This manual documents how to install and use the Multiple Precision Floating-Point Reliable Library, version 2.0.2.


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# Table of Contents

MPFR Copying Conditions .............................................. 1

1 Introduction to MPFR .......................... 2
   1.1 How to use this Manual .................................. 2

2 Installing MPFR ............................................. 3
   2.1 Known Build Problems ................................... 3

3 Reporting Bugs .............................................. 4

4 MPFR Basics .................................................. 5
   4.1 Nomenclature and Types .................................. 5
   4.2 Function Classes ........................................... 5
   4.3 MPFR Variable Conventions ................................. 5
   4.4 Compatibility with MPF .................................... 6
   4.5 Getting the Latest Version of MPFR ......................... 6

5 Floating-point Functions ............................... 7
   5.1 Rounding Modes ............................................ 7
   5.2 Exceptions ................................................ 8
   5.3 Initialization Functions .................................. 9
   5.4 Assignment Functions ................................... 10
   5.5 Combined Initialization and Assignment Functions ........ 11
   5.6 Conversion Functions .................................... 11
   5.7 Basic Arithmetic Functions ............................... 12
   5.8 Comparison Functions ................................... 14
   5.9 Special Functions ........................................ 16
   5.10 Input and Output Functions .............................. 17
   5.11 Miscellaneous Functions ................................. 18
   5.12 Internals ................................................ 19

Contributors ............................................... 21

References ..................................................... 22

Appendix A GNU Free Documentation License .......... 23
   A.1 ADDENDUM: How to use this License for your documents ... 28

Concept Index ................................................ 29

Function and Type Index ................................. 30
MPFR Copying Conditions

This library is free; this means that everyone is free to use it and free to redistribute it on a free basis. The library is not in the public domain; it is copyrighted and there are restrictions on its distribution, but these restrictions are designed to permit everything that a good cooperating citizen would want to do. What is not allowed is to try to prevent others from further sharing any version of this library that they might get from you.

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1 Introduction to MPFR

MPFR is a portable library written in C for arbitrary precision arithmetic on floating-point numbers. It is based on the GNU MP library. It aims to extend the class of floating-point numbers provided by the GNU MP library by a precise semantics. The main differences with the mpf class from GNU MP are:

- the mpfr code is portable, i.e. the result of any operation does not depend (or should not) on the machine word size mp_bits_per_limb (32 or 64 on most machines);
- the precision in bits can be set exactly to any valid value for each variable (including very small precision);
- mpfr provides the four rounding modes from the IEEE 754-1985 standard.

In particular, with a precision of 53 bits, mpfr should be able to exactly reproduce all computations with double-precision machine floating-point numbers (double type in C), except the default exponent range is much wider and subnormal numbers are not implemented.

This version of MPFR is released under the GNU Lesser General Public License. It is permitted to link MPFR to non-free programs, as long as when distributing them the MPFR source code and a means to re-link with a modified MPFR library is provided.

1.1 How to use this Manual

Everyone should read Chapter 4 [MPFR Basics], page 5. If you need to install the library yourself, you need to read Chapter 2 [Installing MPFR], page 3, too.

The rest of the manual can be used for later reference, although it is probably a good idea to glance through it.
Chapter 2: Installing MPFR

2 Installing MPFR

Here are the steps needed to install the library on Unix systems (more details are provided in the ‘INSTALL’ file):

1. To build MPFR, you first have to install GNU MP (version 4.1 or higher) on your computer. You need a C compiler, preferably GCC, but any reasonable compiler should work. And you need a standard Unix ‘make’ program, plus some other standard Unix utility programs. MPFR needs some internal GMP header files that are not installed. So, keep the GMP build directory as is, at least until you have built MPFR.

2. In the MPFR build directory, type ‘./configure --with-gmp-include=GMPBUILD
--with-gmp-lib=GMPINSTALL/lib’ where ‘GMPBUILD’ is the GMP build directory and ‘GMPINSTALL’ the directory where you have installed GMP. Because of the internal header files required by MPFR, the option ‘--with-gmp=GMPINSTALL’ is not sufficient and should not be used. If you get error messages, you might check that you use the same compiler and compile options as for GNU MP (see the ‘INSTALL’ file).

3. ‘make’
   This will compile MPFR, and create a library archive file ‘libmpfr.a’ in the working directory. No dynamic library is provided yet.

4. ‘make check’
   This will make sure MPFR was built correctly. If you get error messages, please report this to ‘mpfr@loria.fr’. (See Chapter 3 [Reporting Bugs], page 4, for information on what to include in useful bug reports.)

5. ‘make install’
   This will copy the files ‘mpfr.h’ and ‘mpf2mpfr.h’ to the directory ‘/usr/local/include’, the file ‘libmpfr.a’ to the directory ‘/usr/local/lib’, and the file ‘mpfr.info’ to the directory ‘/usr/local/info’ (or if you passed the ‘--prefix’ option to ‘configure’, using the prefix directory given as argument to ‘--prefix’ instead of ‘/usr/local’).

There are some other useful make targets:

- ‘mpfr.info’ or ‘info’
  Create an info version of the manual, in ‘mpfr.info’.
- ‘mpfr.dvi’ or ‘dvi’
  Create a DVI version of the manual, in ‘mpfr.dvi’.
- ‘mpfr.ps’
  Create a Postscript version of the manual, in ‘mpfr.ps’.
- ‘clean’
  Delete all object files and archive files, but not the configuration files.
- ‘distclean’
  Delete all files not included in the distribution.
- ‘uninstall’
  Delete all files copied by ‘make install’.

2.1 Known Build Problems

MPFR suffers from all bugs from the GNU MP library, plus many many more.

Please report other problems to ‘mpfr@loria.fr’. See Chapter 3 [Reporting Bugs], page 4. Some bug fixes are available on the MPFR web page http://www.loria.fr/projets/mpfr/ or http://www.mpfr.org/.
3 Reporting Bugs

If you think you have found a bug in the MPFR library, first have a look on the MPFR web page http://www.mpfr.org/ or http://www.loria.fr/projets/mpfr/: perhaps this bug is already known, in which case you may find there a workaround for it. Otherwise, please investigate and report it. We have made this library available to you, and it is not to ask too much from you, to ask you to report the bugs that you find.

There are a few things you should think about when you put your bug report together.

You have to send us a test case that makes it possible for us to reproduce the bug. Include instructions on how to run the test case.

You also have to explain what is wrong; if you get a crash, or if the results printed are incorrect and in that case, in what way.

Please include compiler version information in your bug report. This can be extracted using ‘cc -V’ on some machines, or, if you’re using gcc, ‘gcc -v’. Also, include the output from ‘uname -a’.

If your bug report is good, we will do our best to help you to get a corrected version of the library; if the bug report is poor, we won’t do anything about it (aside of chiding you to send better bug reports).

Send your bug report to: ‘mpfr@loria.fr’.

If you think something in this manual is unclear, or downright incorrect, or if the language needs to be improved, please send a note to the same address.
Chapter 4: MPFR Basics

4 MPFR Basics

All declarations needed to use MPFR are collected in the include file `mpfr.h`. It is designed to work with both C and C++ compilers. You should include that file in any program using the MPFR library:

```c
#include <mpfr.h>
```

4.1 Nomenclature and Types

A floating-point number or float for short, is an arbitrary precision mantissa with a limited precision exponent. The C data type for such objects is `mpfr_t`. A floating-point number can have three special values: Not-a-Number (NaN) or plus or minus Infinity. NaN represents an uninitialized object, the result of an invalid operation (like 0 divided by 0), or a value that cannot be determined (like +Infinity minus +Infinity). Moreover, like in the IEEE 754-1985 standard, zero is signed, i.e. there are both +0 and -0; the behavior is the same as in the IEEE 754-1985 standard and it is generalized to the other functions supported by MPFR.

The Precision is the number of bits used to represent the mantissa of a floating-point number; the corresponding C data type is `mp_prec_t`. The precision can be any integer between MPFR_PREC_MIN and MPFR_PREC_MAX. In the current implementation, MPFR_PREC_MIN is equal to 2 and MPFR_PREC_MAX is equal to ULONG_MAX/2.

The rounding mode specifies the way to round the result of a floating-point operation, in case the exact result cannot be represented exactly in the destination mantissa; the corresponding C data type is `mp_rnd_t`.

A limb means the part of a multi-precision number that fits in a single word. (We chose this word because a limb of the human body is analogous to a digit, only larger, and containing several digits.) Normally a limb contains 32 or 64 bits. The C data type for a limb is `mp_limb_t`.

4.2 Function Classes

There is only one class of functions in the MPFR library:

1. Functions for floating-point arithmetic, with names beginning with `mpfr_`. The associated type is `mpfr_t`.

4.3 MPFR Variable Conventions

As a general rule, all MPFR functions expect output arguments before input arguments. This notation is based on an analogy with the assignment operator.

MPFR allows you to use the same variable for both input and output in the same expression. For example, the main function for floating-point multiplication, `mpfr_mul`, can be used like this: `mpfr_mul (x, x, x, rnd_mode)`. This computes the square of x with rounding mode `rnd_mode` and puts the result back in x.

Before you can assign to an MPFR variable, you need to initialize it by calling one of the special initialization functions. When you’re done with a variable, you need to clear it out, using one of the functions for that purpose.

A variable should only be initialized once, or at least cleared out between each initialization. After a variable has been initialized, it may be assigned to any number of times.
For efficiency reasons, avoid to initialize and clear out a variable in loops. Instead, initialize it before entering the loop, and clear it out after the loop has exited.

You don’t need to be concerned about allocating additional space for MPFR variables, since any variable has a mantissa of fixed size. Hence unless you change its precision, or clear and reinitialize it, a floating-point variable will have the same allocated space during all its life.

### 4.4 Compatibility with MPF

A header file `mpf2mpfr.h` is included in the distribution of MPFR for compatibility with the GNU MP class MPF. After inserting the following two lines after the `#include <gmp.h>` line,

```c
#include <mpfr.h>
#include <mpf2mpfr.h>
```

any program written for MPF can be compiled directly with MPFR without any changes. All operations are then performed with the default MPFR rounding mode, which can be reset with `mpfr_set_default_rounding_mode`.

```c
mp_rnd_t __mpfr_default_rounding_mode
```

Global Variable

The default rounding mode (to nearest initially).

### 4.5 Getting the Latest Version of MPFR

5 Floating-point Functions

The floating-point functions expect arguments of type `mpfr_t`.

The MPFR floating-point functions have an interface that is similar to the GNU MP integer functions. The function prefix for floating-point operations is `mpfr_`.

There is one significant characteristic of floating-point numbers that has motivated a difference between this function class and other GNU MP function classes: the inherent inexactness of floating-point arithmetic. The user has to specify the precision for each variable. A computation that assigns a variable will take place with the precision of the assigned variable; the cost of that computation should not depend from the precision of variables used as input (on average).

The semantics of a calculation in MPFR is specified as follows: Compute the requested operation exactly (with “infinite accuracy”), and round the result to the precision of the destination variable, with the given rounding mode. The MPFR floating-point functions are intended to be a smooth extension of the IEEE 754-1985 arithmetic. The results obtained on one computer should not differ from the results obtained on a computer with a different word size.

MPFR does not keep track of the accuracy of a computation. This is left to the user or to a higher layer. As a consequence, if two variables are used to store only a few significant bits, and their product is stored in a variable with large precision, then MPFR will still compute the result with full precision.

5.1 Rounding Modes

The following four rounding modes are supported:

- `GMP_RNDN`: round to nearest
- `GMP_RNDZ`: round towards zero
- `GMP_RNDU`: round towards plus infinity
- `GMP_RNDD`: round towards minus infinity

The ‘round to nearest’ mode works as in the IEEE 754-1985 standard: in case the number to be rounded lies exactly in the middle of two representable numbers, it is rounded to the one with the least significant bit set to zero. For example, the number 5/2, which is represented by \((10.1)\) in binary, is rounded to \((10.0) = 2\) with a precision of two bits, and not to \((11.0) = 3\). This rule avoids the drift phenomenon mentioned by Knuth in volume 2 of The Art of Computer Programming (Section 4.2.2).

Most MPFR functions take as first argument the destination variable, as second and following arguments the input variables, as last argument a rounding mode, and have a return value of type `int`, called the ternary value. The value stored in the destination variable is exactly rounded, i.e. MPFR behaves as if it computed the result with an infinite precision, then rounded it to the precision of this variable. The input variables are regarded as exact (in particular, their precision does not affect the result).

Unless documented otherwise, functions returning an `int` return a ternary value. If the ternary value is zero, it means that the value stored in the destination variable is the exact result of the corresponding mathematical function. If the ternary value is positive (resp. negative), it means the value stored in the destination variable is greater (resp. lower) than the exact result. For example with the `GMP_RNDU` rounding mode, the ternary value is usually positive, except when the result is exact, in which case it is zero. In the case of an infinite result, it is considered as inexact when it was obtained by overflow, and exact otherwise. A NaN result (Not-a-Number) always corresponds to an exact return value.
Function

void mpfr_set_default_rounding_mode (mp_rnd_t rnd)
Sets the default rounding mode to *rnd*. The default rounding mode is to nearest initially.

Function

int mpfr_prec_round (mpfr_t x, mp_prec_t prec, mp_rnd_t rnd)
Rounds *x* according to *rnd* with precision *prec*, which must be an integer between MPFR_PREC_MIN and MPFR_PREC_MAX (otherwise the behavior is undefined). If *prec* is greater or equal to the precision of *x*, then new space is allocated for the mantissa, and it is filled with zeros. Otherwise, the mantissa is rounded to precision *prec* with the given direction. In both cases, the precision of *x* is changed to *prec*.

Function

int mpfr_round_prec (mpfr_t x, mp_rnd_t rnd, mp_prec_t prec)
[This function is obsolete. Please use mpfr_prec_round instead.]

Function

char * mpfr_print_rnd_mode (mp_rnd_t rnd)
Returns the input string (GMP_RNDD, GMP_RNDU, GMP_RNDN, GMP_RNDZ) corresponding to the rounding mode *rnd* or a null pointer if *rnd* is an invalid rounding mode.

### 5.2 Exceptions

Note: Overflow handling is still experimental and currently implemented very partially. If an overflow occurs internally at the wrong place, anything can happen (crash, wrong results, etc).

Function

mp_exp_t mpfr_get_emin (void)
mp_exp_t mpfr_get_emax (void)
Return the (current) smallest and largest exponents allowed for a floating-point variable. The smallest positive value of a floating-point variable is \(1/2 \times 2^{emin}\) and the largest value has the form \((1 - \varepsilon) \times 2^{emax}\).

Function

int mpfr_set_emin (mp_exp_t exp)
int mpfr_set_emax (mp_exp_t exp)
Set the smallest and largest exponents allowed for a floating-point variable. Return a non-zero value when *exp* is not in the range accepted by the implementation (in that case the smallest or largest exponent is not changed), and zero otherwise. If the user changes the exponent range, it is her/his responsibility to check that all current floating-point variables are in the new allowed range (for example using mpfr_check_range), otherwise the subsequent behavior will be undefined, in the sense of the ISO C standard.

Function

int mpfr_check_range (mpfr_t x, int t, mp_rnd_t rnd)
This function forces *x* to be in the current range of acceptable values, *t* being the current ternary value: negative if *x* is smaller than the exact value, positive if *x* is larger than the exact value and zero if *x* is exact (before the call). It generates an underflow or an overflow if the exponent of *x* is outside the current allowed range; the value of *t* may be used to avoid a double rounding. This function returns zero if the rounded result is equal to the exact one, a positive value if the rounded result is larger than the exact one, a negative value if the rounded result is smaller than the exact one. Note that unlike most functions, the result is compared to the exact one, not the input value *x*, i.e. the ternary value is propagated.
void mpfr_clear_underflow (void)
void mpfr_clear_overflow (void)
void mpfr_clear_nanflag (void)
void mpfr_clear_inexflag (void)

Clear the underflow, overflow, invalid, and inexact flags.

void mpfr_clear_flags (void)
Clear all global flags (underflow, overflow, inexact, invalid).

int mpfr_underflow_p (void)
int mpfr_overflow_p (void)
int mpfr_nanflag_p (void)
int mpfr_inexflag_p (void)

Return the corresponding (underflow, overflow, invalid, inexact) flag, which is non-zero iff the flag is set.

5.3 Initialization Functions

void mpfr_set_default_prec (mp_prec_t prec)
Set the default precision to be exactly prec bits. The precision of a variable means the number of bits used to store its mantissa. All subsequent calls to mpfr_init will use this precision, but previously initialized variables are unaffected. This default precision is set to 53 bits initially. The precision can be any integer between MPFR_PREC_MIN and MPFR_PREC_MAX.

mp_prec_t mpfr_get_default_prec (void)
Returns the default MPFR precision in bits.

An mpfr_t object must be initialized before storing the first value in it. The functions mpfr_init and mpfr_init2 are used for that purpose.

void mpfr_init (mpfr_t x)
Initialize x and set its value to NaN.

Normally, a variable should be initialized once only or at least be cleared, using mpfr_clear, between initializations. The precision of x is the default precision, which can be changed by a call to mpfr_set_default_prec.

void mpfr_init2 (mpfr_t x, mp_prec_t prec)
Initialize x, set its precision to be exactly prec bits and its value to NaN.

Normally, a variable should be initialized once only or at least be cleared, using mpfr_clear, between initializations. To change the precision of a variable which has already been initialized, use mpfr_set_prec. The precision prec must be an integer between MPFR_PREC_MIN and MPFR_PREC_MAX (otherwise the behavior is undefined).

void mpfr_clear (mpfr_t x)
Free the space occupied by x. Make sure to call this function for all mpfr_t variables when you are done with them.
Here is an example on how to initialize floating-point variables:

```c
{
    mpfr_t x, y;
    mpfr_init (x); /* use default precision */
    mpfr_init2 (y, 256); /* precision exactly 256 bits */
    ...
    /* When the program is about to exit, do ... */
    mpfr_clear (x);
    mpfr_clear (y);
}
```

The following functions are useful for changing the precision during a calculation. A typical use would be for adjusting the precision gradually in iterative algorithms like Newton-Raphson, making the computation precision closely match the actual accurate part of the numbers.

```c
void mpfr_set_prec (mpfr_t x, mp_prec_t prec)  
Function
Reset the precision of x to be exactly prec bits, and set its value to NaN. The previous value stored in x is lost. It is equivalent to a call to mpfr_clear(x) followed by a call to mpfr_init2(x, prec), but more efficient as no allocation is done in case the current allocated space for the mantissa of x is enough. The precision prec can be any integer between MPFR_PREC_MIN and MPFR_PREC_MAX.

In case you want to keep the previous value stored in x, use mpfr_prec_round instead.

```c
mp_prec_t mpfr_get_prec (mpfr_t x)
Function
Return the precision actually used for assignments of x, i.e. the number of bits used to store its mantissa.
```

```c
void mpfr_set_prec_raw (mpfr_t x, mp_prec_t prec)  
Function
Reset the precision of x to be exactly prec bits. The only difference with mpfr_set_prec is that prec is assumed to be small enough so that the mantissa fits into the current allocated memory space for x. Otherwise the behavior is undefined.
```

### 5.4 Assignment Functions

These functions assign new values to already initialized floats (see Section 5.3 [Initialization Functions], page 9).

```c
int mpfr_set (mpfr_t rop, mpfr_t op, mp_rnd_t rnd)  
Function
int mpfr_set_ui (mpfr_t rop, unsigned long int op, mp_rnd_t rnd)  
Function
int mpfr_set_si (mpfr_t rop, long int op, mp_rnd_t rnd)  
Function
int mpfr_set_d (mpfr_t rop, double op, mp_rnd_t rnd)  
Function
int mpfr_set_ld (mpfr_t rop, long double op, mp_rnd_t rnd)  
Function
int mpfr_set_z (mpfr_t rop, mpz_t op, mp_rnd_t rnd)  
Function
int mpfr_set_q (mpfr_t rop, mpq_t op, mp_rnd_t rnd)  
Function
int mpfr_set_f (mpfr_t rop, mpf_t op, mp_rnd_t rnd)  
Function
Set the value of rop from op, rounded towards the given direction rnd.
```

```c
int mpfr_set_str (mpfr_t x, const char *s, int base, mp_rnd_t rnd)  
Function
Set x to the value of the whole string s in base base (between 2 and 36), rounded in direction rnd. See the documentation of mpfr_inp_str for a detailed description of the
valid string formats. This function returns 0 if the entire string up to the final \(\backslash 0\) is a valid number in base base; otherwise it returns \(-1\).

```c
void mpfr_set_inf (mpfr_t x, int sign) // Function
void mpfr_set_nan (mpfr_t x) // Function
Set the variable x to infinity or NaN (Not-a-Number) respectively. In mpfr_set_inf, x is set to plus infinity iff sign is nonnegative.
```

```c
void mpfr_swap (mpfr_t x, mpfr_t y) // Function
Swap the values x and y efficiently. Warning: the precisions are exchanged too; in case the precisions are different, mpfr_swap is thus not equivalent to three mpfr_set calls using a third auxiliary variable.
```

### 5.5 Combined Initialization and Assignment Functions

```c
int mpfr_init_set (mpfr_t rop, mpfr_t op, mp_rnd_t rnd) // Macro
int mpfr_init_set_ui (mpfr_t rop, unsigned long int op, mp_rnd_t rnd) // Macro
int mpfr_init_set_si (mpfr_t rop, signed long int op, mp_rnd_t rnd) // Macro
int mpfr_init_set_d (mpfr_t rop, double op, mp_rnd_t rnd) // Macro
int mpfr_init_set_ld (mpfr_t rop, long double op, mp_rnd_t rnd) // Macro
int mpfr_init_set_z (mpfr_t rop, mpz_t op, mp_rnd_t rnd) // Macro
int mpfr_init_set_q (mpfr_t rop, mpq_t op, mp_rnd_t rnd) // Macro
int mpfr_init_set_f (mpfr_t rop, mpf_t op, mp_rnd_t rnd) // Macro
```

Initialize rop and set its value from op, rounded in the direction rnd. The precision of rop will be taken from the active default precision, as set by mpfr_set_default_prec.

```c
int mpfr_init_set_str (mpfr_t x, const char *s, int base, mp_rnd_t rnd) // Function
```

Initialize x and set its value from the string s in base base, rounded in the direction rnd. See mpfr_set_str.

### 5.6 Conversion Functions

```c
double mpfr_get_d (mpfr_t op, mp_rnd_t rnd) // Function
long double mpfr_get_ld (mpfr_t op, mp_rnd_t rnd) // Function
```

Convert op to a double (respectively long double), using the rounding mode rnd.

```c
double mpfr_get_d1 (mpfr_t op) // Function
```

Convert op to a double, using the default MPFR rounding mode (see function mpfr_set_default_rounding_mode). This function is obsolete.

```c
double mpfr_get_d_2exp (long *exp, mpfr_t op, mp_rnd_t rnd) // Function
```

Return d and set exp such that 0.5 \(\leq |d| < 1\) and \(d \times 2^\text{exp}\) equals op rounded to double precision, using the given rounding mode.

```c
long mpfr_get_si (mpfr_t op, mp_rnd_t rnd) // Function
unsigned long mpfr_get_ui (mpfr_t op, mp_rnd_t op) // Function
```

Convert op to a long or unsigned long, after rounding it with respect to rnd. If op is NaN or Inf, or too big for the return type, the result is undefined.

See also mpfr_fits_slong_p and mpfr_fits_ulong_p.
Function

mpfr_get_z_exp (mpz_t \( z \), mpfr_t \( op \))

Put the scaled mantissa of \( op \) (regarded as an integer, with the precision of \( op \)) into \( z \), and return the exponent \( \exp \) (which may be outside the current exponent range) such that \( op \) exactly equals \( z \times 2^\exp \). If the exponent is not representable in the \( \text{mp}_\exp\_t \) type, the behavior is undefined.

Function

char * mpfr_get_str (char *\( str \), mp_exp_t *\( expptr \), int \( base \), size_t \( n \), mpfr_t \( op \), mp_rnd_t \( rnd \))

Convert \( op \) to a string of digits in base \( base \), with rounding in direction \( rnd \). The base may vary from 2 to 36.

The generated string is a fraction, with an implicit radix point immediately to the left of the first digit. For example, the number 3.1416 would be returned as "31416" in the string and 1 written at \( expptr \).

If \( n \) is zero, the number of digits of the mantissa is determined automatically from the precision of \( op \) and the value of \( base \). Warning: this functionality may disappear or change in future versions. Otherwise generate exactly \( n \) significant digits, which must be at least 2.

If \( str \) is a null pointer, space for the mantissa is allocated using the current allocation function, and a pointer to the string is returned. The block will be \( \text{strlen}(s)+1 \) bytes. For more information on how this block is allocated and how to free it: see section “Custom Allocation” in GNU MP.

If \( str \) is not a null pointer, it should point to a block of storage large enough for the mantissa, i.e., at least \( n + 2 \). The extra two bytes are for a possible minus sign, and for the terminating null character.

If \( n \) is 0, note that the space requirements for \( str \) in this case will be impossible for the user to predetermine. Therefore, one needs to pass a null pointer for the string argument whenever \( n \) is 0.

If the input number is an ordinary number, the exponent is written through the pointer \( expptr \) (the current minimal exponent for 0).

A pointer to the string is returned, unless there is an error, in which case a null pointer is returned.

Function

int mpfrfits_ulong (mpfr_t \( op \), mp_rnd_t \( rnd \))

int mpfrfits_slong (mpfr_t \( op \), mp_rnd_t \( rnd \))

int mpfrfits_uint (mpfr_t \( op \), mp_rnd_t \( rnd \))

int mpfrfits_sint (mpfr_t \( op \), mp_rnd_t \( rnd \))

int mpfrfits_ushort (mpfr_t \( op \), mp_rnd_t \( rnd \))

int mpfrfits_sshort (mpfr_t \( op \), mp_rnd_t \( rnd \))

Return non-zero if \( op \) would fit in the respective C data type, when rounded to an integer in the direction \( rnd \).

5.7 Basic Arithmetic Functions

Function

int mpfr_add (mpfr_t \( rop \), mpfr_t \( op1 \), mpfr_t \( op2 \), mp_rnd_t \( rnd \))

int mpfr_add_ui (mpfr_t \( rop \), mpfr_t \( op1 \), unsigned long int \( op2 \), mp_rnd_t \( rnd \))

int mpfr_add_z (mpfr_t \( rop \), mpfr_t \( op1 \), mpz_t \( op2 \), mp_rnd_t \( rnd \))

int mpfr_add_q (mpfr_t \( rop \), mpfr_t \( op1 \), mpq_t \( op2 \), mp_rnd_t \( rnd \))

Set \( rop \) to \( op1 + op2 \) rounded in the direction \( rnd \).
Chapter 5: Floating-point Functions

int mpfr_sub (mpfr_t rop, mpfr_t op1, mpfr_t op2, mp_rnd_t rnd)  
  Function
int mpfr_ui_sub (mpfr_t rop, unsigned long int op1, mpfr_t op2, 
  mp_rnd_t rnd)  
  Function
int mpfr_sub_ui (mpfr_t rop, mpfr_t op1, unsigned long int op2, 
  mp_rnd_t rnd)  
  Function
int mpfr_sub_z (mpfr_t rop, mpfr_t op1, mpz_t op2, mp_rnd_t rnd)  
  Function
int mpfr_sub_q (mpfr_t rop, mpfr_t op1, mpq_t op2, mp_rnd_t rnd)  
  Function
  
  Set rop to op1 – op2 rounded in the direction rnd.

int mpfr_mul (mpfr_t rop, mpfr_t op1, mpfr_t op2, mp_rnd_t rnd)  
  Function
int mpfr_mul_ui (mpfr_t rop, mpfr_t op1, unsigned long int op2, 
  mp_rnd_t rnd)  
  Function
int mpfr_mul_z (mpfr_t rop, mpfr_t op1, mpz_t op2, mp_rnd_t rnd)  
  Function
int mpfr_mul_q (mpfr_t rop, mpfr_t op1, mpq_t op2, mp_rnd_t rnd)  
  Function
  
  Set rop to op1 × op2 rounded in the direction rnd.

int mpfr_div (mpfr_t rop, mpfr_t op1, mpfr_t op2, mp_rnd_t rnd)  
  Function
int mpfr_ui_div (mpfr_t rop, unsigned long int op1, mpfr_t op2, 
  mp_rnd_t rnd)  
  Function
int mpfr_div_ui (mpfr_t rop, mpfr_t op1, unsigned long int op2, 
  mp_rnd_t rnd)  
  Function
int mpfr_div_z (mpfr_t rop, mpfr_t op1, mpz_t op2, mp_rnd_t rnd)  
  Function
int mpfr_div_q (mpfr_t rop, mpfr_t op1, mpq_t op2, mp_rnd_t rnd)  
  Function
  
  Set rop to op1/op2 rounded in the direction rnd.

int mpfr_sqrt (mpfr_t rop, mpfr_t op, mp_rnd_t rnd)  
  Function
int mpfr_sqrt_ui (mpfr_t rop, unsigned long int op, mp_rnd_t rnd)  
  Function
  
  Set rop to \( \sqrt{op} \) rounded in the direction rnd. Return \(-0\) if rop is \(-0\) (to be consistent with the IEEE 754-1985 standard). Set rop to NaN if op is negative.

int mpfr_cbrt (mpfr_t rop, mpfr_t op, mp_rnd_t rnd)  
  Function
  
  Set rop to the cubic root (defined over the real numbers) of op rounded in the direction rnd.

int mpfr_pow (mpfr_t rop, mpfr_t op1, mpfr_t op2, mp_rnd_t rnd)  
  Function
int mpfr_pow_ui (mpfr_t rop, mpfr_t op1, unsigned long int op2, 
  mp_rnd_t rnd)  
  Function
int mpfr_pow_si (mpfr_t rop, mpfr_t op1, long int op2, mp_rnd_t rnd)  
  Function
int mpfr_ui_pow_ui (mpfr_t rop, unsigned long int op1, unsigned 
  long int op2, mp_rnd_t rnd)  
  Function
int mpfr_ui_pow (mpfr_t rop, unsigned long int op1, mpfr_t op2, 
  mp_rnd_t rnd)  
  Function
  
  Set rop to \( op_1^{op_2} \), rounded in the direction rnd. Special values are currently handled as described in the ISO C99 standard for the pow function:

  - pow(±0, y) returns plus or minus infinity for y a negative odd integer.
  - pow(±0, y) returns infinity for y negative and not an odd integral.
  - pow(±0, y) returns plus or minus zero for y a positive odd integer.
  - pow(±0, y) returns plus zero for y positive and not an odd integer.
  - pow(−1, ±inf) returns 1.
  - pow(+1, y) returns 1 for any x, even a NaN.
• \( \text{pow}(x, y) \) returns NaN for finite negative \( x \) and finite non-integer \( y \).

• \( \text{pow}(x, -\infty) \) returns plus infinity for \( 0 < |x| < 1 \), and plus zero for \( |x| > 1 \).

• \( \text{pow}(x, +\infty) \) returns plus zero for \( 0 < |x| < 1 \), and plus infinity for \( |x| > 1 \).

• \( \text{pow}(-\infty, y) \) returns minus zero for \( y \) a negative odd integer.

• \( \text{pow}(-\infty, y) \) returns plus zero for \( y \) negative and not an odd integer.

• \( \text{pow}(-\infty, y) \) returns minus infinity for \( y \) a positive odd integer.

• \( \text{pow}(+\infty, y) \) returns plus infinity for \( y \) positive and not an odd integer.

• \( \text{pow}(+\infty, y) \) returns plus zero for \( y \) negative, and plus infinity for \( y \) positive.

\[
\text{int mpfr_neg (mpfr_t rop, mpfr_t op, mp_rnd_t rnd)}
\]
\[
\text{Set rop to } -\text{op rounded in the direction rnd. Just changes the sign if rop and op are the same variable.}
\]

\[
\text{int mpfr_abs (mpfr_t rop, mpfr_t op, mp_rnd_t rnd)}
\]
\[
\text{Set rop to the absolute value of op, rounded in the direction rnd.}
\]

\[
\text{int mpfr_mul_2ui (mpfr_t rop, mpfr_t op1, unsigned long int op2, mp_rnd_t rnd)}
\]
\[
\text{int mpfr_mul_2si (mpfr_t rop, mpfr_t op1, long int op2, mp_rnd_t rnd)}
\]
\[
\text{int mpfr_mul_2exp (mpfr_t rop, mpfr_t op1, unsigned long int op2, mp_rnd_t rnd)}
\]
\[
\text{Set rop to op1 } \times 2^{\text{op2}} \text{ rounded in the direction rnd. Just increases the exponent by op2 when rop and op1 are identical. [mpfr_mul_2exp is kept for upward compatibility.]}
\]

\[
\text{int mpfr_div_2ui (mpfr_t rop, mpfr_t op1, unsigned long int op2, mp_rnd_t rnd)}
\]
\[
\text{int mpfr_div_2si (mpfr_t rop, mpfr_t op1, long int op2, mp_rnd_t rnd)}
\]
\[
\text{int mpfr_div_2exp (mpfr_t rop, mpfr_t op1, unsigned long int op2, mp_rnd_t rnd)}
\]
\[
\text{Set rop to op1 } / 2^{\text{op2}} \text{ rounded in the direction rnd. Just decreases the exponent by op2 when rop and op1 are identical. [mpfr_div_2exp is kept for upward compatibility.]}
\]

### 5.8 Comparison Functions

\[
\text{int mpfr_cmp (mpfr_t op1, mpfr_t op2)}
\]
\[
\text{int mpfr_cmp_ui (mpfr_t op1, unsigned long int op2)}
\]
\[
\text{int mpfr_cmp_si (mpfr_t op1, signed long int op2)}
\]
\[
\text{int mpfr_cmp_d (mpfr_t op1, double op2)}
\]
\[
\text{Compare op1 and op2. Return a positive value if op1 > op2, zero if op1 = op2, and a negative value if op1 < op2. Both op1 and op2 are considered to their full own precision, which may differ. If one of the operands is NaN (Not-a-Number), the behavior is undefined.}
\]

\[
\text{int mpfr_cmp_ui_2exp (mpfr_t op1, unsigned long int op2, mp_exp_t e)}
\]
\[
\text{int mpfr_cmp_si_2exp (mpfr_t op1, long int op2, mp_exp_t e)}
\]
\[
\text{Compare op1 and op2 } \times 2^{\text{e}}. \text{ Similar as above.}
\]
Function `int mpfr_cmpabs (mpfr_t op1, mpfr_t op2)` 
Compare $|op1|$ and $|op2|$. Return a positive value if $|op1| > |op2|$, zero if $|op1| = |op2|$, and a negative value if $|op1| < |op2|$. If one of the operands is NaN (Not-a-Number), the behavior is undefined.

Function `int mpfr_eq (mpfr_t op1, mpfr_t op2, unsigned long int op3)` 
Return non-zero if $op1$ and $op2$ are both non-zero ordinary numbers with the same exponent and the same first $op3$ bits, both zero, or both infinities of the same sign. Return zero otherwise. This function is defined for compatibility with `mpf`, but does not make much sense.

Function `int mpfr_nan_p (mpfr_t op)` 
Return non-zero if $op$ is respectively Not-a-Number (NaN), an infinity, an ordinary number (i.e. neither Not-a-Number nor an infinity). Return zero otherwise.

Function `int mpfr_inf_p (mpfr_t op)` 

Function `int mpfr_number_p (mpfr_t op)` 
Return non-zero if $op$ is respectively Not-a-Number (NaN), an infinity, an ordinary number (i.e. neither Not-a-Number nor an infinity). Return zero otherwise.

Function `void mpfr_reldiff (mpfr_t rop, mpfr_t op1, mpfr_t op2, mp_rnd_t rnd)` 
Compute the relative difference between $op1$ and $op2$ and store the result in $rop$. This function does not guarantee the exact rounding on the relative difference; it just computes $|op1 - op2|/op1$, using the rounding mode $rnd$ for all operations and the precision of $rop$.

Function `int mpfr_sgn (mpfr_t op)` 
Return a positive value if $op > 0$, zero if $op = 0$, and a negative value if $op < 0$. Its result is undefined when $op$ is NaN (Not-a-Number).

This function is actually implemented as a macro. It may evaluate its argument multiple times.

Function `int mpfr_greater_p (mpfr_t op1, mpfr_t op2)` 
Return non-zero if $op1 > op2$, zero otherwise.

Function `int mpfr_greaterequal_p (mpfr_t op1, mpfr_t op2)` 
Return non-zero if $op1 \geq op2$, zero otherwise.

Function `int mpfr_less_p (mpfr_t op1, mpfr_t op2)` 
Return non-zero if $op1 < op2$, zero otherwise.

Function `int mpfr_lerossequal_p (mpfr_t op1, mpfr_t op2)` 
Return non-zero if $op1 \leq op2$, zero otherwise.

Function `int mpfr_lessgreater_p (mpfr_t op1, mpfr_t op2)` 
Return non-zero if $op1 < op2$ or $op1 > op2$ (i.e. neither $op1$, nor $op2$ is NaN, and $op1 \neq op2$), zero otherwise (i.e. $op1$ and/or $op2$ are NaN, or $op1 = op2$).

Function `int mpfr_equal_p (mpfr_t op1, mpfr_t op2)` 
Return non-zero if $op1 = op2$, zero otherwise (i.e. $op1$ and/or $op2$ are NaN, or $op1 \neq op2$).

Function `int mpfr_unordered_p (mpfr_t op1, mpfr_t op2)` 
Return non-zero if $op1$ or $op2$ is a NaN (i.e. they cannot be compared), zero otherwise.
### 5.9 Special Functions

All those functions, except explicitly stated, return zero for an exact return value, a positive value for a return value larger than the exact result, and a negative value otherwise.

#### Function

```c
int mpfr_log (mpfr_t rop, mpfr_t op, mp_rnd_t rnd)
```

Set `rop` to the natural logarithm of `op`, rounded in the direction `rnd`.

```c
int mpfr_log2 (mpfr_t rop, mpfr_t op, mp_rnd_t rnd)
```

Set `rop` to the base-2 logarithm of `op`, rounded in the direction `rnd`.

```c
int mpfr_log10 (mpfr_t rop, mpfr_t op, mp_rnd_t rnd)
```

Set `rop` to the base-10 logarithm of `op`, rounded in the direction `rnd`.

#### Function

```c
int mpfr_exp (mpfr_t rop, mpfr_t op, mp_rnd_t rnd)
```

Set `rop` to the exponential of `op`, rounded in the direction `rnd`.

```c
int mpfr_exp2 (mpfr_t rop, mpfr_t op, mp_rnd_t rnd)
```

Set `rop` to $2^op$, rounded in the direction `rnd`.

#### Function

```c
int mpfr_cos (mpfr_t rop, mpfr_t op, mp_rnd_t rnd)
int mpfr_sin (mpfr_t rop, mpfr_t op, mp_rnd_t rnd)
int mpfr_tan (mpfr_t rop, mpfr_t op, mp_rnd_t rnd)
```

Set `rop` to the cosine, sine or tangent of `op`, rounded in the direction `rnd`.

#### Function

```c
int mpfr_sin_cos (mpfr_t sop, mpfr_t cop, mpfr_t op, mp_rnd_t rnd)
```

Set simultaneously `sop` to the sine of `op` and `cop` to the cosine of `op`, rounded in the direction `rnd` with the corresponding precisions of `sop` and `cop`. Return 0 iff both results are exact.

#### Function

```c
int mpfr_acos (mpfr_t rop, mpfr_t op, mp_rnd_t rnd)
int mpfr_asin (mpfr_t rop, mpfr_t op, mp_rnd_t rnd)
int mpfr_atan (mpfr_t rop, mpfr_t op, mp_rnd_t rnd)
```

Set `rop` to the arc-cosine, arc-sine or arc-tangent of `op`, rounded in the direction `rnd`.

#### Function

```c
int mpfr_cosh (mpfr_t rop, mpfr_t op, mp_rnd_t rnd)
int mpfr_sinh (mpfr_t rop, mpfr_t op, mp_rnd_t rnd)
int mpfr_tanh (mpfr_t rop, mpfr_t op, mp_rnd_t rnd)
```

Set `rop` to the hyperbolic cosine, sine or tangent of `op`, rounded in the direction `rnd`.

#### Function

```c
int mpfr_acosh (mpfr_t rop, mpfr_t op, mp_rnd_t rnd)
int mpfr_asinh (mpfr_t rop, mpfr_t op, mp_rnd_t rnd)
int mpfr_atanh (mpfr_t rop, mpfr_t op, mp_rnd_t rnd)
```

Set `rop` to the inverse hyperbolic cosine, sine or tangent of `op`, rounded in the direction `rnd`.

#### Function

```c
int mpfr_fac_ui (mpfr_t rop, unsigned long int op, mp_rnd_t rnd)
```

Set `rop` to the factorial of the `unsigned long int` `op`, rounded in the direction `rnd`.

#### Function

```c
int mpfr_log1p (mpfr_t rop, mpfr_t op, mp_rnd_t rnd)
```

Set `rop` to the logarithm of one plus `op`, rounded in the direction `rnd`. 
5.10 Input and Output Functions

This section describes functions that perform input from an input/output stream, and functions that output to an input/output stream. Passing a null pointer for a stream argument to any of these functions will make them read from stdin and write to stdout, respectively.

When using any of these functions, you must include the <stdio.h> standard header before ‘mpfr.h’, to allow ‘mpfr.h’ to define prototypes for these functions.

size_t mpfr_out_str (FILE *stream, int base, size_t n, mpfr_t op, mp_rnd_t rnd)  
Output op on stream stream, as a string of digits in base base, rounded in direction rnd. The base may vary from 2 to 36. Print n significant digits exactly, or if n is 0, the maximum number of digits accurately representable by op (this feature may disappear).

In addition to the significant digits, a decimal point at the right of the first digit and a trailing exponent in base 10, in the form ‘eNNN’, are printed. If base is greater than 10, ‘@’ will be used instead of ‘e’ as exponent delimiter.

Return the number of bytes written, or if an error occurred, return 0.
size_t mpfr_inp_str (mpfr_t rop, FILE *stream, int base, mp_rnd_t rnd)

Input a string in base base from stream stream, rounded in direction rnd, and put the
read float in rop. The string is of the form ‘M@N’ or, if the base is 10 or less, alternatively
‘MeN’ or ‘MEN’, or, if the base is 16, alternatively ‘MpB’ or ‘MPB’. ‘M’ is the mantissa in the
specified base, ‘N’ is the exponent written in decimal for the specified base, and in base
16, ‘B’ is the binary exponent written in decimal (i.e. it indicates the power of 2 by which
the mantissa is to be scaled). The argument base may be in the range 2 to 36.

Special values can be read as follows (the case does not matter): @NaN@, @Inf@, +@Inf@ and
-@Inf@, possibly followed by other characters; if the base is smaller or equal to 16,
the following strings are accepted too: NaN, Inf, +Inf and -Inf.

Return the number of bytes read, or if an error occurred, return 0.

5.11 Miscellaneous Functions

int mpfr_rint (mpfr_t rop, mpfr_t op, mp_rnd_t rnd)

Set rop to op rounded to an integer. mpfr_rint rounds to the nearest representable integer
in the given rounding mode, mpfr ceil rounds to the next higher or equal representable
integer, mpfr floor to the next lower or equal representable integer, mpfr round to the
nearest representable integer, rounding halfway cases away from zero, and mpfr trunc to
the next representable integer towards zero.

The returned value is zero when the result is exact, positive when it is greater than the
original value of op, and negative when it is smaller. More precisely, the returned value
is 0 when op is an integer representable in rop, 1 or −1 when op is an integer that is not
representable in rop, 2 or −2 when op is not an integer.

Note that mpfr_round is different from mpfr_rint called with the rounding to the nearest
mode (where halfway cases are rounded to an even integer or mantissa). Note also that
no double rounding is performed; for instance, 4.5 (100.1 in binary) is rounded by mpfr_{
round} to 4 (100 in binary) in 2-bit precision, though round(4.5) is equal to 5 and 5 (101
in binary) is rounded to 6 (110 in binary) in 2-bit precision.

int mpfr_frac (mpfr_t rop, mpfr_t op, mp_rnd_t rnd)

Set rop to the fractional part of op, having the same sign as op, rounded in the direction
rnd (unlike in mpfr_rint, rnd affects only how the exact fractional part is rounded, not
how the fractional part is generated).

int mpfr_integer_p (mpfr_t op)

Return non-zero iff op is an integer.

void mpfr_nexttoward (mpfr_t x, mpfr_t y)

If x or y is NaN, set x to NaN. Otherwise, if x is different from y, replace x by the
next floating-point number (with the precision of x and the current exponent range) in
the direction of y, if there is one (the infinite values are seen as the smallest and largest
floating-point numbers). If the result is zero, it keeps the same sign. No underflow or
overflow is generated.
void mpfr_nextabove (mpfr_t x)
   Equivalent to mpfr_nexttoward where y is plus infinity.

void mpfr_nextbelow (mpfr_t x)
   Equivalent to mpfr_nexttoward where y is minus infinity.

int mpfr_urandomb (mpfr_t rop, gmp_randstate_t state)
   Generate a uniformly distributed random float in the interval 0 ≤ rop < 1. Return 0,
   unless the exponent is not in the current exponent range, in which case rop is set to NaN
   and a non-zero value is returned.

void mpfr_random (mpfr_t rop)
   Generate a uniformly distributed random float in the interval 0 ≤ rop < 1. This function
   is deprecated; mpfr_urandomb should be used instead.

void mpfr_random2 (mpfr_t rop, mp_size_t size, mp_exp_t exp)
   Generate a random float of at most size limbs, with long strings of zeros and ones in the
   binary representation. The exponent of the number is in the interval −exp to exp. This
   function is useful for testing functions and algorithms, since this kind of random numbers
   have proven to be more likely to trigger corner-case bugs. Negative random numbers are
   generated when size is negative.

5.12 Internals
The following types and functions were mainly designed for the implementation of mpfr, but
may be useful for users too. However no upward compatibility is guaranteed. You may need to
include ‘mpfr-impl.h’ to use them.

The mpfr_t type consists of four fields. The _mpfr_prec field is used to store the precision of
the variable (in bits); this is not less than MPFR_PREC_MIN.

The _mpfr_size field is used to store the number of allocated limbs, with the high bits reserved
to store the sign (bit 31), the NaN flag (bit 30), and the Infinity flag (bit 29); thus bits 0 to
28 remain for the number of allocated limbs, with a maximal value of 536870911. A NaN is
indicated by the NaN flag set, and the other fields are undefined. An Infinity is indicated by the
NaN flag clear and the Infinity flag set; the sign bit of an Infinity indicates the sign, the limb
data and the exponent are undefined.

The _mpfr_exp field stores the exponent. An exponent of 0 means a radix point just above the
most significant limb. Non-zero values n are a multiplier 2^n relative to that point.

Finally, the _mpfr_d is a pointer to the limbs, least significant limbs stored first. The number of
limbs in use is controlled by _mpfr_prec, namely ceil(_mpfr_prec/BITS_PER_MP_LIMB). Zeros
are represented by the most significant limb being zero, other limb data and the exponent are
undefined (this implies that the corresponding objects may contain invalid values, thus should
not be evaluated even if they are not taken into account). Non-zero values always have the most
significant bit of the most significant limb set to 1. When the precision does not correspond
to a whole number of limbs, the excess bits at the low end of the data are zero. When the
precision has been lowered by mpfr_set_prec, the space allocated at _mpfr_d remains as given
by _mpfr_size, but _mpfr_prec indicates how much of that space is actually used.
Function \texttt{int mpfr\_add\_one\_ulp (mpfr\_t x, mp\_rnd\_t rnd)}

Add one unit in last place (ulp) to \(x\) if \(x\) is finite and positive, subtract one ulp if \(x\) is finite and negative; otherwise, \(x\) is not changed. The return value is zero unless an overflow occurs, in which case the \texttt{mpfr\_add\_one\_ulp} function behaves like a conventional addition.

Function \texttt{int mpfr\_sub\_one\_ulp (mpfr\_t x, mp\_rnd\_t rnd)}

Subtract one ulp to \(x\) if \(x\) is finite and positive, add one ulp if \(x\) is finite and negative; otherwise, \(x\) is not changed. The return value is zero unless an underflow occurs, in which case the \texttt{mpfr\_sub\_one\_ulp} function behaves like a conventional subtraction.

Function \texttt{int mpfr\_can\_round (mpfr\_t b, mp\_exp\_t err, mp\_rnd\_t rnd1, mp\_rnd\_t rnd2, mp\_prec\_t prec)}

Assuming \(b\) is an approximation of an unknown number \(x\) in direction \(rnd1\) with error at most two to the power \(E(b) - err\) where \(E(b)\) is the exponent of \(b\), returns a non-zero value if one is able to round exactly \(x\) to precision \(prec\) with direction \(rnd2\), and 0 otherwise (including for NaN and Inf). This function \textbf{does not modify} its arguments.

Function \texttt{mp\_exp\_t mpfr\_get\_exp (mpfr\_t x)}

Get the exponent of \(x\), assuming that \(x\) is a non-zero ordinary number.

Function \texttt{int mpfr\_set\_exp (mpfr\_t x, mp\_exp\_t e)}

Set the exponent of \(x\) if \(e\) is in the current exponent range, and return 0 (even if \(x\) is not a non-zero ordinary number); otherwise, return 1.

Function \texttt{void mpfr\_set\_str\_binary (mpfr\_t x, const char *s)}

Set \(x\) to the value of the binary number in string \(s\), which has to be of the form +/-xxxx.xxxxxxEyy. The exponent is read in decimal, but is interpreted as the power of two to be multiplied by the mantissa. The mantissa length of \(s\) has to be less or equal to the precision of \(x\), otherwise an error occurs. If \(s\) starts with N, it is interpreted as NaN (Not-a-Number); if it starts with I after the sign, it is interpreted as infinity, with the corresponding sign.

Function \texttt{void mpfr\_print\_binary (mpfr\_t float)}

Output \texttt{float} on stdout in raw binary format (the exponent is written in decimal, yet).
Contributors

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References

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Concept Index

A
Accuracy .......................................................... 7
Arithmetic functions ......................................... 12
Assignment functions ........................................ 10

B
Basic arithmetic functions .................................. 12

C
Combined initialization and assignment functions .......................................................... 11
Comparison functions ......................................... 14
Conditions for copying MPFR .................................. 1
Conversion functions .......................................... 11
Copying conditions ........................................... 1

E
Exceptions .......................................................... 8

F
FDL, GNU Free Documentation License ................... 23
Float arithmetic functions ................................... 12
Float comparisons functions .................................. 14
Float functions .................................................. 7
Float input and output functions ............................ 17
Floating-point functions ...................................... 7
Floating-point number ......................................... 5

G
GNU Free Documentation License .......................... 23

I
I/O functions .......................................................... 17
Initialization functions ....................................... 9
Input functions .................................................. 17
Installation ...................................................... 3
Internals ............................................................. 19

L
Limb ................................................................. 5

M
Miscellaneous float functions ................................ 18
\texttt{mpfr.h} .......................................................... 5

O
Output functions .................................................. 17

P
Precision ........................................................... 5, 7

R
Reporting bugs .................................................... 4
Rounding Mode ................................................... 5
Rounding modes .................................................. 7

S
Special functions .................................................. 16
Function and Type Index

mpf_prec_t .......................... 5
mpfr_prec_t .......................... 5
mpfr_abs ............................ 14
mpfr_acos ............................ 16
mpfr_acosh ........................... 16
mpfr_add ................................ 12
mpfr_add_one_ulp ......................... 19
mpfr_add_q ............................ 12
mpfr_add_ui ................................ 12
mpfr_agm .................................. 17
mpfr_asin .................................. 16
mpfr_asinh .................................. 16
mpfr_atan .................................. 16
mpfr_atanh ................................ 16
mpfr_cbrt .................................. 13
mpfr_check_range ......................... 8
mpfr_clear ................................ 9
mpfr_clear_flags ......................... 9
mpfr_clear_inexflag ....................... 9
mpfr_clear_nanflag ....................... 9
mpfr_clear_underflow ...................... 8
mpfr_cmp ................................... 14
mpfr_cmp_d ................................ 14
mpfr_cmp_si ................................ 14
mpfr_cmp_si_2exp ......................... 14
mpfr_cmp_ui ................................ 14
mpfr_cmp_z ................................ 14
mpfr_cosh .................................. 16
mpfr_ctx .................................. 16
mpfr_div ................................ 13
mpfr_div_2exp .............................. 14
mpfr_div_2si ................................ 14
mpfr_div_2ui ................................ 14
mpfr_div_q ................................ 14
mpfr_div_z ................................ 13
mpfr_eq ................................... 15
mpfr_equal .................................. 15
mpfr_erf ................................... 17
mpfr_exp .................................. 16
mpfr_exp2 ................................ 16
mpfr_exp1 ................................ 17
mpfr_fac .................................. 16
mpfr_fits_si ................................ 12
mpfr_fits_slong ......................... 12
mpfr_fits_sshort ......................... 12
mpfr_fits_uint ............................ 12
mpfr_fits_ulong ......................... 12
mpfr_fits_ushort ......................... 12
mpfr_floor .................................. 18
mpfr_fma .................................. 17
mpfr_frac .................................. 18
mpfr_gamma .................................. 17
mpfr_get .................................. 11
mpfr_get_d .................................. 11
mpfr_get_d1 ................................ 11
mpfr_get_default_prec .................... 9
mpfr_get_emax ................................ 8
mpfr_get_emin ......................... 8
mpfr_get_exp ............................ 20
mpfr_get_ld ................................ 11
mpfr_get_prec .......................... 10
mpfr_get_si ............................ 11
mpfr_get_str ......................... 12
mpfr_get_ui ................................ 11
mpfr_get_z_exp ......................... 12
mpfr_greater ................................ 15
mpfr_greater_equal ....................... 15
mpfr_holder ................................ 9
mpfr_init .................................. 9
mpfr_init_set ......................... 11
mpfr_int ................................ 11
mpfr_init_set_d ......................... 11
mpfr_init_set_f ......................... 11
mpfr_init_set_ld ......................... 11
mpfr_init_set_q ......................... 11
mpfr_init_set_si ......................... 11
mpfr_init_set_str ....................... 11
mpfr_init_set_ui ......................... 11
mpfr_init_set_z ......................... 11
mpfr_init2 .................................. 9
mpfr_inp .................................. 18
mpfr_integer ................................ 18
mpfr_less .................................. 15
mpfr_less_equal ......................... 15
mpfr_less_equal ................................ 16
mpfr_less_greater ....................... 15
mpfr_lessgreater ......................... 15
mpfr_log .................................. 16
mpfr_log10 ................................ 16
mpfr_log1p ................................ 16
mpfr_log2 .................................. 16
mpfr_mul .................................. 13
mpfr_mul_2exp ......................... 14
mpfr_mul_2si ................................ 14
mpfr_mul_2ui ................................ 14
mpfr_mul .................................. 13
mpfr_mul_z ................................ 13
mpfr_mul .................................. 13
mpfr_nan .................................. 15
mpfr_nanflag ................................ 9
mpfr_neg .................................. 14
mpfr_nextabove ......................... 18
mpfr_nextbelow ......................... 19
mpfr_nexttoward ......................... 18
mpfr_number ................................ 15
mpfr_out .................................. 17
mpfr_overflow ......................... 9
mpfr_pow ................................ 13
mpfr_pow ................................ 13
mpfr_pow_si ................................ 13
mpfr_pow .................................. 13
mpfr_prec .................................. 8
mpfr_print .................................. 8
mpfr_print_binary ....................... 20
mpfr_print_rnd_mode .................... 8
mpfr_random ................................ 9
mpfr_random2 ................................ 9
mpfr_reldiff ................................ 15
mpfr_rint .................................. 18
mpfr_round .................................. 18
mpfr_round .................................. 18
mpfr_round_prec .......................... 8
<table>
<thead>
<tr>
<th>Function</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>mpfr_set</td>
<td>10</td>
</tr>
<tr>
<td>mpfr_set_d</td>
<td>10</td>
</tr>
<tr>
<td>mpfr_set_default_prec</td>
<td>9</td>
</tr>
<tr>
<td>mpfr_set_default_rounding_mode</td>
<td>7</td>
</tr>
<tr>
<td>mpfr_set_emax</td>
<td>8</td>
</tr>
<tr>
<td>mpfr_set_emin</td>
<td>8</td>
</tr>
<tr>
<td>mpfr_set_exp</td>
<td>20</td>
</tr>
<tr>
<td>mpfr_set_inf</td>
<td>11</td>
</tr>
<tr>
<td>mpfr_set_ld</td>
<td>10</td>
</tr>
<tr>
<td>mpfr_set_nan</td>
<td>11</td>
</tr>
<tr>
<td>mpfr_set_prec</td>
<td>10</td>
</tr>
<tr>
<td>mpfr_set_prec_raw</td>
<td>10</td>
</tr>
<tr>
<td>mpfr_set_q</td>
<td>10</td>
</tr>
<tr>
<td>mpfr_set_si</td>
<td>10</td>
</tr>
<tr>
<td>mpfr_set_str</td>
<td>10</td>
</tr>
<tr>
<td>mpfr_set_str_binary</td>
<td>20</td>
</tr>
<tr>
<td>mpfr_set_z</td>
<td>10</td>
</tr>
<tr>
<td>mpfr_sgn</td>
<td>15</td>
</tr>
<tr>
<td>mpfr_sin</td>
<td>16</td>
</tr>
<tr>
<td>mpfr_sin_cos</td>
<td>16</td>
</tr>
<tr>
<td>mpfr_sinh</td>
<td>16</td>
</tr>
<tr>
<td>mpfr_sqrt</td>
<td>13</td>
</tr>
<tr>
<td>mpfr_sqrt_ui</td>
<td>13</td>
</tr>
<tr>
<td>mpfr_sub</td>
<td>13</td>
</tr>
<tr>
<td>mpfr_sub_one_ulp</td>
<td>20</td>
</tr>
<tr>
<td>mpfr_sub_q</td>
<td>13</td>
</tr>
<tr>
<td>mpfr_sub_ui</td>
<td>13</td>
</tr>
<tr>
<td>mpfr_sub_z</td>
<td>13</td>
</tr>
<tr>
<td>mpfr_swap</td>
<td>11</td>
</tr>
<tr>
<td>mpfr_t</td>
<td>5</td>
</tr>
<tr>
<td>mpfr_tan</td>
<td>16</td>
</tr>
<tr>
<td>mpfr_tanh</td>
<td>16</td>
</tr>
<tr>
<td>mpfr_trunc</td>
<td>18</td>
</tr>
<tr>
<td>mpfr_ui_div</td>
<td>13</td>
</tr>
<tr>
<td>mpfr_ui_pow</td>
<td>13</td>
</tr>
<tr>
<td>mpfr_ui_pow_ui</td>
<td>13</td>
</tr>
<tr>
<td>mpfr_ui_sub</td>
<td>13</td>
</tr>
<tr>
<td>mpfr_underflow_p</td>
<td>9</td>
</tr>
<tr>
<td>mpfr_unordered_p</td>
<td>15</td>
</tr>
<tr>
<td>mpfr_urandomb</td>
<td>19</td>
</tr>
<tr>
<td>mpfr_zeta</td>
<td>17</td>
</tr>
</tbody>
</table>