x, /) → mpz`

Return the previous *probable* prime number $< x$. Only present when compiled with GMP 6.3.0 or later.

`gmpy2.primorial(n, /) → mpz`

Return the product of all positive prime numbers less than or equal to *n*.

`gmpy2.remove(x, f, /) → tuple[mpz, mpz]`

Return a 2-element tuple (*y*, *m*) such that $x = y * (f**m)$ and *f* does not divide *y*. Remove the factor *f* from *x* as many times as possible. *m* is the multiplicity *f* in *x*. $f > 1$.

`gmpy2.t_div(x, y, /) → mpz`

Return the quotient of *x* divided by *y*. The quotient is rounded towards 0. *x* and *y* must be integers.

`gmpy2.t_div_2exp(x, n, /) → mpz`

Return the quotient of *x* divided by $2^{**}n$. The quotient is rounded towards zero (truncation). *n* must be > 0 .

`gmpy2.t_divmod(x, y, /) → tuple[mpz, mpz]`

Return the quotient and remainder of *x* divided by *y*. The quotient is rounded towards zero (truncation) and the remainder will have the same sign as *x*. *x* and *y* must be integers.

`gmpy2.t_divmod_2exp(x, n, /) → tuple[mpz, mpz]`

Return the quotient and remainder of `x` divided by `2**n`. The quotient is rounded towards zero (truncation) and the remainder will have the same sign as `x`. `x` must be an integer. `n` must be `>0`.

`gmpy2.t_mod(x, y, /) → mpz`

Return the remainder of `x` divided by `y`. The remainder will have the same sign as `x`. `x` and `y` must be integers.

`gmpy2.t_mod_2exp(x, n, /) → mpz`

Return the remainder of `x` divided by `2**n`. The remainder will have the same sign as `x`. `x` must be an integer. `n` must be `>0`.

`gmpy2.unpack(x, n, /) → list`

Unpack an integer `x` into a list of `n`-bit values. Equivalent to repeated division by `2**n`. Raises error if `x` is negative.

1.5 Integers (Advanced topics)

`gmpy2` provides access to an experimental integer type called `xmpz`. The `xmpz` type is a mutable integer type. In-place operations (`+=`, `//=`, etc.) modify the original object and do not create a new object. Instances of `xmpz` cannot be used as dictionary keys.

```
>>> from gmpy2 import xmpz
>>> a = xmpz(123)
>>> b = a
>>> a += 1
>>> a
xmpz(124)
>>> b
xmpz(124)
```

The ability to change an `xmpz` object in-place allows for efficient and rapid bit manipulation.

Individual bits can be set or cleared:

```
>>> a[10]=1
>>> a
xmpz(1148)
```

Slice notation is supported. The bits referenced by a slice can be either ‘read from’ or ‘written to’. To clear a slice of bits, use a source value of 0. In 2s-complement format, 0 is represented by an arbitrary number of 0-bits. To set a slice of bits, use a source value of `~0`. The *tilde* operator inverts, or complements the bits in an integer. (`~0` is `-1` so you can also use `-1`.) In 2s-complement format, `-1` is represented by an arbitrary number of 1-bits.

If a value for *stop* is specified in a slice assignment and the actual bit-length of the `xmpz` is less than *stop*, then the destination `xmpz` is logically padded with 0-bits to length *stop*.

```
>>> a=xmpz(0)
>>> a[8:16] = ~0
>>> bin(a)
'0b1111111100000000'
>>> a[4:12] = ~a[4:12]
>>> bin(a)
'0b1111000011110000'
```

Bits can be reversed:

```
>>> a = xmpz(1148)
>>> bin(a)
'0b10001111100'
>>> a[::-1] = a[::-1]
>>> bin(a)
'0b111110001'
```

The `iter_bits()` method returns a generator that returns True or False for each bit position. The methods `iter_clear()`, and `iter_set()` return generators that return the bit positions that are 1 or 0. The methods support arguments `start` and `stop` that define the beginning and ending bit positions that are used. To mimic the behavior of slices, the bit positions checked include `start` but the last position checked is `stop - 1`.

```
>>> a=xmpz(117)
>>> bin(a)
'0b1110101'
>>> list(a.iter_bits())
[True, False, True, False, True, True, True]
>>> list(a.iter_clear())
[1, 3]
>>> list(a.iter_set())
[0, 2, 4, 5, 6]
>>> list(a.iter_bits(stop=12))
[True, False, True, False, True, True, True, False, False, False, False, False]
```

The following program uses the Sieve of Eratosthenes to generate a list of prime numbers.

```
import time
import gmpy2

def sieve(limit=1000000):
    """Returns a generator that yields the prime numbers up to limit."""

    # Increment by 1 to account for the fact that slices do not include
    # the last index value but we do want to include the last value for
    # calculating a list of primes.
    sieve_limit = gmpy2.isqrt(limit) + 1
    limit += 1

    # Mark bit positions 0 and 1 as not prime.
    bitmap = gmpy2.xmpz(3)

    # Process 2 separately. This allows us to use p+p for the step size
    # when sieving the remaining primes.
    bitmap[4 : limit : 2] = -1

    # Sieve the remaining primes.
    for p in bitmap.iter_clear(3, sieve_limit):
        bitmap[p*p : limit : p+p] = -1

    return bitmap.iter_clear(2, limit)

if __name__ == "__main__":
    start = time.time()
```

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```
result = list(sieve())
print(time.time() - start)
print(len(result))
```

1.5.1 The `xmpz` type

class `gmpy2.xmpz(n=0, /)`

class `gmpy2.xmpz(s, /, base=0)`

Return a mutable integer constructed from a numeric value `n` or a string `s` made of digits in the given base. Every input, that is accepted by the `mpz` type constructor is also accepted.

Note: This type can be faster when used for augmented assignment (`+=`, `-=`, etc), but `xmpz` objects cannot be used as dictionary keys.

__format__(`fnt`) → `str`

Return a Python string by formatting `mpz` ‘`x`’ using the format string ‘`fnt`’. A valid format string consists of:

optional alignment code:

‘<’ -> left shifted in field ‘>’ -> right shifted in field ‘^’ -> centered in field

optional leading sign code:

‘+’ -> always display leading sign ‘-’ -> only display minus sign ‘ ’ -> minus for negative values, space for positive values

optional base indicator

‘#’ -> precede binary, octal, or hex with 0b, 0o or 0x

optional width

optional conversion code:

‘d’ -> decimal format ‘b’ -> binary format ‘o’ -> octal format ‘x’ -> hex format ‘X’ -> upper-case hex format

The default format is ‘d’.

bit_clear(`n, /`) → `mpz`

Return a copy of `x` with the `n`-th bit cleared.

bit_flip(`n, /`) → `mpz`

Return a copy of `x` with the `n`-th bit inverted.

bit_length() → `int`

Return the number of significant bits in the radix-2 representation of `x`. Note: `mpz(0).bit_length()` returns 0.

bit_scan0(`n=0, /`) → `int` | `None`

Return the index of the first 0-bit of `x` with index `>= n`. `n >= 0`. If there are no more 0-bits in `x` at or above index `n` (which can only happen for `x < 0`, assuming an infinitely long 2’s complement format), then `None` is returned.

bit_scan1(*n*=0, /) → int | None

Return the index of the first 1-bit of *x* with index $\geq n$. $n \geq 0$. If there are no more 1-bits in *x* at or above index *n* (which can only happen for $x \geq 0$, assuming an infinitely long 2's complement format), then **None** is returned.

bit_set(*n*, /) → mpz

Return a copy of *x* with the *n*-th bit set.

bit_test(*n*, /) → bool

Return the value of the *n*-th bit of *x*.

conjugate() → mpz

Return the conjugate of *x* (which is just a new reference to *x* since *x* is not a complex number).

copy() → xmpz

Return a copy of a *x*.

digits(*base*=10, /) → str

Return Python string representing *x* in the given base. Values for base can range between 2 to 62. A leading '-' is present if $x < 0$ but no leading '+' is present if $x \geq 0$.

iter_bits(*start*=0, *stop*=-1) → collections.abc.Iterator

Return **True** or **False** for each bit position in *x* beginning at 'start'. If a positive value is specified for 'stop', iteration is continued until 'stop' is reached. If a negative value is specified, iteration is continued until the last 1-bit. Note: the value of the underlying *xmpz* object can change during iteration.

iter_clear(*start*=0, *stop*=-1) → collections.abc.Iterator

Return every bit position that is clear in *x*, beginning at 'start'. If a positive value is specified for 'stop', iteration is continued until 'stop' is reached. If a negative value is specified, iteration is continued until the last 1-bit. Note: the value of the underlying *xmpz* object can change during iteration.

iter_set(*start*=0, *stop*=-1) → collections.abc.Iterator

Return an iterator yielding the bit position for every bit that is set in *x*, beginning at 'start'. If a positive value is specified for 'stop', iteration is continued until 'stop' is reached. To match the behavior of slicing, 'stop' is not included. If a negative value is specified, iteration is continued until the last 1-bit. Note: the value of the underlying *xmpz* object can change during iteration.

limbs_finish(*n*, /) → None

Must be called after writing to the address returned by *x*.limbs_write(*n*) or *x*.limbs_modify(*n*) to update the limbs of *x*.

limbs_modify(*n*, /) → int

Returns the address of a mutable buffer representing the limbs of *x*, resized so that it may hold at least *n* limbs. Must be followed by a call to *x*.limbs_finish(*n*) after writing to the returned address in order for the changes to take effect.

limbs_read() → int

Returns the address of the immutable buffer representing the limbs of *x*.

limbs_write(*n*, /) → int

Returns the address of a mutable buffer representing the limbs of *x*, resized so that it may hold at least *n* limbs. Must be followed by a call to *x*.limbs_finish(*n*) after writing to the returned address in order for the changes to take effect. WARNING: this operation is destructive and may destroy the old value of *x*.

make_mpz() → mpz

Return an *mpz* by converting *x* as quickly as possible.

NOTE: Optimized for speed so the original *xmpz* value is set to 0!

num_digits(base=10, /) → int

Return length of string representing the absolute value of x in the given base. Values for base can range between 2 and 62. The value returned may be 1 too large.

num_limbs() → int

Return the number of limbs of x.

denominator

the denominator of a rational number in lowest terms

numerator

the numerator of a rational number in lowest terms

real

the real part of a complex number

1.5.2 Advanced Number Theory Functions

The following functions are based on mpz_lucas.c and mpz_prp.c by David Cleaver.

A good reference for probable prime testing is <http://www.pseudoprime.com/pseudo.html>

gmpy2.is_bpsw_prp(n, /) → bool

Return **True** if n is a Baillie-Pomerance-Selfridge-Wagstaff probable prime. A BPSW probable prime passes the **is_strong_prp()** test with base 2 and the **is_selfridge_prp()** test.

gmpy2.is_euler_prp(n, a, /) → bool

Return **True** if n is an Euler (also known as Solovay-Strassen) probable prime to the base a. Assuming:

$\gcd(n, a) == 1$ n is odd

Then an Euler probable prime requires:

$a^{((n-1)/2)} == (a/n) \pmod n$

where (a/n) is the Jacobi symbol.

gmpy2.is_extra_strong_lucas_prp(n, p, /) → bool

Return **True** if n is an extra strong Lucas probable prime with parameters (p,1). Assuming:

n is odd $D = p^2 - 4$, $D \neq 0$ $\gcd(n, 2*D) == 1$ $n = s*(2^{**r}) + \text{Jacobi}(D, n)$, s odd

Then an extra strong Lucas probable prime requires:

$\text{lucasu}(p, 1, s) == 0 \pmod n$ and $\text{lucasv}(p, 1, s) == \pm 2 \pmod n$ or $\text{lucasv}(p, 1, s*(2^{**t})) == 0 \pmod n$
for some t, $0 \leq t < r$

gmpy2.is_fermat_prp(n, a, /) → bool

Return **True** if n is a Fermat probable prime to the base a. Assuming:

$\gcd(n, a) == 1$

Then a Fermat probable prime requires:

$a^{(n-1)} == 1 \pmod n$

gmpy2.is_fibonacci_prp(n, p, q, /) → bool

Return **True** if n is a Fibonacci probable prime with parameters (p,q). Assuming:

n is odd $p > 0$, $q = \pm 1$ $p^2 - 4*q \neq 0$

Then a Fibonacci probable prime requires:

$\text{lucasv}(p, q, n) == p \pmod n$.

`gmpy2.is_lucas_prp(n, p, q, /) → bool`

Return **True** if n is a Lucas probable prime with parameters (p, q) . Assuming:

n is odd $D = p^2 - 4q$, $D \neq 0$ $\gcd(n, 2qD) == 1$

Then a Lucas probable prime requires:

$\text{lucasu}(p, q, n - \text{Jacobi}(D, n)) == 0 \pmod n$

`gmpy2.is_selfridge_prp(n, /) → bool`

Return **True** if n is a Lucas probable prime with Selfridge parameters (p, q) . The Selfridge parameters are chosen by finding the first element D in the sequence $\{5, -7, 9, -11, 13, \dots\}$ such that $\text{Jacobi}(D, n) == -1$. Then let $p=1$ and $q = (1-D)/4$. Then perform a Lucas probable prime test.

`gmpy2.is_strong_bpsw_prp(n, /) → bool`

Return **True** if n is a strong Baillie-Pomerance-Selfridge-Wagstaff probable prime. A strong BPSW probable prime passes the `is_strong_prp()` test with base and the `is_strong_selfridge_prp()` test.

`gmpy2.is_strong_lucas_prp(n, p, q, /) → bool`

Return **True** if n is a strong Lucas probable prime with parameters (p, q) . Assuming:

n is odd $D = p^2 - 4q$, $D \neq 0$ $\gcd(n, 2qD) == 1$ $n = s(2^r) + \text{Jacobi}(D, n)$, s odd

Then a strong Lucas probable prime requires:

$\text{lucasu}(p, q, s) == 0 \pmod n$ or $\text{lucasv}(p, q, s(2^t)) == 0 \pmod n$ for some t , $0 \leq t < r$

`gmpy2.is_strong_prp(n, a, /) → bool`

Return **True** if n is a strong (also known as Miller-Rabin) probable prime to the base a . Assuming:

$\gcd(n, a) == 1$ n is odd $n = s(2^r) + 1$, with s odd

Then a strong probable prime requires one of the following is true:

$a^s \equiv 1 \pmod n$ or $a^{s(2^t)} \equiv -1 \pmod n$ for some t , $0 \leq t < r$.

`gmpy2.is_strong_selfridge_prp(n, /) → bool`

Return **True** if n is a strong Lucas probable prime with Selfridge parameters (p, q) . The Selfridge parameters are chosen by finding the first element D in the sequence $\{5, -7, 9, -11, 13, \dots\}$ such that $\text{Jacobi}(D, n) == -1$. Then let $p=1$ and $q = (1-D)/4$. Then perform a strong Lucas probable prime test.

`gmpy2.lucasu(p, q, k, /) → mpz`

Return the k -th element of the Lucas U sequence defined by p, q . $p^2 - 4q$ must not equal 0; k must be greater than or equal to 0.

`gmpy2.lucasu_mod(p, q, k, n, /) → mpz`

Return the k -th element of the Lucas U sequence defined by $p, q \pmod n$. $p^2 - 4q$ must not equal 0; k must be greater than or equal to 0; n must be greater than 0.

`gmpy2.lucasv(p, q, k, /) → mpz`

Return the k -th element of the Lucas V sequence defined by p, q . $p^2 - 4q$ must not equal 0; k must be greater than or equal to 0.

`gmpy2.lucasv_mod(p, q, k, n, /) → mpz`

Return the k -th element of the Lucas V sequence defined by $p, q \pmod n$. $p^2 - 4q$ must not equal 0; k must be greater than or equal to 0; n must be greater than 0.

1.6 Rationals

1.6.1 mpq type

class gmpy2.**mpq**(*n=0, /*)

class gmpy2.**mpq**(*n, m, /*)

class gmpy2.**mpq**(*s, /, base=10*)

Return a rational number constructed from a non-complex number *n* exactly or from a pair of [Rational](#) values *n* and *m* or from a string *s* made up of digits in the given base. Every input, that is accepted by the [Fraction](#) type constructor is also accepted.

A string may be made up to two integers in the same base separated by a `'/'` character, both parsed the same as the [mpz](#) type constructor does. If base is 0 then the leading characters are used to recognize the base, this is done separately for the numerator and denominator. If base=10, any string that represents a finite value and is accepted by the [float](#) constructor is also accepted.

as_integer_ratio() \rightarrow tuple[[mpz](#), [mpz](#)]

Return a pair of integers, whose ratio is exactly equal to the original number. The ratio is in lowest terms and has a positive denominator.

conjugate() \rightarrow [mpz](#)

Return the conjugate of *x* (which is just a new reference to *x* since *x* is not a complex number).

digits(*base=10, /*) \rightarrow str

Return a Python string representing *x* in the given base (2 to 62, default is 10). A leading `'-'` is present if *x*<0, but no leading `'+'` is present if *x*>=0.

from_decimal(*dec, /*) \rightarrow [mpq](#)

Converts a finite [decimal.Decimal](#) instance to a rational number, exactly.

from_float(*f, /*) \rightarrow [mpq](#)

Converts a finite float to a rational number, exactly.

denominator

the denominator of a rational number in lowest terms

imag

the imaginary part of a complex number

numerator

the numerator of a rational number in lowest terms

real

the real part of a complex number

1.6.2 mpq Functions

gmpy2.**qdiv**(*x, y=l, /*) \rightarrow [mpz](#) | [mpq](#)

Return *x/y* as [mpz](#) if possible, or as [mpq](#) if *x* is not exactly divisible by *y*.

1.7 Contexts

`context()` creates a new context. `set_context()` will set the active context. `get_context()` will return a reference to the active context. Note that contexts are mutable: modifying the reference returned by `get_context()` will modify the active context until a new context is enabled with `set_context()`. The `context.copy()` method will return a copy of the context. Contexts that implement the standard *single*, *double*, and *quadruple* precision floating point types can be created using `ieee()`.

1.7.1 Context Type

```
class gmpy2.context(**kwargs)
```

```
class gmpy2.context(ctx, /, **kwargs)
```

Return a new context for controlling gmpy2 arithmetic, based either on the default context or on a given by ctx value. Context options additionally can be overridden by keyword arguments.

abs(x, /) → *mpz* | *mpq* | *mpfr*

Return abs(x), the context is applied to the result.

acos(x, /) → *mpfr* | *mpc*

Return inverse cosine of x; result in radians.

acosh(x, /) → *mpfr* | *mpc*

Return inverse hyperbolic cosine of x.

add(x, y, /) → *mpz* | *mpq* | *mpfr* | *mpc*

Return x + y.

agm(x, y, /) → *mpfr*

Return arithmetic-geometric mean of x and y.

ai(x, /) → *mpfr*

Return Airy function of x.

asin(x, /) → *mpfr* | *mpc*

Return inverse sine of x; result in radians.

asinh(x, /) → *mpfr* | *mpc*

Return inverse hyperbolic sine of x.

atan(x, /) → *mpfr* | *mpc*

Return inverse tangent of x; result in radians.

atan2(y, x, /) → *mpfr*

Return arc-tangent of (y/x); result in radians.

atanh(x, /) → *mpfr* | *mpc*

Return inverse hyperbolic tangent of x.

cbrt(x, /) → *mpfr*

Return the cube root of x.

ceil(x, /) → *mpfr*

Return an *mpfr* that is the smallest integer >= x.

check_range(*x*, /) → *mpfr*

Return a new *mpfr* with exponent that lies within the range of *emin* and *emax* specified by context.

clear_flags() → *None*

Clear all MPFR exception flags.

const_catalan() → *mpfr*

Return the catalan constant using the context's precision.

const_euler() → *mpfr*

Return the euler constant using the context's precision.

const_log2() → *mpfr*

Return the log2 constant using the context's precision.

const_pi() → *mpfr*

Return the constant pi using the context's precision.

copy() → *context*

Return a copy of a context.

cos(*x*, /) → *mpfr* | *mpc*

Return cosine of *x*; *x* in radians.

cosh(*x*, /) → *mpfr* | *mpc*

Return hyperbolic cosine of *x*.

cot(*x*, /) → *mpfr*

Return cotangent of *x*; *x* in radians.

coth(*x*, /) → *mpfr*

Return hyperbolic cotangent of *x*.

csc(*x*, /) → *mpfr*

Return cosecant of *x*; *x* in radians.

csch(*x*, /) → *mpfr*

Return hyperbolic cosecant of *x*.

degrees(*x*, /) → *mpfr*

Convert angle *x* from radians to degrees. Note: In rare cases the result may not be correctly rounded.

digamma(*x*, /) → *mpfr*

Return digamma of *x*.

div(*x*, *y*, /) → *mpz* | *mpq* | *mpfr* | *mpc*

Return *x* / *y*; uses true division.

div_2exp(*x*, *n*, /) → *mpfr* | *mpc*

Return *mpfr* or *mpc* divided by 2^{**n} .

divmod(*x*, *y*, /) → tuple[*mpz* | *mpfr*, *mpz* | *mpq* | *mpfr*]

Return divmod(*x*, *y*).

Note: overflow, underflow, and inexact exceptions are not supported for *mpfr* arguments.

eint(*x*, /) → *mpfr*

Return exponential integral of *x*.

erf(*x*, /) → *mpfr*
 Return error function of *x*.

erfc(*x*, /) → *mpfr*
 Return complementary error function of *x*.

exp(*x*, /) → *mpfr* | *mpc*
 Return the exponential of *x*.

exp10(*x*, /) → *mpfr*
 Return 10^{**x} .

exp2(*x*, /) → *mpfr*
 Return 2^{**x} .

expm1(*x*, /) → *mpfr*
 Return $\exp(x) - 1$.

factorial(*n*, /) → *mpfr*
 Return the floating-point approximation to the factorial of *n*.
 See [fac\(\)](#) to get the exact integer result.

floor(*x*, /) → *mpfr*
 Return an *mpfr* that is the largest integer $\leq x$.

floor_div(*x*, *y*, /) → *mpz* | *mpfr*
 Return $x // y$; uses floor division.

fma(*x*, *y*, *z*, /) → *mpz* | *mpq* | *mpfr* | *mpc*
 Return correctly rounded result of $(x * y) + z$.

fmma(*x*, *y*, *z*, *t*, /) → *mpfr*
 Return correctly rounded result of $(x * y) + (z * t)$.

fms(*x*, *y*, *z*, *t*, /) → *mpfr*
 Return correctly rounded result of $(x * y) - (z * t)$.

fmod(*x*, *y*, /) → *mpfr*
 Return $x - n*y$ where *n* is the integer quotient of x/y , rounded to 0.

fms(*x*, *y*, *z*, /) → *mpz* | *mpq* | *mpfr* | *mpc*
 Return correctly rounded result of $(x * y) - z$.

frac(*x*, /) → *mpfr*
 Return fractional part of *x*.

frexp(*x*, /) → tuple[int, *mpfr*]
 Return a tuple containing the exponent and mantissa of *x*.

fsum(*iterable*, /) → *mpfr*
 Return an accurate sum of the values in the iterable.

gamma(*x*, /) → *mpfr*
 Return gamma of *x*.

gamma_inc(*a*, *x*, /) → *mpfr*
 Return (upper) incomplete gamma of *a* and *x*.

hypot(x, y, /) → *mpfr*

Return square root of $(x**2 + y**2)$.

is_finite(x, /) → *bool*

Return *True* if x is an actual number (i.e. non NaN or Infinity). If x is an *mpc*, return *True* if both x.real and x.imag are finite.

is_infinite(x, /) → *bool*

Return *True* if x is +Infinity or -Infinity. If x is an *mpc*, return *True* if either x.real or x.imag is infinite. Otherwise return *False*.

is_integer(x, /) → *bool*

Return *True* if x is an integer; *False* otherwise.

is_nan(x, /) → *bool*

Return *True* if x is NaN (Not-A-Number) else *False*.

is_regular(x, /) → *bool*

Return *True* if x is not zero, NaN, or Infinity; *False* otherwise.

is_signed(x, /) → *bool*

Return *True* if the sign bit of x is set.

is_zero(x, /) → *bool*

Return *True* if x is equal to 0. If x is an *mpc*, return *True* if both x.real and x.imag are equal to 0.

j0(x, /) → *mpfr*

Return first kind Bessel function of order 0 of x.

j1(x, /) → *mpfr*

Return first kind Bessel function of order 1 of x.

jn(n, x, /) → *mpfr*

Return the first kind Bessel function of order n of x. Note: the order of the arguments changed in gmpy2 2.2.0a2

lgamma(x, /) → *tuple*[*mpfr*, *int*]

Return a *tuple* containing the logarithm of the absolute value of gamma(x) and the sign of gamma(x)

li2(x, /) → *mpfr*

Return real part of dilogarithm of x.

lngamma(x, /) → *mpfr*

Return natural logarithm of gamma(x).

log(x, /) → *mpfr* | *mpc*

Return the natural logarithm of x.

log10(x, /) → *mpfr* | *mpc*

Return the base-10 logarithm of x.

log1p(x, /) → *mpfr*

Return natural logarithm of (1+x).

log2(x, /) → *mpfr*

Return base-2 logarithm of x.

maxnum(x, y, /) → *mpfr*

Return the maximum number of x and y. If x and y are not *mpfr*, they are converted to *mpfr*. The result is rounded to match the specified context. If only one of x or y is a number, then that number is returned.

minnum(x, y, /) → *mpfr*

Return the minimum number of x and y. If x and y are not *mpfr*, they are converted to *mpfr*. The result is rounded to match the specified context. If only one of x or y is a number, then that number is returned.

minus(x, /) → *mpz* | *mpq* | *mpfr* | *mpc*

Return -x. The context is applied to the result.

mod(x, y, /) → *mpz* | *mpq* | *mpfr*

Return mod(x, y). Note: overflow, underflow, and inexact exceptions are not supported for *mpfr* arguments.

modf(x, /) → tuple[*mpfr*, *mpfr*]

Return a tuple containing the integer and fractional portions of x.

mul(x, y, /) → *mpz* | *mpq* | *mpfr* | *mpc*

Return x * y.

mul_2exp(x, n, /) → *mpfr* | *mpc*

Return *mpfr* or *mpc* multiplied by 2**n.

next_above(x, /) → *mpfr*

Return the next *mpfr* from x toward +Infinity.

next_below(x, /) → *mpfr*

Return the next *mpfr* from x toward -Infinity.

next_toward(x, y, /) → *mpfr*

Return the next *mpfr* from x in the direction of y. The result has the same precision as x.

norm(x, /) → *mpfr*

Return the norm of a complex x. The norm(x) is defined as x.real**2 + x.imag**2. abs(x) is the square root of norm(x).

phase(x, /) → *mpfr*

Return the phase angle, also known as argument, of a complex x.

plus(x, /) → *mpz* | *mpq* | *mpfr* | *mpc*

Return +x, the context is applied to the result.

polar(x, /) → tuple[*mpfr*, *mpfr*]

Return the polar coordinate form of a complex x that is in rectangular form.

pow(x, y, /) → *mpz* | *mpq* | *mpfr* | *mpc*

Return x ** y.

proj(x, /) → *mpc*

Returns the projection of a complex x on to the Riemann sphere.

radians(x, /) → *mpfr*

Convert angle x from degrees to radians. Note: In rare cases the result may not be correctly rounded.

rec_sqrt(x, /) → *mpfr*

Return the reciprocal of the square root of x.

rect(*r*, *phi*, /) → *mpc*

Return the rectangular coordinate form of a complex number that is given in polar form.

reldiff(*x*, *y*, /) → *mpfr*

Return the relative difference between *x* and *y*. Result is equal to $\text{abs}(x-y)/x$.

remainder(*x*, *y*, /) → *mpfr*

Return $x - n*y$ where *n* is the integer quotient of x/y , rounded to the nearest integer and ties rounded to even.

remquo(*x*, *y*, /) → *tuple*[*mpfr*, *int*]

Return a *tuple* containing the remainder(*x*,*y*) and the low bits of the quotient.

rint(*x*, /) → *mpfr*

Return *x* rounded to the nearest integer using the context rounding mode.

rint_ceil(*x*, /) → *mpfr*

Return *x* rounded to the nearest integer by first rounding to the next higher or equal integer and then, if needed, using the context rounding mode.

rint_floor(*x*, /) → *mpfr*

Return *x* rounded to the nearest integer by first rounding to the next lower or equal integer and then, if needed, using the context rounding mode.

rint_round(*x*, /) → *mpfr*

Return *x* rounded to the nearest integer by first rounding to the nearest integer (ties away from 0) and then, if needed, using the context rounding mode.

rint_trunc(*x*, /) → *mpfr*

Return *x* rounded to the nearest integer by first rounding towards zero and then, if needed, using the context rounding mode.

root(*x*, *n*, /) → *mpfr*

Return *n*-th root of *x*. The result always an *mpfr*. Note: not IEEE 754-2008 compliant; result differs when $x = -0$ and *n* is even. See `context.rootn()`.

root_of_unity(*n*, *k*, /) → *mpc*

Return the *n*-th root of $\text{mpc}(1)$ raised to the *k*-th power..

rootn(*x*, *n*, /) → *mpfr*

Return *n*-th root of *x*. The result always an *mpfr*. Note: this is IEEE 754-2008 compliant version of `context.root()`.

round2(*x*, *n=0*, /) → *mpfr*

Return *x* rounded to *n* bits. Uses default precision if *n* is not specified. See `context.round_away()` to access the `mpfr_round()` function of the MPFR.

round_away(*x*, /) → *mpfr*

Return an *mpfr* that is *x* rounded to the nearest integer, with ties rounded away from 0.

sec(*x*, /) → *mpfr*

Return secant of *x*; *x* in radians.

sech(*x*, /) → *mpfr*

Return hyperbolic secant of *x*.

sin(*x*, /) → *mpfr* | *mpc*

Return sine of *x*; *x* in radians.

sin_cos(x, /) → tuple[mpfr | mpc, mpfr | mpc]

Return a tuple containing the sine and cosine of x; x in radians.

sinh(x, /) → mpfr | mpc

Return hyperbolic sine of x.

sinh_cosh(x, /) → tuple[mpfr, mpfr]

Return a tuple containing the hyperbolic sine and cosine of x.

sqrt(x, /) → mpfr | mpc

Return the square root of x.

square(x, /) → mpz | mpq | mpfr | mpc

Return $x * x$.

sub(x, y, /) → mpz | mpq | mpfr | mpc

Return $x - y$.

tan(x, /) → mpfr | mpc

Return tangent of x; x in radians.

tanh(x, /) → mpfr | mpc

Return hyperbolic tangent of x.

trunc(x, /) → mpfr

Return an mpfr that is x truncated towards 0. Same as x.floor() if $x \geq 0$ or x.ceil() if $x < 0$.

y0(x, /) → mpfr

Return second kind Bessel function of order 0 of x.

y1(x, /) → mpfr

Return second kind Bessel function of order 1 of x.

yn(n, x, /) → mpfr

Return the second kind Bessel function of order n of x. Note: the order of the arguments changed in gmpy2 2.2.0a2

zeta(x, /) → mpfr

Return Riemann zeta of x.

allow_complex

This attribute controls whether or not an mpc result can be returned if an mpfr result would normally not be possible.

allow_release_gil

If set to True, many mpz and mpq computations will release the GIL.

This is considered an experimental feature.

divzero

This flag is not user controllable. It is automatically set if a division by zero occurred and NaN result was returned.

emax

This attribute controls the maximum allowed exponent of an mpfr result. The maximum exponent is platform dependent and can be retrieved with get_emax_max().

emin

This attribute controls the minimum allowed exponent of an *mpfr* result. The minimum exponent is platform dependent and can be retrieved with *get_emin_min()*.

erange

This flag is not user controllable. It is automatically set if an erange error occurred.

imag_prec

This attribute controls the precision of the imaginary part of an *mpc* result. If the value is Default, then the value of *real_prec* is used.

imag_round

This attribute controls the rounding mode for the imaginary part of an *mpc* result. If the value is Default, then the value of the *real_round* attribute is used. Note: RoundAwayZero is not a valid rounding mode for *mpc*.

inexact

This flag is not user controllable. It is automatically set if an inexact result is returned.

invalid

This flag is not user controllable. It is automatically set if an invalid (Not-A-Number) result is returned.

overflow

This flag is not user controllable. It is automatically set if a result overflowed to +/-Infinity and *trap_overflow* is *False*.

precision

This attribute controls the precision of an *mpfr* result. The precision is specified in bits, not decimal digits. The maximum precision that can be specified is platform dependent and can be retrieved with *get_max_precision()*.

Note: Specifying a value for precision that is too close to the maximum precision will cause the MPFR library to fail.

rational_division

If set to *True*, *mpz* / *mpz* will return an *mpq* instead of an *mpfr*.

real_prec

This attribute controls the precision of the real part of an *mpc* result. If the value is Default, then the value of the *precision* attribute is used.

real_round

This attribute controls the rounding mode for the real part of an *mpc* result. If the value is Default, then the value of the round attribute is used. Note: RoundAwayZero is not a valid rounding mode for *mpc*.

round

There are five rounding modes available to *mpfr* type:

- RoundAwayZero - The result is rounded away from 0.0.
- RoundDown - The result is rounded towards -Infinity.
- RoundToNearest - Round to the nearest value; ties are rounded to an even value.
- RoundToZero - The result is rounded towards 0.0.
- RoundUp - The result is rounded towards +Infinity.

subnormalize

The usual IEEE-754 floating point representation supports gradual underflow when the minimum exponent is reached. The MFPR library does not enable gradual underflow by default but it can be enabled to precisely mimic the results of IEEE-754 floating point operations.

trap_divzero

This attribute controls whether or not a *DivisionByZeroError* exception is raised if division by 0 occurs. The *DivisionByZeroError* is a sub-class of Python's *ZeroDivisionError*.

trap_erange

This attribute controls whether or not a *RangeError* exception is raised when certain operations are performed on NaN and/or Infinity values. Setting *trap_erange* to *True* can be used to raise an exception if comparisons are attempted with a NaN.

trap_inexact

This attribute controls whether or not an *InexactResultError* exception is raised if an inexact result is returned. To check if the result is greater or less than the exact result, check the *rc* attribute of the *mpfr* result.

trap_invalid

This attribute controls whether or not an *InvalidOperationError* exception is raised if a numerical result is not defined. A special NaN (Not-A-Number) value will be returned if an exception is not raised. The *InvalidOperationError* is a sub-class of Python's *ValueError*.

For example, `gmpy2.sqrt(-2)` will normally return `mpfr('nan')`. However, if *allow_complex* is set to *True*, then an *mpc* result will be returned.

trap_overflow

If set to *False*, a result that is larger than the largest possible *mpfr* given the current exponent range will be replaced by +/-Infinity. If set to *True*, an *OverflowResultError* exception is raised.

trap_underflow

If set to *False*, a result that is smaller than the smallest possible *mpfr* given the current exponent range will be replaced by +/-0.0. If set to *True*, an *UnderflowResultError* exception is raised.

underflow

This flag is not user controllable. It is automatically set if a result underflowed to +/-0.0 and *trap_underflow* is *False*.

1.7.2 Context Functions

`gmpy2.get_context()` → *context*

Return a reference to the current context.

`gmpy2.ieee(size, /, subnormalize=True)` → *context*

Return a new context corresponding to a standard IEEE floating point format. The supported sizes are 16, 32, 64, 128, and multiples of 32 greater than 128.

`gmpy2.local_context(**kwargs)` → *context*

`gmpy2.local_context(context, /, **kwargs)` → *context*

Return a new context for controlling gmpy2 arithmetic, based either on the current context or on a ctx value. Context options additionally can be overridden by keyword arguments.

`gmpy2.set_context(context, /)` → *None*

Activate a context object controlling gmpy2 arithmetic.

1.8 Exceptions

`exception gmpy2.RangeError`

`exception gmpy2.InexactResultError`

`exception gmpy2.OverflowResultError`

`exception gmpy2.UnderflowResultError`

`exception gmpy2.InvalidOperationError`

`exception gmpy2.DivisionByZeroError`

1.9 Multiple-precision Reals

1.9.1 mpfr Type

`class gmpy2.mpfr(n=0, /, precision=0)`

`class gmpy2.mpfr(n, /, precision, context)`

`class gmpy2.mpfr(s, /, precision=0, base=0)`

`class gmpy2.mpfr(s, /, precision, base, context)`

Return a floating-point number after converting a numeric value `n` or a string `s` made of digits in the given base.

A string can be with fraction-part (with a period as a separator) and/or exponent-part with an exponent marker ‘e’ or ‘E’ for bases up to 10, else ‘@’ in any base. In bases 2 and 16, the exponent prefix can also be ‘p’ or ‘P’, in which case the exponent indicates a multiplication by a power of 2 instead of the base. The value of an exponent is always written in base 10. The fractional-part digits are parsed the same as the `mpz` type constructor does and both the whole number and exponent-part optionally can be preceded by ‘+’ or ‘-’. Every input, accepted by the `float` type constructor or the `float.fromhex` method is also accepted.

If a precision greater than or equal to 2 is specified, then it is used. A precision of 0 (the default) implies the precision of either the specified context or the current context is used. A precision of 1 minimizes the loss of precision by following these rules:

- 1) If `n` is a radix-2 floating point number, then the full precision of `n` is retained.
- 2) If `n` is an integer, then the precision is the bit length of the integer.

`__format__(fmt) → str`

Return a Python string by formatting ‘x’ using the format string ‘fmt’. A valid format string consists of:

optional alignment code:

‘<’ -> left shifted in field ‘>’ -> right shifted in field ‘^’ -> centered in field

optional leading sign code

‘+’ -> always display leading sign ‘-’ -> only display minus for negative values ‘ ‘ -> minus for negative values, space for positive values

optional width.precision

optional rounding mode:

‘U’ -> round toward plus Infinity ‘D’ -> round toward minus Infinity ‘Y’ -> round away from zero ‘Z’ -> round toward zero ‘N’ -> round to nearest

optional conversion code:

‘a’, ‘A’ -> hex format ‘b’ -> binary format ‘e’, ‘E’ -> scientific format ‘f’, ‘F’ -> fixed point
format ‘g’, ‘G’ -> fixed or float format

The default format is ‘.6f’.

as_integer_ratio() → tuple[mpz, mpz]

Return the exact rational equivalent of an *mpfr*. Value is a tuple for compatibility with Python’s *float*.
as_integer_ratio.

as_mantissa_exp() → tuple[mpz, mpz]

Return the mantissa and exponent of an *mpfr*.

as_simple_fraction(precision=0) → mpq

Return a simple rational approximation to x. The result will be accurate to ‘precision’ bits. If ‘precision’ is 0, the precision of ‘x’ will be used.

conjugate() → mpz

Return the conjugate of x (which is just a new reference to x since x is not a complex number).

digits(base=10, prec=0, /) → tuple[str, int, int]

Returns up to ‘prec’ digits in the given base. If ‘prec’ is 0, as many digits that are available are returned. No more digits than available given x’s precision are returned. ‘base’ must be between 2 and 62, inclusive. The result is a three element tuple containing the mantissa, the exponent, and the number of bits of precision.

is_finite() → bool

Return *True* if x is an actual number (i.e. non NaN or Infinity). If x is an *mpc*, return *True* if both x.real and x.imag are finite.

is_infinite() → bool

Return *True* if x is +Infinity or -Infinity. If x is an *mpc*, return *True* if either x.real or x.imag is infinite. Otherwise return *False*.

is_integer() → bool

Return *True* if x is an integer; *False* otherwise.

is_nan() → bool

Return *True* if x is NaN (Not-A-Number) else *False*.

is_regular() → bool

Return *True* if x is not zero, NaN, or Infinity; *False* otherwise.

is_signed() → bool

Return *True* if the sign bit of x is set.

is_zero() → bool

Return *True* if x is equal to 0. If x is an *mpc*, return *True* if both x.real and x.imag are equal to 0.

imag

imaginary component

precision

precision in bits

rc

return code

real

real component

1.9.2 mpfr Functions

`gmpy2.agm(x, y, /) → mpfr`

Return arithmetic-geometric mean of x and y.

`gmpy2.ai(x, /) → mpfr`

Return Airy function of x.

`gmpy2.atan2(y, x, /) → mpfr`

Return arc-tangent of (y/x); result in radians.

`gmpy2.cbrt(x, /) → mpfr`

Return the cube root of x.

`gmpy2.ceil(x, /) → mpfr`

Return an 'mpfr' that is the smallest integer $\geq x$.

`gmpy2.check_range(x, /) → mpfr`

Return a new *mpfr* with exponent that lies within the current range of emin and emax.

`gmpy2.cmp(x, y, /) → int`

Return -1 if $x < y$; 0 if $x = y$; or 1 if $x > y$. Both x and y must be integer, rational or real. Note: 0 is returned (and exception flag set) if either argument is NaN.

`gmpy2.const_catalan(precision=0) → mpfr`

Return the catalan constant using the specified precision. If no precision is specified, the default precision is used.

`gmpy2.const_euler(precision=0) → mpfr`

Return the euler constant using the specified precision. If no precision is specified, the default precision is used.

`gmpy2.const_log2(precision=0) → mpfr`

Return the log2 constant using the specified precision. If no precision is specified, the default precision is used.

`gmpy2.const_pi(precision=0) → mpfr`

Return the constant pi using the specified precision. If no precision is specified, the default precision is used.

`gmpy2.cot(x, /) → mpfr`

Return cotangent of x; x in radians.

`gmpy2.coth(x, /) → mpfr`

Return hyperbolic cotangent of x.

`gmpy2.csc(x, /) → mpfr`

Return cosecant of x; x in radians.

`gmpy2.csch(x, /) → mpfr`

Return hyperbolic cosecant of x.

`gmpy2.degrees(x, /) → mpfr`

Convert angle x from radians to degrees. Note: In rare cases the result may not be correctly rounded.

`gmpy2.digamma(x, /) → mpfr`

Return digamma of x.

`gmpy2.eint(x, /) → mpfr`

Return exponential integral of x.

`gmpy2.erf(x, /) → mpfr`

Return error function of x.

`gmpy2.erfc(x, /) → mpfr`

Return complementary error function of x.

`gmpy2.exp10(x, /) → mpfr`

Return $10^{**}x$.

`gmpy2.exp2(x, /) → mpfr`

Return $2^{**}x$.

`gmpy2.expm1(x, /) → mpfr`

Return $\exp(x) - 1$.

`gmpy2.factorial(n, /) → mpfr`

Return the floating-point approximation to the factorial of n.

See `fac()` to get the exact integer result.

`gmpy2.floor(x, /) → mpfr`

Return an `mpfr` that is the largest integer $\leq x$.

`gmpy2.fmma(x, y, z, t, /) → mpfr`

Return correctly rounded result of $(x * y) + (z + t)$.

`gmpy2.fmms(x, y, z, t, /) → mpfr`

Return correctly rounded result of $(x * y) - (z + t)$.

`gmpy2.fmod(x, y, /) → mpfr`

Return $x - n*y$ where n is the integer quotient of x/y , rounded to 0.

`gmpy2.frac(x, /) → mpfr`

Return fractional part of x.

`gmpy2.frexp(x, /) → tuple[int, mpfr]`

Return a `tuple` containing the exponent and mantissa of x.

`gmpy2.fsum(iterable, /) → mpfr`

Return an accurate sum of the values in the iterable.

`gmpy2.gamma(x, /) → mpfr`

Return gamma of x.

`gmpy2.gamma_inc(a, x, /) → mpfr`

Return (upper) incomplete gamma of a and x.

`gmpy2.get_exp(x, /) → int`

Return the exponent of x. Returns 0 for NaN or Infinity and sets the `context.erange` flag of the current context and will raise an exception if `context.trap_erange` is set.

`gmpy2.hypot(x, y, /) → mpfr`

Return square root of $(x^{**}2 + y^{**}2)$.

`gmpy2.inf(n, /) → mpfr`

Return an `mpfr` initialized to Infinity with the same sign as n. If n is not given, +Infinity is returned.

`gmpy2.is_finite(x, /) → bool`

Return `True` if `x` is an actual number (i.e. non NaN or Infinity). If `x` is an `mpc`, return `True` if both `x.real` and `x.imag` are finite.

`gmpy2.is_infinite(x, /) → bool`

Return `True` if `x` is +Infinity or -Infinity. If `x` is an `mpc`, return `True` if either `x.real` or `x.imag` is infinite. Otherwise return `False`.

`gmpy2.is_regular(x, /) → bool`

Return `True` if `x` is not zero, NaN, or Infinity; `False` otherwise.

`gmpy2.is_signed(x, /) → bool`

Return `True` if the sign bit of `x` is set.

`gmpy2.is_unordered(x, y, /) → bool`

Return `True` if either `x` and/or `y` is NaN.

`gmpy2.j0(x, /) → mpfr`

Return first kind Bessel function of order 0 of `x`.

`gmpy2.j1(x, /) → mpfr`

Return first kind Bessel function of order 1 of `x`.

`gmpy2.jn(n, x, /) → mpfr`

Return the first kind Bessel function of order `n` of `x`. Note: the order of the arguments changed in gmpy2 2.2.0a2

`gmpy2.lgamma(x, /) → tuple[mpfr, int]`

Return a `tuple` containing the logarithm of the absolute value of `gamma(x)` and the sign of `gamma(x)`

`gmpy2.li2(x, /) → mpfr`

Return real part of dilogarithm of `x`.

`gmpy2.lgamma(x, /) → mpfr`

Return natural logarithm of `gamma(x)`.

`gmpy2.log1p(x, /) → mpfr`

Return natural logarithm of $(1+x)$.

`gmpy2.log2(x, /) → mpfr`

Return base-2 logarithm of `x`.

`gmpy2.maxnum(x, y, /) → mpfr`

Return the maximum number of `x` and `y`. If `x` and `y` are not `mpfr`, they are converted to `mpfr`. The result is rounded to match the current context. If only one of `x` or `y` is a number, then that number is returned.

`gmpy2.minnum(x, y, /) → mpfr`

Return the minimum number of `x` and `y`. If `x` and `y` are not `mpfr`, they are converted to `mpfr`. The result is rounded to match the current context. If only one of `x` or `y` is a number, then that number is returned.

`gmpy2.modf(x, /) → tuple[mpfr, mpfr]`

Return a `tuple` containing the integer and fractional portions of `x`.

`gmpy2.mpfr_from_old_binary(string, /) → mpfr`

Return an `mpfr` from a GMPY 1.x binary mpf format.

`gmpy2.mpfr_grandom(random_state, /) → tuple[mpfr, mpfr]`

Return two random numbers with gaussian distribution.

`gmpy2.mpf_rnrandom(random_state, /)`

Return a random number with gaussian distribution.

`gmpy2.mpf_random(random_state, /) → mpfr`

Return uniformly distributed number between [0,1].

`gmpy2.nan() → mpfr`

Return an `mpfr` initialized to NaN (Not-A-Number).

`gmpy2.next_above(x, /) → mpfr`

Return the next `mpfr` from x toward +Infinity.

`gmpy2.next_below(x, /) → mpfr`

Return the next `mpfr` from x toward -Infinity.

`gmpy2.radians(x, /) → mpfr`

Convert angle x from degrees to radians. Note: In rare cases the result may not be correctly rounded.

`gmpy2.rec_sqrt(x, /) → mpfr`

Return the reciprocal of the square root of x.

`gmpy2.reldiff(x, y, /) → mpfr`

Return the relative difference between x and y. Result is equal to $\text{abs}(x-y)/x$.

`gmpy2.remainder(x, y, /) → mpfr`

Return $x - n*y$ where n is the integer quotient of x/y , rounded to the nearest integer and ties rounded to even.

`gmpy2.remquo(x, y, /) → tuple[mpfr, int]`

Return a `tuple` containing the `remainder(x,y)` and the low bits of the quotient.

`gmpy2 rint(x, /) → mpfr`

Return x rounded to the nearest integer using the current rounding mode.

`gmpy2.rint_ceil(x, /) → mpfr`

Return x rounded to the nearest integer by first rounding to the next higher or equal integer and then, if needed, using the current rounding mode.

`gmpy2.rint_floor(x, /) → mpfr`

Return x rounded to the nearest integer by first rounding to the next lower or equal integer and then, if needed, using the current rounding mode.

`gmpy2.rint_round(x, /) → mpfr`

Return x rounded to the nearest integer by first rounding to the nearest integer (ties away from 0) and then, if needed, using the current rounding mode.

`gmpy2.rint_trunc(x, /) → mpfr`

Return x rounded to the nearest integer by first rounding towards zero and then, if needed, using the current rounding mode.

`gmpy2.root(x, n, /) → mpfr`

Return n-th root of x. The result always an `mpfr`. Note: not IEEE 754-2008 compliant; result differs when $x = -0$ and n is even. See `rootn()`.

`gmpy2.rootn(x, n, /) → mpfr`

Return n-th root of x. The result always an `mpfr`. Note: this is IEEE 754-2008 compliant version of `root()`.

`gmpy2.round2(x, n=0, /) → mpfr`

Return `x` rounded to `n` bits. Uses default precision if `n` is not specified. See `round_away()` to access the `mpfr_round()` function of the MPFR.

`gmpy2.round_away(x, /) → mpfr`

Return an `mpfr` that is `x` rounded to the nearest integer, with ties rounded away from 0.

`gmpy2.sec(x, /) → mpfr`

Return secant of `x`; `x` in radians.

`gmpy2.sech(x, /) → mpfr`

Return hyperbolic secant of `x`.

`gmpy2.set_exp(x, n, /) → mpfr`

Set the exponent of `x` to `n`. If `n` is outside the range of valid exponents, `set_exp()` will set the `context.erange` flag of the current context and either return the original value or raise an exception if `context.trap_erange` is set.

`gmpy2.set_sign(x, s, /) → mpfr`

If `s` is `True`, then return `x` with the sign bit set.

`gmpy2.sign(x, /) → int`

Return -1 if `x < 0`, 0 if `x == 0`, or +1 if `x > 0`.

`gmpy2.sinh_cosh(x, /) → tuple[mpfr, mpfr]`

Return a `tuple` containing the hyperbolic sine and cosine of `x`.

`gmpy2.trunc(x, /) → mpfr`

Return an `mpfr` that is `x` truncated towards 0. Same as `x.floor()` if `x ≥ 0` or `x.ceil()` if `x < 0`.

`gmpy2.y0(x, /) → mpfr`

Return second kind Bessel function of order 0 of `x`.

`gmpy2.y1(x, /) → mpfr`

Return second kind Bessel function of order 1 of `x`.

`gmpy2.yn(n, x, /) → mpfr`

Return the second kind Bessel function of order `n` of `x`. Note: the order of the arguments changed in gmpy2 2.2.0a2

`gmpy2.zero(n, /) → mpfr`

Return an `mpfr` initialized to 0.0 with the same sign as `n`. If `n` is not given, +0.0 is returned.

`gmpy2.zeta(x, /) → mpfr`

Return Riemann zeta of `x`.

`gmpy2.get_max_precision() → int`

Return the maximum bits of precision that can be used for calculations. Note: to allow extra precision for intermediate calculations, avoid setting precision close the maximum precision.

`gmpy2.get_emax_max() → int`

Return the maximum possible exponent that can be set for `mpfr`.

`gmpy2.get_emin_min() → int`

Return the minimum possible exponent that can be set for `mpfr`.

`gmpy2.copy_sign(x, y, /) → mpfr`

Return an `mpfr` composed of `x` with the sign of `y`.

`gmpy2.can_round(b, err, rnd1, rnd2, prec, /) → bool`

Let b be an approximation to an unknown number x that is rounded according to rnd1 . Assume the b has an error at most two to the power of $E(b)-\text{err}$ where $E(b)$ is the exponent of b . Then return `True` if x can be rounded correctly to prec bits with rounding mode rnd2 .

`gmpy2.free_cache() → None`

Free the internal cache of constants maintained by MPFR.

1.10 Multiple-precision Complex

1.10.1 mpc Type

`class gmpy2.mpc(c=0, /, precision=0)`

`class gmpy2.mpc(c=0, /, precision, context)`

`class gmpy2.mpc(real, /, imag=0, precision=0)`

`class gmpy2.mpc(real, /, imag, precision, context)`

`class gmpy2.mpc(s, /, precision=0, base=10)`

`class gmpy2.mpc(s, /, precision, base, context)`

Return a complex floating-point number constructed from a numeric value c or from a pair of two non-complex numbers real and imag or from a string s made of digits in the given base.

A string can be possibly with real-part and/or imaginary-part (that have ‘j’ as a suffix), separated by ‘+’ and parsed the same as the `mpfr` constructor does (but the base must be up to 36).

The precision can be specified by either a single number that is used for both the real and imaginary components, or as a pair of different precisions for the real and imaginary components. For every component, the meaning of its precision value is the same as in the `mpfr` type constructor.

`__format__(fmt) → str`

Return a Python string by formatting ‘x’ using the format string ‘fmt’. A valid format string consists of:

optional alignment code:

‘<’ -> left shifted in field ‘>’ -> right shifted in field ‘^’ -> centered in field

optional leading sign code

‘+’ -> always display leading sign ‘-’ -> only display minus for negative values ‘ ‘ -> minus for negative values, space for positive values

optional width.real_precision.imag_precision

optional rounding mode:

‘U’ -> round toward plus infinity ‘D’ -> round toward minus infinity ‘Z’ -> round toward zero ‘N’ -> round to nearest

optional output style:

‘P’ -> Python style, 1+2j, (default) ‘M’ -> MPC style, (1 2)

optional conversion code:

‘a’, ‘A’ -> hex format ‘b’ -> binary format ‘e’, ‘E’ -> scientific format ‘f’, ‘F’ -> fixed point format ‘g’, ‘G’ -> fixed or scientific format

The default format is ‘f’.

conjugate() → *mpc*

Returns the conjugate of x.

digits(*base=10, prec=0, /*) → *tuple[tuple[str, int, int], tuple[str, int, int]]*

Returns up to ‘prec’ digits in the given base. If ‘prec’ is 0, as many digits that are available given c’s precision are returned. ‘base’ must be between 2 and 62. The result consists of 2 three-element tuples that contain the mantissa, exponent, and number of bits of precision of the real and imaginary components.

is_finite() → *bool*

Return *True* if x is an actual number (i.e. non NaN or Infinity). If x is an *mpc*, return *True* if both x.real and x.imag are finite.

is_infinite() → *bool*

Return *True* if x is +Infinity or -Infinity. If x is an *mpc*, return *True* if either x.real or x.imag is infinite. Otherwise return *False*.

is_nan() → *bool*

Return *True* if x is NaN (Not-A-Number) else *False*.

is_zero() → *bool*

Return *True* if x is equal to 0. If x is an *mpc*, return *True* if both x.real and x.imag are equal to 0.

imag

imaginary component

precision

precision in bits

rc

return code

real

real component

1.10.2 mpc Functions

gmpy2.acos(*x, /*) → *mpfr | mpc*

Return inverse cosine of x; result in radians.

gmpy2.acosh(*x, /*) → *mpfr | mpc*

Return inverse hyperbolic cosine of x.

gmpy2.asin(*x, /*) → *mpfr | mpc*

Return inverse sine of x; result in radians.

gmpy2.asinh(*x, /*) → *mpfr | mpc*

Return inverse hyperbolic sine of x.

gmpy2.atan(*x, /*) → *mpfr | mpc*

Return inverse tangent of x; result in radians.

gmpy2.atanh(*x, /*) → *mpfr | mpc*

Return inverse hyperbolic tangent of x.

gmpy2.cos(*x, /*) → *mpfr | mpc*

Return cosine of x; x in radians.

`gmpy2.cosh(x, /)` → *mpfr* | *mpc*

Return hyperbolic cosine of x.

`gmpy2.div_2exp(x, n, /)` → *mpfr* | *mpc*

Return x divided by 2^{**n} .

`gmpy2.exp(x, /)` → *mpfr* | *mpc*

Return the exponential of x.

`gmpy2.is_nan(x, /)` → *bool*

Return *True* if x is NaN (Not-A-Number) else *False*.

`gmpy2.is_zero(x, /)` → *bool*

Return *True* if x is equal to 0. If x is an *mpc*, return *True* if both x.real and x.imag are equal to 0.

`gmpy2.log(x, /)` → *mpfr* | *mpc*

Return the natural logarithm of x.

`gmpy2.log10(x, /)` → *mpfr* | *mpc*

Return the base-10 logarithm of x.

`gmpy2.mpc_random(random_state, /)` → *mpc*

Return uniformly distributed number in the unit square $[0,1] \times [0,1]$.

`gmpy2.mul_2exp(x, n, /)` → *mpfr* | *mpc*

Return x multiplied by 2^{**n} .

`gmpy2.norm(x, /)` → *mpfr*

Return the norm of a complex x. The `norm(x)` is defined as $x.\text{real}^{**2} + x.\text{imag}^{**2}$. `abs(x)` is the square root of `norm(x)`.

`gmpy2.phase(x, /)` → *mpfr*

Return the phase angle, also known as argument, of a complex x.

`gmpy2.polar(x, /)` → *tuple*[*mpfr*, *mpfr*]

Return the polar coordinate form of a complex x that is in rectangular form.

`gmpy2.proj(x, /)` → *mpc*

Returns the projection of a complex x on to the Riemann sphere.

`gmpy2.rect(r, phi, /)` → *mpc*

Return the rectangular coordinate form of a complex number that is given in polar form.

`gmpy2.root_of_unity(n, k, /)` → *mpc*

Return the n-th root of `mpc(1)` raised to the k-th power..

`gmpy2.sin(x, /)` → *mpfr* | *mpc*

Return sine of x; x in radians.

`gmpy2.sin_cos(x, /)` → *tuple*[*mpfr* | *mpc*, *mpfr* | *mpc*]

Return a tuple containing the sine and cosine of x; x in radians.

`gmpy2.sinh(x, /)` → *mpfr* | *mpc*

Return hyperbolic sine of x.

`gmpy2.sqrt(x, /)` → *mpfr* | *mpc*

Return the square root of x.

`gmpy2.tan(x, /)` → *mpfr* | *mpc*
Return tangent of x; x in radians.

`gmpy2.tanh(x, /)` → *mpfr* | *mpc*
Return hyperbolic tangent of x.

1.11 Generic Functions

`gmpy2.add(x, y, /)` → *mpz* | *mpq* | *mpfr* | *mpc*
Return $x + y$.

`gmpy2.div(x, y, /)` → *mpz* | *mpq* | *mpfr* | *mpc*
Return x / y ; uses true division.

`gmpy2.mul(x, y, /)` → *mpz* | *mpq* | *mpfr* | *mpc*
Return $x * y$.

`gmpy2.sub(x, y, /)` → *mpz* | *mpq* | *mpfr* | *mpc*
Return $x - y$.

`gmpy2.square(x, /)` → *mpz* | *mpq* | *mpfr* | *mpc*
Return $x * x$.

`gmpy2.f2q(x, err=0, /)` → *mpz* | *mpq*
Return the ‘best’ *mpq* approximating x to within relative error err. Default is the precision of x. Uses Stern-Brocot tree to find the ‘best’ approximation. An *mpz* object is returned if the denominator is 1. If $err < 0$, relative error is $2.0 ** err$.

`gmpy2.fma(x, y, z, /)` → *mpz* | *mpq* | *mpfr* | *mpc*
Return correctly rounded result of $(x * y) + z$.

`gmpy2.fms(x, y, z, /)` → *mpz* | *mpq* | *mpfr* | *mpc*
Return correctly rounded result of $(x * y) - z$.

`gmpy2.cmp_abs(x, y, /)` → *int*
Return -1 if $\text{abs}(x) < \text{abs}(y)$; 0 if $\text{abs}(x) = \text{abs}(y)$; or 1 else.

1.12 Miscellaneous Functions

`gmpy2.digits(x, base=10, prec=0, /)` → *str*
Return string representing a number x.

`gmpy2.from_binary(bytes, /)` → *mpz* | *xmpz* | *mpq* | *mpfr* | *mpc*
Return a Python object from a byte sequence created by `to_binary()`.

`gmpy2.license()` → *str*
Return string giving license information.

`gmpy2.mp_limbsize()` → *int*
Return the number of bits per limb.

`gmpy2.mp_version()` → *str*
Return string giving current GMP version.

`gmpy2.mpc_version()` → `str`

Return string giving current MPC version.

`gmpy2.mpfr_version()` → `str`

Return string giving current MPFR version.

`gmpy2.random_state(seed=0, /)` → `object`

Return new object containing state information for the random number generator. An optional integer can be specified as the seed value.

`gmpy2.to_binary(x, /)` → `bytes`

Return a Python byte sequence that is a portable binary representation of a gmpy2 object `x`. The byte sequence can be passed to `from_binary()` to obtain an exact copy of `x`'s value. Raises a `TypeError` if `x` is not a gmpy2 object.

`gmpy2.version()` → `str`

Return string giving current GMPY2 version.

1.13 Cython usage

The gmpy2 module provides a C-API that can be conveniently used from Cython. All types and functions are declared in the header `gmpy2.pxd` that is installed automatically in your Python path together with the library.

1.13.1 Initialization

In order to use the C-API you need to make one call to the function `void import_gmpy2(void)`.

1.13.2 Types

The types `mpz`, `mpq`, `mpfr` and `mpc` are declared as extension types in `gmpy2.pxd`. They correspond respectively to the C structures `MPZ_Object`, `MPQ_Object`, `MPFR_Object` and `MPC_Object`.

Fast type checking can be done with the following C functions

bint `MPZ_Check(object)`

equivalent to `isinstance(obj, mpz)`

bint `MPQ_Check(object)`

equivalent to `isinstance(obj, mpq)`

bint `MPFR_Check(object)`

equivalent to `isinstance(obj, mpfr)`

bint `MPC_Check(object)`

equivalent to `isinstance(obj, mpc)`

1.13.3 Object creation

To create a new gmpy2 types there are four basic functions

mpz GMPy_MPZ_New(void * ctx)

create a new mpz object from a given context ctx

mpq GMPy_MPQ_New(void * ctx)

create a new mpq object from a given context ctx

mpfr MPFR_New(void * ctx, mpfr_prec_t prec)

create a new mpfr object with given context ctx and precision prec

mpc MPC_New(void * ctx, mpfr_prec_t rprec, mpfr_prec_t iprec)

create a new mpc object with given context ctx, precisions rprec and iprec of respectively real and imaginary parts

The context can be set to **NULL** and controls the default behavior (e.g. precision).

The gmpy2.pxd header also provides convenience macro to wrap a (copy of) a mpz_t, mpq_t, mpfr_t or a mpc_t object into the corresponding gmpy2 type.

mpz GMPy_MPZ_From_mpz(mpz_srcptr z)

return a new mpz object with a given mpz_t value z

mpq GMPy_MPQ_From_mpq(mpq_srcptr q)

return a new mpq object from a given mpq_t value q

mpq GMPy_MPQ_From_mpz(mpz_srcptr num, mpz_srcptr den)

return a new mpq object with a given mpz_t numerator num and mpz_t denominator den

mpfr GMPy_MPFR_From_mpfr(mpfr_srcptr x)

return a new mpfr object with a given mpfr_t value x

mpc GMPy_MPC_From_mpc(mpc_srcptr c)

return a new mpc object with a given mpc_t value c

mpc GMPy_MPC_From_mpfr(mpfr_srcptr re, mpfr_srcptr im)

return a new mpc object with a given mpfr_t real part re and mpfr_t imaginary part im

1.13.4 Access to the underlying C type

Each of the gmpy2 objects has a field corresponding to the underlying C type. The following functions give access to this field

mpz_t MPZ(mpz)

mpq_t MPQ(mpq)

mpfr_t MPFR(mpfr)

mpc_t MPC(mpc)

1.13.5 Compilation

The header `gmpy2.pxd` as well as the C header `gmpy2.h` from which it depends are installed in the Python path. In order to make Cython and the C compiler aware of the existence of these files, the Python path should be part of the include directories.

Recall that `import_gmpy2()` needs to be called *before* any other function of the C-API.

Here is a minimal example of a Cython file `test_gmpy2.pyx`:

```
"A minimal cython file test_gmpy2.pyx"

from gmpy2 cimport *

cdef extern from "gmp.h":
    void mpz_set_si(mpz_t, long)

import_gmpy2() # needed to initialize the C-API

cdef mpz z = GMPy_MPZ_New(NULL)
mpz_set_si(MPZ(z), -7)

print(z + 3)
```

The corresponding `setup.py` is given below.

```
"A minimal setup.py for compiling test_gmpy2.pyx"

import sys

from setuptools import Extension, setup
from Cython.Build import cythonize

ext = Extension("test_gmpy2", ["test_gmpy2.pyx"],
                include_dirs=sys.path, libraries=['gmp', 'mpfr', 'mpc'])

setup(name="cython_gmpy_test",
      ext_modules=cythonize([ext], include_path=sys.path))
```

With these two files in the same repository, you should be able to compile your module using

```
$ python setup.py build_ext --inplace
```

For more about compilation and installation of cython files and extension modules, please refer to the official documentation of Cython and distutils.

1.14 Conversion Methods

A python object could interact with gmpy2 if it implements one of the following methods:

- `__mpz__` : return an object of type `mpz`.
- `__mpq__` : return an object of type `mpq`.
- `__mpfr__` : return an object of type `mpfr`.
- `__mpc__` : return an object of type `mpc`.

Implementing on of these methods allow gmpy2 to convert a python object into a gmpy2 type. Example:

```
>>> from gmpy2 import mpz
>>> class CustInt:
...     def __init__(self, x):
...         self.x = x
...     def __mpz__(self):
...         return mpz(self.x)
...
>>> ci = CustInt(5)
>>> z = mpz(ci); z
mpz(5)
>>> type(z)
<class 'gmpy2.mpz'>
```

1.14.1 Arithmetic operations

gmpy2 allow arithmetic operations between gmpy2 numbers and objects with conversion methods. Operation with object that implements floating conversion and exact conversion methods are not supported. That means that only the following cases are supported:

- An integer type have to implement `__mpz__`
- A rational type have to implement `__mpq__` and can implement `__mpz__`
- A real type have to implement `__mpfr__`
- A complex type have to implement `__mpc__` and can implement `__mpfr__`

Examples:

```
>>> import gmpy2
>>> from gmpy2 import mpz, mpq, mpfr, mpc
>>> gmpy2.set_context(gmpy2.context())
>>> class Q:
...     def __mpz__(self): return mpz(1)
...     def __mpq__(self): return mpq(3,2)
>>> q = Q()
>>> mpz(2) + q
mpq(7,2)
>>> mpq(1,2) * q
mpq(3,4)
>>> mpfr(10) * q
mpfr('15.0')
```


1.15 Release Notes

1.15.1 Changes in gmpy2 2.2.0

- Remove support for versions of Python < 3.7. (skirpichev)
- Support more modern build tools. (skirpichev)
- Use contextvars to manage gmpy2 contexts. (casevh)
- `_mpmath` functions now use vectorcall protocol. (casevh)
- Many documentation updates. (skirpichev)
- Add `mpz.as_integer_ratio()` / `mpz.to_bytes()` and `mpz.from_bytes()`. (skirpichev)
- Add `is_probab_prime()` to directly expose the GMP behavior. (skirpichev)
- `gcd()/lcm()` now uses vectorcall protocol. (skirpichev)
- Expose `context` type. (skirpichev)
- Correct error in `is_strong_bpsw_prp()`. (casevh)
- Added `prev_prime()` when GMP ≥ 6.3 . (sethtroisi)
- Change argument order of `jn()` and `yn()` to match MPFR. (casevh)
- Fix documentation and code for `is_extra_strong_lucas_prp()`. (casevh)

1.15.2 Changes in gmpy2 2.1.5

- Version bump to fix wheel issues. No code changes.

1.15.3 Changes in gmpy2 2.1.4

- Version bump to fix wheel issues. No code changes.

1.15.4 Changes in gmpy2 2.1.3

- Fix `mpz(-3).is_prime()`.
- Add `powmod_sec()`.
- Fix `mpfr('inf')` and `mpfr('nan')` if subnormalization is enabled.
- `powmod()` and `powmod_sec()` release the GIL.
- Fix error messages for `iroot(x,n)` for large `n`.
- Add `powmod_base_list()` and `powmod_exp_list()` (experimental).
- Fix `gmpy2.mpq(mpq, int)`.
- Fix issues with INF, NAN, and `mpfr("-0")` when subnormalization is True

1.15.5 Changes in gmpy2 2.1.2

- Code cleanup.
- Support Apple Silicon binary wheels.
- `is_prime(-2)` now returns False. Issue #312.

1.15.6 Changes in gmpy2 2.1.1

- Code cleanup.
- Properly return NOTIMPLEMENTED for unsupported arguments in `**`. Issue #319.

1.15.7 Changes in gmpy2 2.1.0

- Improvements to `setup.py`.
- Add thread-safe contexts.
- MPFR and MPC are now required.
- Invalid Operation exception now raised for addition, etc.
- `inverse()` now raises exception if inverse does not exist.
- Add context methods.
- Major code refactoring required to properly support thread-safe contexts.
- `__str__` and `__repr__` no longer append “L” on Python 2.
- `mpq(mpfr)` now returns the exact result.
- Fix `repr(mpc)` for precision >325 bits.
- Intermediate conversions of Integer to mpfr are now done with the full precision of the Integer.
- Remove support for interaction with Decimal type.
- No longer attempt to override the memory allocation functions.
- Register gmpy2 types into the numeric tower.
- `mpz(x)` call `int(x)` if `mpz()` does not know how to convert x directly.
- Convert `mpz` to a type using `__new__` instead of a factory function.
- Bug fix for `<<small mpfr>> ** <<small Python integer>>`.
- Compile with Python 3.11.

1.15.8 Changes in gmpy2 2.1.0rc2

- Documentation updates.
- Improvements to build environment.

1.15.9 Changes in gmpy2 2.1.0rc1

- Added support for embedded underscore characters in string literals.
- Allow GIL release for `mpz/xmpz/mpq` types only.

1.15.10 Changes in gmpy2 2.1.0b6

- Improve argument type processing by saving type information to decrease the number of type check calls. Especially helpful for `mpfr` and `mpc` types. (Not complete but common operations are done.)
- Resolve bug in `mpfr` to `mpq` conversion; issue #287.
- Added limited support for releasing the GIL; disabled by default; see `context.allow_release_gil`.
- Refactored handling of inplace operations for `mpz` and `xmpz` types; inplace operations on `xmpz` will only return an `xmpz` result.
- Refactored handling of conversion to C integer types. Some exception types changes to reflect Python types.
- `gcd()` and `lcm()` now support more than two arguments to align with the corresponding functions in the math module.

1.15.11 Changes in gmpy2 2.1.0b5

- Avoid MPFR bug in `mfr_fac_ui` (`factorial()`) on platforms where long is 32-bits and argument is ≥ 44787929 .
- Fixed testing bugs with Python 2.7.
- Fixed `mpz(0)` to C long or long long.
- Fixed incorrect results in `f2q()`.
- Adjust test suite to reflect changes in output in MPFR 4.1.0.

1.15.12 Changes in gmpy2 2.1.0b4

- Fix comparisons with `mpq` and custom rational objects.
- Fixes for some uncommon integer conversions scenarios.

1.15.13 Changes in gmpy2 2.1.0b3

- Version bump only.

1.15.14 Changes in gmpy2 2.1.0b2

- Many bug fixes.

1.15.15 Changes in gmpy2 2.1.0b1

- Added `cmp()` and `cmp_abs()`.
- Improved compatibility with the `numbers` module protocol.
- Many bug fixes.

1.15.16 Changes in gmpy2 2.1.a05

- Fix `qdiv()` not returning `mpz` when it should.
- Added `root_of_unity()`.

1.15.17 Changes in gmpy2 2.1.0a4

- Fix issue 204; missing file for Cython.
- Additional support for MPFR 4
 - Add `fmma()` and `fms()`.

1.15.18 Changes in gmpy2 2.1.0a3

- Updates to `setup.py`.
- Initial support for MPFR4
 - Add `mpfr_nrandom()`
 - `mpfr_grandom()` now calls `nrandom` twice; may return different values versus MPFR3.
 - Add `rootn()`; same as `root()` except different sign when taking even root of -0.0.

1.15.19 Changes in gmpy2 2.1.0a2

- Revised build process.
- Removal of unused code/macros.
- Cleanup of Cython interface.

1.15.20 Changes in gmpy2 2.1.0a1

- Thread-safe contexts are now supported. Properly integrating thread-safe contexts required an extensive rewrite of almost all internal functions.
- MPFR and MPC are now required. It is no longer possible to build a version of gmpy2 that only supports the GMP library.
- The function `inverse()` now raises an exception if the inverse does not exist.
- Context methods have been added for MPFR/MPC related functions.
- A new context option (`rational_division`) has been added that changes the behavior of integer division involving `mpz` instances to return a rational result instead of a floating point result.
- gmpy2 types are now registered in the numeric tower of the `numbers` module.
- In previous versions of gmpy2, `mpz()` was a factory function that returned an `mpz` instance. It is now an actual type. The same is true for the other gmpy2 types.
- If a Python object has an `__mpz__` method, it will be called by `mpz()` to allow an unrecognized type to be converted to an `mpz` instance. The same is true for the other gmpy2 types.
- A new C-API and Cython interface has been added.

1.15.21 Changes in gmpy2 2.0.4

- Fix `bit_scan0()` for negative values.
- Changes to `setup.py` to allow static linking.
- Fix performance regression with `mpmath` and Python 3.

1.15.22 Changes in gmpy2 2.0.3

- Fix `lucas2()` and `atanh()`; they were returning incorrect values.

1.15.23 Changes in gmpy2 2.0.2

- Rebuild Windows binary installers due to MPIR 2.6.0 bug in `next_prime()`.
- Another fix for `is_extra_strong_lucas_prp()`.

1.15.24 Changes in gmpy2 2.0.1

- Updated `setup.py` to work in more situations.
- Corrected exception handling in basic operations with `mpfr` type.
- Correct `InvalidOperation` exception not raised in certain circumstances.
- `invert()` now raises an exception if the modular inverse does not exist.
- Fixed internal exception in `is_bpsw_prp()` and `is_strong_bpsw_prp()`.
- Updated `is_extra_strong_lucas_prp()` to latest version.

1.15.25 Changes in gmpy2 2.0.0

- Fix segmentation fault in `_mpmath_normalize()` (an undocumented helper function for `mpmath`). (casevh)
- Fix issues when compiled without support for MPFR. (casevh)
- Conversion of too large an `mpz` to `float` now raises `OverflowError` instead of returning `inf`. (casevh)
- Renamed `min2()`/`max2()` to `minnum()`/`maxnum()`. (casevh)
- The build and install process (i.e. `setup.py`) has been completely rewritten. See the Installation section for more information. (casevh)
- `get_context()` no longer accepts keyword arguments. (casevh)

1.15.26 Known issues in gmpy2 2.0.0

- The test suite is still incomplete.

1.15.27 Changes in gmpy2 2.0.0b4

- Added `__ceil__()`, `__floor__()`, `__trunc__()`, and `__round__()` methods to `mpz` and `mpq` types. (casevh)
- Added `__complex__()` to `mpc` type. (casevh)
- `round(mpfr)` now correctly returns an `mpz` type. (casevh)
- Add `mpz.denominator` and `mpz.numerator`. (casevh)
- If no arguments are given to `mpz`, `mpq`, `mpfr`, `mpc`, and `xmpz`, return 0 of the appropriate type. (casevh)
- Fix broken comparison between `mpz` and `mpq` when `mpz` is on the left. (casevh)
- Added `__sizeof__()` to all types. Note: `sys.getsizeof()` calls `__sizeof__()` to get the memory size of a gmpy2 object. The returned value reflects the size of the allocated memory which may be larger than the actual minimum memory required by the object. (casevh)

1.15.28 Known issues in gmpy2 2.0.0b4

- The new test suite (`test/runtest.py`) is incomplete and some tests fail on Python 2.x due to formatting issues.

1.15.29 Changes in gmpy2 2.0.0b3

- `mp_version()`, `mpc_version()`, and `mpfr_version()` now return normal strings on Python 2.x instead of Unicode strings. (casevh)
- Fix warnings when shifting 32-bit integer by 32 bits. (casevh)
- Faster conversion of the standard library `Fraction` type to `mpq`. (casevh)
- Improved conversion of the `Decimal` type to `mpfr`. (casevh)
- Consistently return `OverflowError` when converting `inf`. (casevh)
- Fix `mpz.__format__()` when the format code includes “#”. (casevh)
- Add `is_infinite()` and deprecate `is_inf()`. (casevh)
- Add `is_finite()` and deprecate `is_number()`. (casevh)

- Fixed the various `is_XXX()` tests when used with `mpc`. (casevh)
- Fixed error handling with `mpc()`; `mpc(1,"nan")` is properly handled. (casevh)
- Added caching for `mpc` objects. (casevh)
- Faster code path for basic operation if both operands are `mpfr` or `mpc`. (casevh)
- Fix `mpfr` + `float` segmentation fault. (casevh)

1.15.30 Changes in gmpy2 2.0.0b2

- Allow `xmpz` slice assignment to increase length of `xmpz` instance by specifying a value for stop. (casevh)
- Fixed reference counting bug in several `is_XXX_prp()` tests. (casevh)
- Added `iter_bits()`, `iter_clear()`, `iter_set()` methods to `xmpz`. (casevh)
- Added `powmod()` for easy access to three argument `pow()`. (casevh)
- Removed `addmul()` and `submul()` which were added in 2.0.0b1 since they are slower than just using Python code. (casevh)
- Bug fix in `gcd_ext` when both arguments are not `mpz`. (casevh)
- Added `ieee()` to create contexts for 32, 64, or 128 bit `float`'s. (casevh)
- Bug fix in `context()` not setting `emax/emax` correctly if they had been changed earlier. (casevh)
- Contexts can be directly used in with statement without requiring `set_context()/local_context()` sequence. (casevh)
- `local_context()` now accepts an optional context. (casevh)

1.15.31 Changes in gmpy2 2.0.0b1

- Rename to gmpy2 to allow backwards incompatible changes (casevh)
- Renamed 'mpf' to 'mpfr' to reflect use of MPFR (casevh)
- Renamed functions that manipulate individual bits to `bit_XXX()` to align with `bit_length()`.
- Added caching for `mpq`. (casevh)
- Added `rootrem()`, `fib2()`, `lucas()`, `lucas2()`. (casevh)
- Support changed hash function in Python 3.2. (casevh)
- Added `is_even()`, `is_odd()`. (casevh)
- Add caching of the calculated hash value. (casevh)
- Add `xmpz` (mutable `mpz`) type. (casevh)
- Fix `mpq` formatting issue. (casevh)
- Add read/write bit access using slices to `xmpz`. (casevh)
- Add read-only bit access using slices to `mpz`. (casevh)
- Add `pack()/unpack()` methods to split/join an integer into n-bit chunks. (casevh)
- Add support for MPFR (casevh)
- Removed `fcoform` float conversion modifier. (casevh)

- Add support for MPC. (casevh)
- Added context manager. (casevh)
- Allow building with just GMP/MPIR if MPFR not available. (casevh)
- Allow building with GMP/MPIR and MPFR if MPC not available. (casevh)
- Removed most instance methods in favor of `gmpy2.function`. The general guideline is that *properties* of an instance can be done via instance methods but *functions* that return a new result are done using `gmpy2.function`. (casevh)
- Added `__ceil__()`, `__floor__()`, and `__trunc__()` methods since they are called by `math.ceil()`, `math.floor()`, and `math.trunc()`. (casevh)
- Removed `gmpy2.pow()` to avoid conflicts. (casevh)
- Removed `gmpy2._copy()` and added `xmpz.copy()`. (casevh)
- Added support for `__format__()`. (casevh)
- Added `as_integer_ratio()`, `as_mantissa_exp()`, `as_simple_fraction()`. (casevh)
- Updated `rich_compare`. (casevh)
- Require MPFR 3.1.0+ to get `divby0` support. (casevh)
- Added `fsum()`, `degrees()`, `radians()`. (casevh)
- Updated random number generation support. (casevh)
- Changed license to LGPL 3+. (casevh)
- Added `lucasu()`, `lucasu_mod()`, `lucasv()`, and `lucasv_mod()`. (casevh) *Based on code contributed by David Cleaver.*
- Added probable-prime tests. (casevh) *Based on code contributed by David Cleaver.*
- Added `to_binary()/from_binary()`. (casevh)
- Renamed `numdigits()` to `num_digits()`. (casevh)
- Added keyword precision to constants. (casevh)
- Added `addmul()` and `submul()`. (casevh)
- Added `__round__()`, `round2()`, `round_away()` for `mpfr`. (casevh)
- `round()` is no longer a module level function. (casevh)
- Renamed module functions `min()/max()` to `min2()/max2()`. (casevh) No longer conflicts with builtin `min()` and `max()`
- Removed `set_debug()` and related functionality. (casevh)
- Removed `mpf.setprec()`, use `mpf.round()` (casevh)
- Fix test compatibility with Python 3.1.2 and 3.2 (casevh)
- Remove old random number functions, to be replaced later (casevh)
- Remove `tagoff` option (casevh)
- Debug messages only available if compiled with `-DDEBUG` (casevh)
- Renamed `context()` -> `local_context()`, `new_context()` -> `context()` (casevh)
- Added `get_context()` (casevh)

1.15.32 Changes in gmpy 1.11

- Recognize True/False (bug in 1.10) (casevh)
- Optimize argument handling (casevh)
- Added caching for mpz (casevh)

1.15.33 Changes in gmpy 1.10

- Remove dependancy on pymemcompat.h (casevh)
- Remove callback (casevh)
- Added support for -DMPIR to include MPPIR instead of GMP (casevh)
- Major code revisions to add support for Python 3.x (casevh)
- Fixed bug in binary() and qbinary() (casevh)
- Fixed bug in rich comparisons (casevh)
- Added % and divmod support to mpq and mpf (casevh)
- Changed memory allocation functions to use PyMem (casevh)
- Removed small number interning (casevh)
- Added tdivmod, cdivmod, and fdivmod (casevh)
- Added more helper functions for mpmath (casevh)
- Faster mpz<>PyLong conversion (casevh)
- Faster hash(mpz) (casevh)

1.15.34 Changes in gmpy 1.04

- Avoid GMP/mingw32 bug when converting very small floats to mpz. (casevh)
- Significant performance improvement for long->mpz and mpz->long. (casevh)
- Added “rich comparisons” to mpz, mpq and mpf types (aleaxit)
- Added additional tests (casevh, aleaxit)
- Fixed bug when converting very large mpz to str (casevh)
- Faster conversion from mpz->binary and binary->mpz (casevh)
- Added support for pickling (casevh)
- Added divexact (casevh)
- Fixed mpf comparisons by rounding mpf results when GMP returns a longer result. Added fround() (casevh)
- Added bit_length (Thanks Mario Pernici)
- Added helper functions for mpmath (casevh)
- Faster conversion from mpq->binary and binary->mpq (casevh)
- Recognize MPPIR, mpir_version() (casevh)

1.15.35 Changes in gmpy 1.03

- Fixed the bug that caused crashes on `gmpy.mpf(float('inf'))` and other such conversions, implicit and explicit
- Fixed a bug in `get_zconst`'s prototype affecting 64-bit machines, thanks to Gary Bunting
- Fixed a bug in hashing on 64-bit systems. `hash(long)` now equals `hash(mpz)` for large values. (casevh)
- Changed `int()` to return a long value instead of `OverflowError`. Complies with PEP 237. (casevh)
- Added support in `setup.py` for darwinports/macports build of GMP on MacOSX. (aleaxit)

1.15.36 Changes in gmpy 1.02

- fix warning in comparison of `mpq`'s
- added support of `mpq('12.34')` [[string w/o a slash, but with a dot]]
- fixes for 64-bit build (thanks to a patch by dmcooke)
- added experimental support for `decimal.Decimal` (and user-coded types) via wider use of special conversion methods (if present) and their sly insertion on-the-fly into the `decimal.Decimal` class (!)
- two bugfixes, thanks to Simon Burton
- Brought back into C89 compliance (thanks to Chip Turner), had drifted to C99 (declarations in the middle of the code).
- Python 2.5 support (`Py_ssize_t`, `__index__`) thanks to Chip Turner
- Pushed coverage to 93.3% (missing only "sanity check" level error tests [mostly for out-of-memory conditions], output to `stderr` conditioned by `global.debug`, & a couple of very obscure cases)

1.15.37 Changes in gmpy 1.01

- cleanups, ensure support for Python 2.4.1 on MacOSX 10.4/XCode 2.1 as well as Python 2.2 and 2.3 (on MacOSX and Linux)
- fixed memory leak on `divm` (thanks to mensanator@aol.com)
- fixed bug on `mpq('123')` [[`str2mpq` on string w/o a slash]]
- added `floordiv` and `truediv` operators, and tests for them
- NOT tested on GMP 3 (have none left around...), ONLY on GMP 4.*

1.15.38 Changes in gmpy 1.0

- minor cleanups, ensure support for Python 2.3
- fixed misdiagnosis of some argument counts in macro
- `SELF_ONE_ARG_CONVERTED` (tx to Paul Rubin!)

1.15.39 Changes in gmpy 0.9

- change ValueError to OverflowError for ‘too-large’ errors
- fix bug in mpq_pow (negative base, exp. with odd denominator) (fix now corrected – _even_ denominator is the error!)
- fixed gcc warnings reported by K. Briggs
- support GMP 4 (but added no GMP4-only functionality yet)
- updated tests to 0.9, better coverage

1.15.40 Changes in gmpy 0.8

(again, requests & suggestions by great Pearu!)

- raise test coverage 72.5% -> 90.0%
- introduced callbacks (not documented/tested for now; Pearu will test/support/document in PySymbolic)
- some errors went undiagnosed, caused crash: now fixed
- workaround for GMP bug(?s?) in mpz_fits_... (?)
- added exposure of mpf_sqrt and pow_ui

1.15.41 Changes in gmpy 0.7

Good feedback from Keith Briggs, some advice from Tim Peters and Fred Lundh — thanks all!

- fixed bug of “%d” where “%ld” was meant’ in many places and other sundry minor warnings given by gcc
- fixed hash (delegating to Python) so mp[nqz](x) will produce the same value as hash(x) for any Python number x
- workaround for GMP 3.1.1 bug, mpz_root wrongly returning ‘exact’ for non-exact root if dest==source, which stopped needed value-error for inexact mpq**mpq operations
- determined correct ‘actual precision’ of floats
- explicitly stored precision with binary-form mpf’s
- extended explicit-bits request to all ->mpf operations (good in itself, plus, preparing for future MPFR)
- removed the limitation of no binary-form for <0 mpz
- introduced macros to parse args, for conciseness

1.15.42 Changes in gmpy 0.6

(lots of good ideas from Pearu once more!-)

- fixed silly bugs in kronecker and mpq_abs
- gmpy-level workaround for scan0/scan1 bugs (?) in gmp 3.1.1
- added qdiv; anynum->mpq substituted for all such conversions (also anynum->mpz and anynum->mpf by analogy, with care!)
- added global.fcoform for optional use of intermediate string in float2mpf (used for any float->mpf conversion)

- added `set_fcoform` function for `global.fcoform` access
- general cleanup of sources; added `alloca` for `msvc++`; - many sundry minor bugfixes & uniformization; - a little useful refactoring (more would be good...)
- added caching of `mpq` objects
- power for `mpq`
- stern-brocot algorithm for `mpf->mpq` (also exposed as `f2q`) - also used for `float->mpq` - with stricter tracking of `mpf`'s requested-precision - added `getrprec` method to `mpf`, `getrprec` module-function
- exposed `ceil`, `floor` and `trunc` methods/functions for `mpf`'s
- changed a couple exceptions from `value` to `zerodivision`
- added `'qual'` and `'floa'` options to `gmpy.rand`

1.15.43 Changes in gmpy 0.5

- added `jacobi`, `legendre`, `kronecker`
- added random-number generation, seed set/save, shuffling
- added `mpq` (at last!-)

1.15.44 Changes in gmpy 0.4

- split `gmpy.c/gmpy.h` introducing C-API interface (Pearu's suggestion)
- cleanup some casts using Pearu's new macros
- further cache-tweaks at Pearu's suggestion (macros introduced)
- added `sign` (Pearu's request), `getbit`, `setbit`
- added `docstrings`
- renamed copy functions to start with `_` ('internal, private')
- added `.comb` as a synonym of `.bincoef`

1.15.45 Changes in gmpy 0.3

- performance tweaks via `mpz-caching` & `fixed-constants`
- added `get/set` functions for `zcache`, `zco min/max`
- added `get-only` function for versions (of `gmp`, and of `gmpy`)
- removed all 'traces' of mutability (to be re-done... much later!)
- cleaned up all of the `mpz_cmp_ui(X,0)` to `mpz_sgn(X)`
- cleaned up `Py_BuildValue` usage (N vs O, `explicit()` for tuples)
- added `numdigits`, `lowbits`, `root`, `next_prime`, `invert`, `popcount`,
- `hamdist`, `scan0`, `scan1`
- renamed `bin` to `bincoef`

1.15.46 Changes in gmpy 0.2

15 Nov 2000

- pre-alpha: bugfixes re formatting (tx, Peanu!)
- no tags on oct() and hex() of mpz's
- insert 'tagoff' in options (gmpy.mpz() vs mpz() in repr) (for Peanu!)
- speedups for _nonzero & _cmp (tx, Peanu!)
- slight speedup (7/8%?) for excess reallocs 4<->8 bytes (Peanu's help!)
- added copy/fcopy; bin; fib; remove

1.15.47 Changes in gmpy 0.1

6 Nov 2000

- pre-alpha — first placed on sourceforge

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