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1 Compilation and installation of Sollya

Sollya comes in two flavors:

- Either as an interactive tool. This is achieved by running the Sollya executable file.
- Or as a C library that provides all the features of the tool within the C programming language.

The installation of the tool and the library follow the same steps, described below. The present documentation focuses more on the interactive tool. As a matter of fact, the library works exactly the same way as the tool, so it is necessary to know a little about the tool in order to correctly use the library. The reader who is only interested in the library should at least read the following Sections 2, 3 and 5. A documentation specifically describing the library usage is available in Appendix 10 at the end of the present documentation.

1.1 Compilation dependencies

The Sollya distribution can be compiled and installed using the usual ./configure, make, make install procedure. Besides a C and a C++ compiler, Sollya needs the following software libraries and tools to be installed:

- GMP
- MPFR
- MPFI
- fplll
- libxml2
- gnuplot (external tool).

The ./configure script checks for the installation of the libraries. However Sollya will build without error if gnuplot is not installed. In this case an error will be displayed at runtime.

The use of the external tool rlwrap is highly recommended but not required to use the Sollya interactive tool. Use the -A option of rlwrap for correctly displayed ANSI X3.64/ ISO/IEC 6429 colored prompts (see below).

1.2 Sollya command line options

Sollya can read input on standard input or in a file whose name is given as an argument when Sollya is invoked. The tool will always produce its output on standard output, unless specifically instructed by a particular Sollya command that writes to a file. The following lines are valid invocations of Sollya, assuming that bash is used as a shell:

```
~/% sollya
... 
~/% sollya myfile.sollya
... 
~/% sollya < myfile.sollya
```

If a file given as an input does not exist, an error message is displayed.

All configurations of the internal state of the tool are done by commands given on the Sollya prompt or in Sollya scripts. Nevertheless, some command line options are supported; they work at a very basic I/O-level and can therefore not be implemented as commands.

The following options are supported when calling Sollya:
• **--args**: This special argument indicates to Sollya that subsequent command line arguments are no longer to be interpreted but are to be passed as-is to the predefined Sollya variable `__argv`. The `--args` argument is implicitly assumed if a Sollya script filename has already been specified with a preceding command line argument and none of the subsequent command line arguments is one of the special options given in this list.

• **--donotmodifystacksize**: When invoked, Sollya tries to increase the stack size that is available to a user process to the maximum size supported by the kernel. On some systems, the correspondent ioctl does not work properly. Use the option to prevent Sollya from changing the stack size.

• **--flush**: When this option is given, Sollya will flush all its input and output buffers after parsing and executing each command resp. sequence of commands. This option is needed when pipes are used to communicate with Sollya from another program.

• **--help**: Prints help on the usage of the tool and quits.

• **--nocolor**: Sollya supports coloring of the output using ANSI X3.64/ ISO/IEC 6429 escape sequences. Coloring is deactivated when Sollya is connected on standard input to a file that is not a terminal. This option forces the deactivation of ANSI coloring. This might be necessary on very old gray-scale terminals or when encountering problems with old versions of rlwrap.

• **--noprompt**: Sollya prints a prompt symbol when connected on standard input to a pseudo-file that is a terminal. The option deactivates the prompt.

• **--oldautoprint**: The behavior of an undocumented feature for displaying values has changed in Sollya from version 1.1 to version 2.0. The old feature is deprecated. If you wish to use it nevertheless, use this deprecated option.

• **--oldexternalprocprint**: The behavior of an undocumented feature for displaying Sollya objects representing external procedures upon automatic printing at the Sollya prompt has been changed in Sollya from version 4.1 to version 5.0. The old feature is deprecated. If you wish to use it nevertheless, use this deprecated option.

• **--oldrlwrapcompatible**: This option is deprecated. It makes Sollya emit a non ANSI X3.64 compliant coloring escape sequence for making it compatible with versions of rlwrap that do not support the `-A` option. The option is considered a hack since it is known to garble the output of the tool under some particular circumstances.

• **--warninfile[append] <file>**: Normally, Sollya emits warning and information messages together with all other displayed information on either standard output or standard error. This option allows all warning and information messages to get redirected to a file. The filename to be used must be given after the option. When **--warninfile** is used, the existing content (if any) of the file is first removed before writing to the file. With **--warninfileappend**, the messages are appended to an existing file. Even if coloring is used for the displaying all other Sollya output, no coloring sequences are ever written to the file. Let us emphasize on the fact that any file of a unixoid system can be used for output, for instance also a named pipe. This allows for error messaging to be performed on a separate terminal. The use of this option is mutually exclusive with the **--warnonstderr** option.

• **--warnonstderr**: Normally, Sollya prints warning and information messages on standard output, using a warning color when coloring is activated. When this option is given, Sollya will output all warning and information messages on standard error. Coloring will be used even on standard error, when activated. The use of this option is mutually exclusive with the **--warninfile[append]** option.

The Sollya interactive tool process returns the following exit status values, depending on the various reasons the tool exits:

• The exit status 0 is returned when Sollya is quit using the `quit` command. This is the standard way of terminating the Sollya process. The same exit status is returned for cases when Sollya is run with one of the **--help** or **--version** options (see above).
• The exit status 1 is returned when the Sollya is terminated due to an internal error. This case should never happen. This exit status 1 is also returned when two or more command line options (as documented above) are inconsistent, syntactically incorrect or provoke some other low-level error (such as a file in input not being readable).

• The exit status 2 is returned when the Sollya tool is terminated upon a Sollya language level error and dieonerrormode is set to on (see the documentation of that keyword for details).

• The exit status 3 is returned when the last Sollya command gets parsed and executed correctly but input reaches an end-of-file condition without the quit command being executed beforehand.

• The exit status 4 is returned when Sollya reaches an end-of-file condition upon incomplete input, i.e. when it started parsing a new Sollya command (or expression), which is incomplete. Remark that the empty input (end-of-file immediately upon Sollya process launch) is an incomplete input for reasons to be found in the Sollya grammar.

2 Introduction

Sollya is an interactive tool for handling numerical functions and working with arbitrary precision. It can evaluate functions accurately, compute polynomial approximations of functions, automatically implement polynomials for use in math libraries, plot functions, compute infinity norms, etc. Sollya is also a full-featured script programming language with support for procedures etc.

Let us begin this manual with an example. Sollya does not allow command line edition; since this may quickly become uncomfortable, we highly suggest to use the rlwrap tool with Sollya:

```bash
~/% rlwrap -A sollya
```

Sollya manipulates only functions in one variable. The first time that an unbound variable is used, this name is fixed. It will be used to refer to the free variable. For instance, try

```plaintext
> f = sin(x)/x;
> g = cos(y)-1;
Warning: the identifier "y" is neither assigned to, nor bound to a library function nor external procedure, nor equal to the current free variable.
Will interpret "y" as "x".
> g;
\[\cos(x) - 1\]
```

Now, the name \( x \) can only be used to refer to the free variable:

```plaintext
> x = 3;
Warning: the identifier "x" is already bound to the free variable, to a library function, library constant or to an external procedure.
The command will have no effect.
Warning: the last assignment will have no effect.
```

If you really want to unbind \( x \), you can use the rename command and change the name of the free variable:

```plaintext
> rename(x,y);
Information: the free variable has been renamed from "x" to "y".
> g;
\[\cos(y) - 1\]
> x=3;
> x;
3
```
Sollya has a reserved keyword that can always be used to refer to the free variable. This keyword is \_x\_. This is particularly useful in contexts when the name of the variable is not known: typically when referring to the free variable in a pattern matching or inside a procedure.

```plaintext
> f == sin(_x_)/_x_;  
true
```

As you have seen, you can name functions and easily work with them. The basic thing to do with a function is to evaluate it at some point:

```plaintext
> f(-2);  
Warning: rounding has happened. The value displayed is a faithful rounding to 16 5 bits of the true result.
0.45464871341284084769800932955687242135112748572394
> evaluate(f,-2);  
0.45464871341284084769800932955687242135112748572394
```

The printed value is generally a faithful rounding of the exact value at the working precision (\textit{i.e.}, one of the two floating-point numbers enclosing the exact value). Internally Sollya represents numbers as floating-point numbers in arbitrary precision with radix 2: the fact that a faithful rounding is performed in binary does not imply much on the exactness of the digits displayed in decimal. The working precision is controlled by the global variable \texttt{prec}:

```plaintext
> prec;  
165
> prec=200;  
The precision has been set to 200 bits.
> prec;  
200
> f(-2);  
Warning: rounding has happened. The value displayed is a faithful rounding to 20 0 bits of the true result.
0.4546487134128408476980093295568724213511274857239451341894865
```

Sometimes a faithful rounding cannot easily be computed. In such a case, a value is printed that was obtained using floating-point approximations without control on the final accuracy:

```plaintext
> log2(5)/log2(17) - log(5)/log(17);  
Warning: rounding may have happened. 
If there is rounding, the displayed value is \texttt{NOT} guaranteed to be a faithful r ounding of the true result.
0
```

The philosophy of Sollya is: \textit{Whenever something is not exact, print a warning}. This explains the warnings in the previous examples. If the result can be shown to be exact, there is no warning:

```plaintext
> sin(0);  
0
```

Let us finish this Section with a small complete example that shows a bit of what can be done with Sollya:
> restart;
The tool has been restarted.
> prec=50;
The precision has been set to 50 bits.
> f=cos(2*exp(x));
> d=[-1/8;1/8];
> p=remez(f,2,d);
> derivativeZeros = dirtyfindzeros(diff(p-f),d);
> derivativeZeros = inf(d).:derivativeZeros:.sup(d);
> maximum=0;
> for t in derivativeZeros do {
    r = evaluate(abs(p-f), t);
    if r > maximum then { maximum=r; argmaximum=t; };
};
> print("The infinity norm of", p-f, "is", maximum, "and is reached at", argmaximum);
The infinity norm of \[-3.89710727796949e-2 * x^2 + -1.79806720921853 * x + (-0.4162655728752966) - \cos(2 * \exp(x))\] is \[8.6306594443227e-4\] and is reached at \[6.66355088071379e-2\]

In this example, we define a function \(f\), an interval \(d\) and we compute the best degree-2 polynomial approximation of \(f\) on \(d\) with respect to the infinity norm. In other words, \(\max_{x \in d} \{|p(x) - f(x)|\}\) is minimal among polynomials with degree not greater than 2. Then, we compute the list of the zeros of the derivative of \(p - f\) and add the bounds of \(d\) to this list. Finally, we evaluate \(|p - f|\) for each point in the list and store the maximum and the point where it is reached. We conclude by printing the result in a formatted way.

Let us mention as a side-note that you do not really need to use such a script for computing an infinity norm; as we will see, the command `dirtyinfnorm` does this for you.

### 3 General principles

The first purpose of Sollya is to help people using numerical functions and numerical algorithms in a safe way. It is first designed to be used interactively but it can also be used in scripts\(^1\).

One of the particularities of Sollya is to work with multi-precision arithmetic (it uses the MPFR library). For safety purposes, Sollya knows how to use interval arithmetic. It uses interval arithmetic to produce tight and safe results with the precision required by the user.

The general philosophy of Sollya is: *When you can perform a computation exactly and sufficiently quickly, do it; when you cannot, do not, unless you have been explicitly asked for.*

The precision of the tool is set by the global variable `prec`. In general, the variable `prec` determines the precision of the outputs of commands: more precisely, the command will internally determine how much precision should be used during the computations in order to ensure that the output is a faithfully rounded result with `prec` bits.

For decidability and efficiency reasons, this general principle cannot be applied every time, so be careful. Moreover certain commands are known to be unsafe: they give in general excellent results and give almost `prec` correct bits in output for everyday examples. However they are merely based on heuristics and should not be used when the result must be safe. See the documentation of each command to know precisely how confident you can be with their result.

A second principle (that comes together with the first one) is the following one: *When a computation leads to inexact results, inform the user with a warning.* This can be quite irritating in some circumstances: in particular if you are using Sollya within other scripts. The global variable `verbosity` lets you change the level of verbosity of Sollya. When the variable is set to 0, Sollya becomes completely silent on standard output and prints only very important messages on standard error. Increase `verbosity` if you want more information about what Sollya is doing. Please keep in mind that when

\(^1\)Remark: some of the behaviors of Sollya slightly change when it is used in scripts. For example, no prompt is printed.
you affect a value to a global variable, a message is always printed even if verbosity is set to 0. In order to silently affect a global variable, use !:

```plaintext
> prec=30;
The precision has been set to 30 bits.
> prec=30!
>
```

For conviviality reasons, values are displayed in decimal by default. This lets a normal human being understand the numbers they manipulate. But since constants are internally represented in binary, this causes permanent conversions that are sources of roundings. Thus you are loosing in accuracy and Sollya is always complaining about inexact results. If you just want to store or communicate your results (to another tools for instance) you can use bit-exact representations available in Sollya. The global variable display defines the way constants are displayed. Here is an example of the five available modes:

```plaintext
> prec=30!
> a = 17.25;
> display=decimal;
Display mode is decimal numbers.
> a;
17.25
> display=binary;
Display mode is binary numbers.
> a;
1.000101_2 * 2^4
> display=powers;
Display mode is dyadic numbers in integer-power-of-2 notation.
> a;
69 * 2^-2
> display=dyadic;
Display mode is dyadic numbers.
> a;
69b-2
> display=hexadecimal;
Display mode is hexadecimal numbers.
> a;
0x1.14p4
```

Please keep in mind that it is possible to maintain the general verbosity level at some higher setting while deactivating all warnings on roundings. This feature is controlled using the roundingwarnings global variable. It may be set to on or off. By default, the warnings are activated (roundingwarnings = on) when Sollya is connected on standard input to a pseudo-file that represents a terminal. They are deactivated when Sollya is connected on standard input to a real file. See 8.164 for further details; the behavior is illustrated with examples there.

As always, the symbol e means \( \times 10^\circ \). The same way the symbol b means \( \times 2^\circ \). The symbol p means \( \times 16^\circ \) and is used only with the 0x prefix. The prefix 0x indicates that the digits of the following number until a symbol p or white-space are hexadecimal. The suffix _2 indicates to Sollya that the previous number has been written in binary. Sollya can parse these notations even if you are not in the corresponding display mode, so you can always use them.

You can also use memory-dump hexadecimal notation frequently used to represent IEEE 754 double and single precision numbers. Since this notation does not allow for exactly representing numbers with arbitrary precision, there is no corresponding display mode. However, the commands printdouble respectively printsingle round the value to the nearest double respectively single. The number is then printed in hexadecimal as the integer number corresponding to the memory representation of the IEEE 754 double or single number.
Sollya can parse these memory-dump hexadecimal notation back in any display mode. The difference of this memory-dump notation with the hexadecimal notation (as defined above) is made by the presence or absence of a p indicator.

4 Variables

As already explained, Sollya can manipulate variate functional expressions in one variable. These expressions contain a unique free variable the name of which is fixed by its first usage in an expression that is not a left-hand-side of an assignment. This global and unique free variable is a variable in the mathematical sense of the term.

Sollya also provides variables in the sense programming languages give to the term. These variables, which must be different in their name from the global free variable, may be global or declared and attached to a block of statements, i.e., a begin-end-block. These programming language variables may hold any object of the Sollya language, as for example functional expressions, strings, intervals, constant values, procedures, external functions and procedures, etc.

Global variables need not to be declared. They start existing, i.e., can be correctly used in expressions that are not left-hand-sides of assignments, when they are assigned a value in an assignment. Since they are global, this kind of variables is recommended only for small Sollya scripts. Larger scripts with code reuse should use declared variables in order to avoid name clashes for example in loop variables.

Declared variables are attached to a begin-end-block. The block structure builds scopes for declared variables. Declared variables in inner scopes shadow (global and declared) variables of outer scopes. The global free variable, i.e., the mathematical variable for variate functional expressions in one variable, cannot be shadowed. Variables are declared using the var keyword. See Section \[8.194\] for details on its usage and semantic.

The following code examples illustrate the use of variables.
> f = exp(x);
> f;
exp(x)
> a = "Hello world";
> a;
Hello world
> b = 5;
> f(b);
Warning: rounding has happened. The value displayed is a faithful rounding to 16
5 bits of the true result.
148.413519025766034221155800405522796234876675938
> {var b; b = 4; f(b); }
Warning: rounding has happened. The value displayed is a faithful rounding to 16
5 bits of the true result.
54.598150033144239078110261202860878402790737038614
> {var x; x = 3; }
Warning: the identifier "x" is already bound to the current free variable.
It cannot be declared as a local variable. The declaration of "x" will have no e
fect.
Warning: the identifier "x" is already bound to the free variable, to a library
function, library constant or to an external procedure.
The command will have no effect.
Warning: the last assignment will have no effect.
> {var a, b; a=5; b=3; {var a; var b; b = true; a = 1; a; b; }; a; b; }
1
true
5
3
> a;
Hello world

Let us state that a variable identifier, just as every identifier in Sollya, contains at least one character,
starts with an ASCII letter and continues with ASCII letters or numerical digits.

Two predefined variables exist when Sollya is started:

- **__argv**: This variable contains, on Sollya startup and after the execution of the **restart** com-
mand, a list of character strings that correspond to the command line options given to Sollya
after the (implicit) command line argument **--args** (see above).

- **__unique_id**: This variable contains, on Sollya startup and after the execution of the **restart**
command, a character string that uniquely identifies the given Sollya session on a system. It hence
allows for concurrent execution of Sollya scripts that use temporary files for communication with
other tools. The character string is made of alphanumeric characters ([0-9a-zA-Z]) and dashes (-)
and underscores (_). In particular, it does not contain any space. After the execution of the
restart command, the **__unique_id** variable is refreshed with a new, unique value.

Even though these variables exist upon Sollya startup with predefined values, they behave like any
other variable: the predefined value can be overwritten by assigning any new value to the variables, the
variables can be shadowed by declared, local variables of the same name and so on.

5 Data types

Sollya has a (very) basic system of types. If you try to perform an illicit operation (such as adding a
number and a string, for instance), you will get a typing error. Let us see the available data types.
5.1 Booleans

There are two special values `true` and `false`. Boolean expressions can be constructed using the boolean connectors `&&` (and), `||` (or), `!` (not), and comparisons.

The comparison operators `<`, `<=`, `>` and `>=` can only be used between two numbers or constant expressions.

The comparison operators `==` and `!=` are polymorphic. You can use them to compare any two objects, like two strings, two intervals, etc. As a matter of fact, polymorphism is allowed on both sides: it is possible to compare objects of different type. Such objects of different type, as they can never be syntactically equal, will always compare unequal (see exception for `error`, Section 8.56) and never equal. It is important to remember that testing the equality between two functions will return `true` if and only if the expression trees representing the two functions are exactly the same or automatic simplification is activated and both functions are polynomials that are equal. See Section 8.56 for an exception concerning the special object `error`. Example:

```plaintext
> 1+x==1+x;
true
```

5.2 Numbers

Sollya represents numbers as binary multi-precision floating-point values. For integer values and values in dyadic, binary, hexadecimal or memory dump notation, it automatically uses a precision needed for representing the value exactly (unless this behavior is overridden using the syntax given below). Additionally, automatic precision adaption takes place for all integer values (even in decimal notation) written without the exponent sign `e` or with the exponent sign `e` and an exponent sufficiently small that they are less than $10^{999}$. Otherwise the values are represented with the current precision `prec`. When a number must be rounded, it is rounded to the precision `prec` before the expression get evaluated:

```plaintext
> prec=12;!
> 4097.1;
Warning: Rounding occurred when converting the constant "4097.1" to floating-point with 12 bits.
If safe computation is needed, try to increase the precision.
4098
> 4098.1;
Warning: Rounding occurred when converting the constant "4098.1" to floating-point with 12 bits.
If safe computation is needed, try to increase the precision.
4098
> 4097.1+1;
Warning: Rounding occurred when converting the constant "4097.1" to floating-point with 12 bits.
If safe computation is needed, try to increase the precision.
4099
```

As a matter of fact, each variable has its own precision that corresponds to its intrinsic precision or, if it cannot be represented, to the value of `prec` when the variable was set. Thus you can work with variables having a precision higher than the current precision.

The same way, if you define a function that refers to some constant, this constant is stored in the function with the current precision and will keep this value in the future, even if `prec` becomes smaller.

If you define a function that refers to some variable, the precision of the variable is kept, independently of the current precision:
> prec = 50;
> a = 4097.1;
Warning: Rounding occurred when converting the constant "4097.1" to floating-point with 50 bits.
If safe computation is needed, try to increase the precision.
> prec = 12;
> f = x + a;
> g = x + 4097.1;
Warning: Rounding occurred when converting the constant "4097.1" to floating-point with 12 bits.
If safe computation is needed, try to increase the precision.
> prec = 120;
The precision has been set to 120 bits.
> f;
4097.0999999999998544808477163314819336 + x
> g;
4098 + x

In some rare cases, it is necessary to read in decimal constants with a particular precision being used in the conversion to the binary floating-point format, which Sollya uses. Setting prec to that precision may prove to be an insufficient means for doing so, for example when several different precisions have to be used in one expression. For these rare cases, Sollya provides the following syntax: decimal constants may be written \%precision\%constant, where precision is a constant integer, written in decimal, and constant is the decimal constant. Sollya will convert the constant constant with precision precision, regardless of the global variable prec and regardless if constant is an integer or would otherwise be representable.
Sollya is an environment that uses floating-point arithmetic. The IEEE 754-2008 standard on floating-point arithmetic does not only define floating-point numbers that represent real numbers but also floating-point data representing infinities and Not-a-Numbers (NaNs). Sollya also supports infinities and NaNs in the spirit of the IEEE 754-2008 standard without taking the standard's choices literally.

- Signed infinities are available through the Sollya objects `infty`, `-infty`, `@Inf@` and `-@Inf@`.

- Not-a-Numbers are supported through the Sollya objects `NaN` and `@NaN@`. Sollya does not have support for NaN payloads, signaling or quiet NaNs or signs of NaNs. Signaling NaNs are supported on input for single and double precision memory notation (see Section [3]). However, they immediately get converted to plain Sollya NaNs.

The evaluation of an expression involving a NaN or the evaluation of a function at a point being NaN always results in a NaN.

Infinities are considered to be the limits of expressions tending to infinity. They are supported as bounds of intervals in some cases. However, particular commands might prohibit their use even though there might be a mathematical meaning attached to such expressions. For example, while Sollya will evaluate expressions such as \( \lim_{x \to -\infty} e^x \), expressed \( e.g., \) through `evaluate(exp(x),[-infty;0])`, it will
not accept to compute the (finite) value of
\[ \int_{-\infty}^{0} e^x \, dx. \]

The following examples give an idea of what can be done with Sollya infinities and NaNs. Here is what can be done with infinities:

\begin{verbatim}
> f = exp(x) + 5;
> f(-infty);
5
> evaluate(f,[-infty;infty]);
[5;infty]
> f(infty);
infty
> [-infty;5] * [3;4];
[-infty;20]
> -infty < 5;
true
> log(0);
infty
> [log(0);17];
Warning: inclusion property is satisfied but the diameter may be greater than the least possible.
Warning: at least one of the given expressions is not a constant but requires evaluation.
Evaluation is guaranteed to ensure the inclusion property. The approximate result is at least 165 bit accurate.
[-infty;17]
> 
\end{verbatim}

And the following example illustrates NaN behavior.
> 3/0;
Warning: the given expression is undefined or numerically unstable.
NaN
> (-3)/0;
Warning: the given expression is undefined or numerically unstable.
NaN
> infty/infty;
Warning: the given expression is undefined or numerically unstable.
NaN
> infty + infty;
infty
> infty - infty;
Warning: the given expression is undefined or numerically unstable.
NaN
> f = exp(x) + 5;
> f(NaN);
NaN
> NaN == 5;
false
> NaN == NaN;
false
> NaN != NaN;
true
> X = "Vive la Republique!";
> !(X == X);
false
> X = 5;
> !(X == X);
false
> X = NaN;
> !(X == X);
true
>

5.3 Rational numbers and rational arithmetic

The Sollya tool is mainly based on floating-point arithmetic: wherever possible, floating-point algorithms, including algorithms using interval arithmetic, are used to produce approximate but safe results. For some particular cases, floating-point arithmetic is not sufficient: some algorithms just require natural and rational numbers to be handled exactly. More importantly, for these applications, it is required that rational numbers be displayed as such.

Sollya implements a particular mode that offers a lightweight support for rational arithmetic. When needed, it can be enabled by assigning on to the global variable rationalmode. It is disabled by assigning off; the default is off.

When the mode for rational arithmetic is enabled, Sollya’s behavior will change as follows:

- When a constant expression is given at the Sollya prompt, Sollya will first try to simplify the expression to a rational number. If such an evaluation to a rational number is possible, Sollya will display that number as an integer or a fraction of two integers. Only if Sollya is not able to simplify the constant expression to a rational number, it will launch the default behavior of evaluating constant expressions to floating-point numbers that are generally faithful roundings of the expressions.

- When the global mode autosimplify is on, which is the default, Sollya will additionally use rational arithmetic while trying to simplify expressions given in argument of commands.
Even when \texttt{rationalmode} is on, \texttt{Sollya} will not be able to exhibit integer ratios between transcendental quantities. For example, \texttt{Sollya} will not display $\frac{1}{6}$ for $\arcsin\left(\frac{1}{2}\right)/\pi$ but $0.16666...$. \texttt{Sollya}'s evaluator for rational arithmetic is only able to simplify rational expressions based on addition, subtraction, multiplication, division, negation, perfect squares (for square root) and integer powers.

The following example illustrates what can and what cannot be done with \texttt{Sollya}'s mode for rational arithmetic:

\begin{verbatim}
> 1/3 - 1/7;
Warning: rounding has happened. The value displayed is a faithful rounding to 16 5 bits of the true result.
0.19047619047619047619047619047619047619047619047619
> rationalmode = on;
Rational mode has been activated.
> 1/3 - 1/7;
4 / 21
> (2 + 1/7)^2 + (6/7)^2 + 2 * (2 + 1/7) * 6/7;
9
> rationalmode = off;
Rational mode has been deactivated.
> (2 + 1/7)^2 + (6/7)^2 + 2 * (2 + 1/7) * 6/7;
Warning: rounding has happened. The value displayed is a faithful rounding to 16 5 bits of the true result.
9
> rationalmode = on;
Rational mode has been activated.
> asin(1)/pi;
Warning: rounding has happened. The value displayed is a faithful rounding to 16 5 bits of the true result.
0.5
> sin(1/6 * pi);
Warning: rounding has happened. The value displayed is a faithful rounding to 16 5 bits of the true result.
0.5
> exp(1/7 - 3/21) / 7;
1 / 7
> rationalmode = off;
Rational mode has been deactivated.
> exp(1/7 - 3/21) / 7;
Warning: rounding has happened. The value displayed is a faithful rounding to 16 5 bits of the true result.
0.142857142857142857142857142857142857142857142857145
> print(1/7 - 3/21);
1 / 7 - 3 / 21
> rationalmode = on;
Rational mode has been activated.
> print(1/7 - 3/21);
0
\end{verbatim}

### 5.4 Intervals and interval arithmetic

\texttt{Sollya} can manipulate intervals that are closed subsets of the real numbers. Several ways of defining intervals exist in \texttt{Sollya}. There is the most common way where intervals are composed of two numbers or constant expressions representing the lower and the upper bound. These values are separated either by commas or semi-colons. Interval bound evaluation is performed in a way that ensures the inclusion property: all points in the original, unevaluated interval will be contained in the interval with its bounds evaluated to floating-point numbers.
Sollya has a mode for printing intervals that are that thin that their bounds have a number of decimal digits in common when printed. That mode is called \texttt{midpointmode}; see below for an introduction and Section \ref{sec:midpointmode} for details. As Sollya must be able to parse back its own output, a syntax is provided to input intervals in midpoint mode. However, please pay attention to the fact that the notation used in midpoint mode generally increases the width of intervals: hence when an interval is displayed in midpoint mode and read again, the resulting interval may be wider than the original interval.

In some cases, intervals become infinitely thin in theory, in which case one tends to think of point intervals even if their floating-point representation is not infinitely thin. Sollya provides a very convenient way for input of such point intervals. Instead of writing \([a; a]\), it is possible to just write \([a]\). Sollya will expand the notation while making sure that the inclusion property is satisfied:

\begin{verbatim}
> midpointmode = on!;
> [1.725e4;1.75e4];
0.17~2/5~e5
> 0.17~2/5~e5;
> midpointmode = off!;
> 0.17~2/5~e5;
[17200;17500]
\end{verbatim}
When the mode \texttt{midpointmode} is set to \texttt{on} (see Section \ref{8.109}), Sollya will display intervals that are provably reduced to one point in this extended interval syntax. It will use \texttt{midpointmode} syntax for intervals that are sufficiently thin but not reduced to one point (see Section \ref{8.109} for details):

\begin{verbatim}
> midpointmode = off;
Midpoint mode has been deactivated.
> [17;17];
[17;17]
> [exp(pi);exp(pi)];
Warning: at least one of the given expressions is not a constant but requires evaluation.
Evaluation is guaranteed to ensure the inclusion property. The approximate result is at least 165 bit accurate.
[23.1406926327792690057290863679485473802661062426;23.140692632779269005729086367948547380266106242601]
> midpointmode = on;
Midpoint mode has been activated.
> [17;17];
[17]
> [exp(pi);exp(pi)];
Warning: at least one of the given expressions is not a constant but requires evaluation.
Evaluation is guaranteed to ensure the inclusion property. The approximate result is at least 165 bit accurate.
0.231406926327792690057290863679485473802661062426~0/1~e2
\end{verbatim}

Sollya intervals are internally represented with floating-point numbers as bounds; rational numbers are not supported here. If bounds are defined by constant expressions, these are evaluated to floating-point numbers using the current precision. Numbers or variables containing numbers keep their precision for the interval bounds.

Constant expressions get evaluated to floating-point values immediately; this includes \pi and rational numbers, even when \texttt{rationalmode} is \texttt{on} (see Section \ref{5.3} for this mode).

\begin{verbatim}
> prec = 300!;
> a = 4097.1;
Warning: Rounding occurred when converting the constant "4097.1" to floating-point with 300 bits.
If safe computation is needed, try to increase the precision.
> prec = 12!;
> d = [4097.1; a];
Warning: Rounding occurred when converting the constant "4097.1" to floating-point with 12 bits.
The inclusion property is nevertheless satisfied.
> prec = 300!;
> d;
[4096;4097.1]
> prec = 30!;
> [-pi;pi];
Warning: at least one of the given expressions is not a constant but requires evaluation.
Evaluation is guaranteed to ensure the inclusion property. The approximate result is at least 30 bit accurate.
[-3.141592655;3.141592655]
\end{verbatim}

You can get the upper-bound (respectively the lower-bound) of an interval with the command \texttt{sup} (respectively \texttt{inf}). The middle of the interval can be computed with the command \texttt{mid}. Let us also
mention that these commands can also be used on numbers (in that case, the number is interpreted as an interval containing only one single point. In that case the commands inf, mid and sup are just the identity):

```plaintext
> d=[1;3];
> inf(d);
1
> mid(d);
2
> sup(4);
4
```

Let us mention that the mid operator never provokes a rounding. It is rewritten as an unevaluated expression in terms of inf and sup.

Sollya permits intervals to also have non-real bounds, such as infinities or NaNs. When evaluating certain expressions, in particular given as interval bounds, Sollya will itself generate intervals containing infinities or NaNs. When evaluation yields an interval with a NaN bound, the given expression is most likely undefined or numerically unstable. Such results should not be trusted; a warning is displayed.

While computations on intervals with bounds being NaN will always fail, Sollya will try to interpret infinities in the common way as limits. However, this is not guaranteed to work, even if it is guaranteed that no unsafe results will be produced. See also section 5.2 for more detail on infinities in Sollya. The behavior of interval arithmetic on intervals containing infinities or NaNs is subject to debate; moreover, there is no complete consensus on what should be the result of the evaluation of a function \(f\) over an interval \(I\) containing points where \(f\) is not defined. Sollya has its own philosophy regarding these questions. This philosophy is explained in Appendix 9 at the end of this document.

```plaintext
> evaluate(exp(x),[-infty;0]);
[0;1]
> dirtyinfnorm(exp(x),[-infty;0]);
Warning: a bound of the interval is infinite or NaN.
This command cannot handle such intervals.
NaN
> f = log(x);
> [f(0); f(1)];
Warning: inclusion property is satisfied but the diameter may be greater than the least possible.
Warning: at least one of the given expressions is not a constant but requires evaluation.
Evaluation is guaranteed to ensure the inclusion property. The approximate result is at least 165 bit accurate.
[-infty;0]
```

Sollya internally uses interval arithmetic extensively to provide safe answers. In order to provide for algorithms written in the Sollya language being able to use interval arithmetic, Sollya offers native support of interval arithmetic. Intervals can be added, subtracted, multiplied, divided, raised to powers, for short, given in argument to any Sollya function. The tool will apply the rules of interval arithmetic in order to compute output intervals that safely encompass the hull of the image of the function on the given interval:
When such expressions involving intervals are given, Sollya will follow the rules of interval arithmetic in precision \texttt{prec} for immediately evaluating them to interval enclosures. While Sollya’s evaluator always guarantees the inclusion property, it also applies some optimizations in some cases in order to make the image interval as thin as possible. For example, Sollya will use a Taylor expansion based evaluation if a composed function, call it \textit{f}, is applied to an interval. In other words, in this case Sollya will behave as if the \texttt{evaluate} command (see Section \ref{eival}) were implicitly used. In most cases, the result will be different from the one obtained by replacing all occurrences of the free variable of a function by the interval the function is to be evaluated on:

\begin{verbatim}
> f = x - sin(x);
> [-1b-10;1b-10] - sin([-1b-10;1b-10]);
[-1.95312484477957829894e-3;1.95312484477957829894e-3]
> f([-1b-10;1b-10]);
[-1.552204217011176269e-10;1.552204217011176269e-10]
> evaluate(f,[-1b-10;1b-10]);
[-1.552204217011176269e-10;1.552204217011176269e-10]
\end{verbatim}

5.5 Functions

Sollya knows only about functions with one single variable. The first time in a session that an unbound name is used (without being assigned) it determines the name used to refer to the free variable.

The basic functions available in Sollya are the following:

- \( +, -, *, /, ^ \)
- \texttt{sqrt}
- \texttt{abs}
- \texttt{sin, cos, tan, sinh, cosh, tanh}
- \texttt{asin, acos, atan, asinh, acosh, atanh}
- \texttt{exp, expm1} (defined as \texttt{expm1}(\texttt{x}) = \texttt{exp(\texttt{x})} - 1)
- \texttt{log} (natural logarithm), \texttt{log2} (binary logarithm), \texttt{log10} (decimal logarithm), \texttt{log1p} (defined as \texttt{log1p}(\texttt{x}) = \texttt{log(1 + \texttt{x})})
- \texttt{erf, erfc}
- \texttt{halfprecision, single, double, doubleextended, doubledouble, quad, tripledouble} (see sections \ref{halfprecision} \ref{single} \ref{double} \ref{doubleextended} \ref{doubledouble} \ref{quad} \ref{tripledouble})
- \texttt{HP, SG, D, DE, DD, QD, TD} (see sections \ref{halfprecision} \ref{single} \ref{double} \ref{doubleextended} \ref{doubledouble} \ref{quad} \ref{tripledouble})
- \texttt{floor, ceil, nearestint}.

The constant \( \pi \) is available through the keyword \texttt{pi} as a 0-ary function:
Warning: rounding has happened. The value displayed is a faithful rounding to 12 bits of the true result.
1.10010010001_2 * 2^1

Warning: rounding has happened. The value displayed is a faithful rounding to 30 bits of the true result.
1.10010010000111111011010101001_2 * 2^1

The reader may wish to see Sections 8.08 and 8.73 for ways of dynamically adding other base functions to Sollya.

5.6 Strings

Anything written between quotes is interpreted as a string. The infix operator @ concatenates two strings. To get the length of a string, use the length function. You can access the i-th character of a string using brackets (see the example below). There is no character type in Sollya: the i-th character of a string is returned as a string itself.

```
> s1 = "Hello "; s2 = "World!";
> s = s1@s2;
> length(s);
12
> s[0];
H
> s[11];
!
```

Strings may contain the following escape sequences: \\n, \\?, \\a, \\b, \\f, \\r, \\v, \x[hexadecimal number] and \[octal number]. Refer to the C99 standard for their meaning.

5.7 Particular values

Sollya knows about some particular values. These values do not really have a type. They can be stored in variables and in lists. A (possibly not exhaustive) list of such values is the following one:

- on, off (see sections 8.123 and 8.122)
- dyadic, powers, binary, decimal, hexadecimal (see sections 8.52, 8.134, 8.19, 8.35 and 8.82)
- file, postscript, postscriptfile (see sections 8.66, 8.131 and 8.132)
- RU, RN, RD, RZ (see sections 8.151, 8.160 and 8.166)
- absolute, relative (see sections 8.2 and 8.154)
- floating, fixed (see sections 8.69 and 8.68)
- halfprecision, single, double, doubleextended, doubledouble, quad, tripledouble (see sections 8.80, 8.81, 8.49, 8.50, 8.146 and 8.191)
- HP, SG, D, DE, DD, QD, TD (see sections 8.80, 8.172, 8.49, 8.51, 8.50, 8.146 and 8.191)
- perturb (see Section 8.126)
- honorcoeffprec (see Section 8.83)
- default (see Section 8.36)
- error (see Section 8.56)
- void (see Section 8.196)

5.8 Lists

Objects can be grouped into lists. A list can contain elements with different types. As for strings, you can concatenate two lists with \$. The function `length` also gives the length of a list.

You can prepend an element to a list using `:` and you can append an element to a list using `::`.

The following example illustrates some features:

```plaintext
> L = ['foo'];
> L = L:1;
> L = "bar"::L;
> L;
["bar", "foo", 1]
> L[1];
foo
> L@L;
["bar", "foo", 1, "bar", "foo", 1]
```

Lists can be considered arrays and elements of lists can be referenced using brackets. Possible indices start at 0. The following example illustrates this point:

```plaintext
> L = [1, 2, 3, 4, 5];
> L;
[1, 2, 3, 4, 5]
> L[3];
4
```

Lists may contain ellipses indicated by `...`, between elements that are constant and evaluate to integers that are incrementally ordered. `Sollya` translates such ellipses to the full list upon evaluation. The use of ellipses between elements that are not constants is not allowed. This feature is provided for ease of programming; remark that the complexity for expanding such lists is high. For illustration, see the following example:

```plaintext
> [1,...,5];
[1, 2, 3, 4, 5]
> [-5,...,5];
[-5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5]
> [3,...,1];
Warning: at least one of the given expressions or a subexpression is not correctly typed
or its evaluation has failed because of some error on a side-effect.
error
> [true,...,false];
Warning: at least one of the given expressions or a subexpression is not correctly typed
or its evaluation has failed because of some error on a side-effect.
error
```
Lists may be continued to infinity by means of the \ldots indicator after the last element given. At least one element must explicitly be given. If the last element given is a constant expression that evaluates to an integer, the list is considered as continued to infinity by all integers greater than that last element. If the last element is another object, the list is considered as continued to infinity by re-duplicating this last element. Let us remark that bracket notation is supported for such end-elliptic lists even for implicitly given elements. However, evaluation complexity is high. Combinations of ellipses inside a list and in its end are possible. The usage of lists described here is best illustrated by the following examples:

```
> L = [1,2,true,3...];
> L;
[1, 2, true, 3...]
> L[2];
true
> L[3];
3
> L[4];
4
> L[1200];
1200
> L = [1,...,5,true...];
> L;
[1, 2, 3, 4, 5, true...]
> L[1200];
true
```

## 5.9 Structures

In a similar way as in lists, Sollya allows data to be grouped in – untyped – structures. A structure forms an object to which other objects can be added as elements and identified by their names. The elements of a structure can be retrieved under their name and used as usual. The following sequence shows that point:

```
> s.a = 17;
> s.b = exp(x);
> s.a;
17
> s.b;
exp(x)
> s.b(1);
Warning: rounding has happened. The value displayed is a faithful rounding to 16
5 bits of the true result.
2.7182818284590452353602874713526624977572470937
> s.d.a = [-1;1];
> s.d.b = sin(x);
> inf(s.d.a);
-1
> diff(s.d.b);
cos(x)
```

Structures can also be defined literally using the syntax illustrated in the next example. They will also be printed in that syntax.
If the variable \texttt{a} is bound to an existing structure, it is possible to use the “dot notation” \texttt{a.b} to assign the value of the field \texttt{b} of the structure \texttt{a}. This works even if \texttt{b} is not yet a field of \texttt{a}: in this case a new field is created inside the structure \texttt{a}.

Besides, the dot notation can be used even when \texttt{a} is unassigned. In this case a new structure is created with a field \texttt{b}, and this structure is bound to \texttt{a}. However, the dot notation cannot be used if \texttt{a} is already bound to something that is not a structure.

These principles apply recursively: for instance, if \texttt{a} is a structure that contains only one field \texttt{d}, the command \texttt{a.b.c = 3} creates a new field named \texttt{b} inside the structure \texttt{a}; this field itself is a structure containing the field \texttt{c}. The command \texttt{a.d.c = 3} is allowed if \texttt{a.d} is already a structure, but forbidden otherwise (e.g., if \texttt{a.d} was equal to \texttt{sin(x)}). This is summed up in the following example.

```plaintext
> a = { .f = exp(x), .dom = [-1;1] };
> a;
{ .f = exp(x), .dom = [-1;1] }
> a.f;
exp(x)
> a.dom;
[-1;1]
> b.f = sin(x);
> b.dom = [-1b-5;1b-5];
> b;
{ .dom = [-3.125e-2;3.125e-2], .f = sin(x) }
> { .f = asin(x), .dom = [-1;1] }.f(1);
Warning: rounding has happened. The value displayed is a faithful rounding to 16 5 bits of the true result.
1.57079632679489661923132169163975144209858469968754
```

When printed, the elements of a structure are not sorted in any manner. They get printed in an arbitrary order that just maintains the order given in the definition of literate structures. That said, when compared, two structures compare equal iff they contain the same number of identifiers, with the
same names and iff the elements of corresponding names all compare equal. This means the order does not matter in comparisons and otherwise does only for printing.

The following example illustrates this matter:

```sollya
> a = { .f = exp(x), .a = -1, .b = 1 }; 
> a;  
{ .f = exp(x), .a = -1, .b = 1 } 
> a.info = "My function"; 
> a;  
{ .info = "My function", .f = exp(x), .a = -1, .b = 1 } 
> > b = { .a = -1, .f = exp(x), .info = "My function", .b = 1 }; 
> b;  
{ .a = -1, .f = exp(x), .info = "My function", .b = 1 } 
> > a == b; 
true 
> > b.info = "My other function"; 
> a == b; 
false 
> > b.info = "My function"; 
> a == b; 
true 
> b.something = true; 
> a == b; 
false 
```

6 Iterative language elements: assignments, conditional statements and loops

6.1 Blocks

Statements in Sollya can be grouped in blocks, so-called begin-end-blocks. This can be done using the key tokens { and }. Blocks declared this way are considered to be one single statement. As already explained in Section 4 using begin-end-blocks also opens the possibility of declaring variables through the keyword var.

6.2 Assignments

Sollya has two different assignment operators, = and :=. The assignment operator = assigns its right-hand-object “as is”, i.e., without evaluating functional expressions. For instance, if i stood for the value 1000, the statement i = i + 1; would dereference the identifier i with some content, notate it y, build up the expression (function) y + 1 and assign this expression back to i. In the example, if i stood for the value 1000, the statement i = i + 1; would assign “1000 + 1” – and not “1001” – to i. The assignment operator := evaluates constant functional expressions before assigning them. On other expressions it behaves like =. Still in the example, the statement i := i + 1; really assigns 1001 to i.

Both Sollya assignment operators support indexing of lists or strings elements using brackets on the left-hand-side of the assignment operator. The indexed element of the list or string gets replaced by the right-hand-side of the assignment operator. When indexing strings this way, that right-hand side must evaluate to a string of length 1. End-elliptic lists are supported with their usual semantic for this kind of assignment. When referencing and assigning a value in the implicit part of the end-elliptic list, the list gets expanded to the corresponding length.

The following examples well illustrate the behavior of assignment statements:
> autosimplify = off;
> Automatic pure tree simplification has been deactivated.
> i = 1000;
> i = i + 1;
> print(i);
1000 + 1
> i := i + 1;
> print(i);
1002
> L = [|1,...,5|];
> print(L);
[|1, 2, 3, 4, 5|]
> print(L);
[|1, 2, 3, 4 + 1, 6|]
> L[5] = true;
> L;
[|1, 2, 3, 5, 6, true|]
> s = "Hello world";
> s;
Hello world
> s[1] = "a";
> s;
Hallo world
> s[2] = "foo";
Warning: the string to be assigned is not of length 1.
This command will have no effect.
> L = [|true,1,...,5,9...|];
> L;
[|true, 1, 2, 3, 4, 5, 9...|]
> L[5] = "Hello";
> L;
[|true, 1, 2, 3, 4, 5, 9, 10, 11, 12, 13, 14, 15, "Hello", 17...|]

The indexing of lists on left-hand sides of assignments is reduced to the first order. Multiple indexing of lists of lists on assignment is not supported for complexity reasons. Multiple indexing is possible in right-hand sides.

> L = [| 1, 2, [|"a", "b", [|true, false|] |] |];
> L[2][2][1];
false
> L[2][2][1] = true;
Warning: the first element of the left-hand side is not an identifier.
This command will have no effect.
> L[2][2] = "c";
Warning: the first element of the left-hand side is not an identifier.
This command will have no effect.
> L[2] = 3;
> L;
[|1, 2, 3|]

### 6.3 Conditional statements

Sollya supports conditional statements expressed with the keywords if, then and optionally else. Let us mention that only conditional statements are supported and not conditional expressions.
The following examples illustrate both syntax and semantic of conditional statements in Sollya. Concerning syntax, be aware that there must not be any semicolon before the `else` keyword.

```
> a = 3;
> b = 4;
> if (a == b) then print("Hello world");
> b = 3;
> if (a == b) then print("Hello world");
Hello world
> if (a == b) then print("You are telling the truth") else print("Liar");
You are telling the truth
```

## 6.4 Loops

Sollya supports three kinds of loops. General *while-condition* loops can be expressed using the keywords `while` and `do`. One has to be aware of the fact that the condition test is executed always before the loop, there is no *do-until-condition* loop. Consider the following examples for both syntax and semantic:

```
> verbosity = 0!
> prec = 30!
> i = 5;
> while (expm1(i) > 0) do { expm1(i); i := i - 1; }
147.4131591
53.59815
19.08553693
6.3890561
1.718281828
> print(i);
0
```

The second kind of loops are loops on a variable ranging from a numerical start value and an end value. These kind of loops can be expressed using the keywords `for`, `from`, `to`, `do` and optionally `by`. The `by` statement indicates the width of the steps on the variable from the start value to the end value. Once again, syntax and semantic are best explained with an example:

```
> for i from 1 to 5 do print("Hello world",i);
Hello world 1
Hello world 2
Hello world 3
Hello world 4
Hello world 5
> for i from 2 to 1 by -0.5 do print("Hello world",i);
Hello world 2
Hello world 1.5
Hello world 1
```

The third kind of loops are loops on a variable ranging on values contained in a list. In order to ensure the termination of the loop, that list must not be end-elliptic. The loop is expressed using the keywords `for`, `in` and `do` as in the following examples:
For both types of for loops, assigning the loop variable is allowed and possible. When the loop terminates, the loop variable will contain the value that made the loop condition fail. Consider the following examples:

```
> L = [|true, false, 1,...,4, "Hello", exp(x)|];
> for i in L do i;
true
false
1
2
3
4
Hello
exp(x)
```

```
> for i from 1 to 5 do { if (i == 3) then i = 4 else i; };
1
2
5
> i;
6
```

7  Functional language elements: procedures and pattern matching

7.1  Procedures

**Sollya** has some elements of functional languages. In order to avoid confusion with mathematical functions, the associated programming objects are called *procedures* in **Sollya**.

**Sollya** procedures are common objects that can be, for example, assigned to variables or stored in lists. Procedures are declared by the proc keyword; see Section 8.143 for details. The returned procedure object must then be assigned to a variable. It can hence be applied to arguments with common application syntax. The procedure keyword provides an abbreviation for declaring and assigning a procedure; see Section 8.144 for details.

**Sollya** procedures can return objects using the return keyword at the end of the begin-end-block of the procedure. Section 8.158 gives details on the usage of return. Procedures further can take any type of object in argument, in particular also other procedures that are then applied to arguments. Procedures can be declared inside other procedures.

Common **Sollya** procedures are declared with a certain number of formal parameters. When the procedure is applied to actual parameters, a check is performed if the right number of actual parameters is given. Then the actual parameters are applied to the formal parameters. In some cases, it is required that the number of parameters of a procedure be variable. **Sollya** provides support for the case with procedures with an arbitrary number of actual arguments. When the procedure is called, those actual arguments are gathered in a list which is applied to the only formal list parameter of a procedure with an arbitrary number of arguments. See Section 8.144 for the exact syntax and details; an example is given just below.

Let us remark that declaring a procedure does not involve any evaluation or other interpretation of the procedure body. In particular, this means that constants are evaluated to floating-point values inside **Sollya** when the procedure is applied to actual parameters and the global precision valid at this moment.

**Sollya** procedures are well illustrated with the following examples:
> succ = proc(n) { return n + 1; };
> succ(5);
6
> 3 + succ(0);
4
> succ;
proc(n)
{
  nop;
  return (n) + (1);
}

> add = proc(m,n) { var res; res := m + n; return res; };
> add(5,6);
11
> hey = proc() { print("Hello world."); };
> hey();
Hello world.
> print(hey());
Hello world.
void
> hey;
proc()
{
  print("Hello world.");
  return void;
}

> fac = proc(n) { var res; if (n == 0) then res := 1 else res := n * fac(n - 1); return res; };
> fac(5);
120
> fac(11);
39916800
> fac;
proc(n)
{
  var res;
  if (n == 0) then
    res := 1
  else
    res := (n) * (fac((n) - (1)));
  return res;
}
> sumall = proc(args = ...) { var i, acc; acc = 0; for i in args do acc = acc +
i; return acc; }; > sumall; proc(args = ...) {
var i, acc;
acc = 0;
for i in args do
acc = (acc) + (i);
return acc;
}
> sumall(); 0
> sumall(1); 1
> sumall(1,5); 6
> sumall(1,5,9); 15
> sumall @ [|1,5,9,4,8|]; 27
>
Let us note that, when writing a procedure, one does not know what will be the name of the free variable at run-time. This is typically the context when one should use the special keyword _x_:

> ChebPolynomials = proc(n) {
var i, res;
if (n<0) then res = [|1|]
else if (n==0) then res = [|1|]
else {
res = [|1, _x_|];
for i from 2 to n do res[i] = horner(2*_x_*res[i-1]-res[i-2]);
};
return res;
};
> f = sin(x);
> T = ChebPolynomials(4);
> canonical = on!;
> for i from 0 to 4 do T[i];
1
x
-1 + 2 * x^-2
-3 * x + 4 * x^-3
1 + -8 * x^-2 + 8 * x^-4

Sollya also supports external procedures, i.e., procedures written in C (or some other language) and dynamically bound to Sollya identifiers. See [8.64] for details.

7.2 Pattern matching

Starting with version 3.0, Sollya supports matching expressions with expression patterns. This feature is important for an extended functional programming style. Further, and most importantly, it allows expression trees to be recursively decomposed using native constructs of the Sollya language. This means no help from external procedures or other compiled-language mechanisms is needed here anymore.

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Basically, pattern matching supports relies on one Sollya construct:

```plaintext
match expr with
  pattern1 : (return-expr1)
  pattern2 : (return-expr2)
  ...
  patternN : (return-exprN)
```

That construct has the following semantic: try to match the expression `expr` with the patterns `pattern1` through `patternN`, proceeding in natural order. If a pattern `patternI` is found that matches, evaluate the whole `match ... with` construct to the return expression `return-exprI` associated with the matching pattern `patternI`. If no matching pattern is found, display an error warning and return `error`. Note that the parentheses around the expressions `return-exprI` are mandatory.

Matching a pattern means the following:

- If a pattern does not contain any programming-language-level variables (different from the free mathematical variable), it matches expressions that are syntactically equal to itself. For instance, the pattern `exp(sin(3 * x))` will match the expression `exp(sin(3 * x))`, but it does not match `exp(sin(x * 3))` because the expressions are not syntactically equal.

- If a pattern does contain variables, it matches an expression `expr` if these variables can be bound to subexpressions of `expr` such that once the pattern is evaluated with that variable binding, it becomes syntactically equal to the expression `expr`. For instance, the pattern `exp(sin(a * x))` will match the expression `exp(sin(3 * x))` as it is possible to bind `a` to `3` such that `exp(sin(a * x))` evaluates to `exp(sin(3 * x))`.

If a pattern `patternI` with variables is matched in a `match ... with` construct, the variables in the pattern stay bound during the evaluation of the corresponding return expression `return-exprI`. This allows subexpressions to be extracted from expressions and/or recursively handled as needed.

The following examples illustrate the basic principles of pattern matching in Sollya. One can remark that it is useful to use the keyword `_x_` when one wants to be sure to refer to the free variable in a pattern matching:
As Sollya is not a purely functional language, the match ... with construct can also be used in a more imperative style, which makes it become closer to constructs like switch in C or Perl. In lieu of a simple return expression, a whole block of imperative statements can be given. The expression to be returned by that block is indicated in the end of the block, using the return keyword. That syntax is illustrated in the next example:
> match exp(sin(x)) with
  exp(a) : {
    write("Exponential of ", a, "\n");
    return a;
  }
  sin(x) : {
    var foo;
    foo = 17;
    write("Sine of x\n");
    return foo;
  }
  default : {
    write("Something else\n");
    bashexecute("LANG=C date");
    return true;
  }

Exponential of sin(x)

sin(x)

> match sin(x) with
  exp(a) : {
    write("Exponential of ", a, "\n");
    return a;
  }
  sin(x) : {
    var foo;
    foo = 17;
    write("Sine of x\n");
    return foo;
  }
  default : {
    write("Something else\n");
    bashexecute("LANG=C date");
    return true;
  }

Sine of x
17

> match acos(17 * pi * x) with
  exp(a) : {
    write("Exponential of ", a, "\n");
    return a;
  }
  sin(x) : {
    var foo;
    foo = 17;
    write("Sine of x\n");
    return foo;
  }
  default : {
    write("Something else\n");
    bashexecute("LANG=C date");
    return true;
  }

Something else
Fri Aug 24 11:17:01 CEST 2018
true
In the case when no return statement is indicated for a statement-block in a `match ... with` construct, the construct evaluates to the special value `void` if that pattern matches.

In order to well understand pattern matching in Sollya, it is important to realize the meaning of variables in patterns. This meaning is different from the one usually found for variables. In a pattern, variables are never evaluated to whatever they might have set before the pattern is executed. In contrast, all variables in patterns are new, free variables that will freshly be bound to subexpressions of the matching expression. If a variable of the same name already exists, it will be shadowed during the evaluation of the statement block and the return expression corresponding to the matching expression. This type of semantic implies that patterns can never be computed at run-time, they must always be hard-coded beforehand. However this is necessary to make pattern matching context-free.

As a matter of course, all variables figuring in the expression `expr` to be matched are evaluated before pattern matching is attempted. In fact, `expr` is a usual Sollya expression, not a pattern.

In Sollya, the use of variables in patterns does not need to be linear. This means the same variable might appear twice or more in a pattern. Such a pattern will only match an expression if it contains the same subexpression, associated with the variable, in all places indicated by the variable in the pattern.

The following examples illustrate the use of variables in patterns in detail:

```sollya
> a = 5;
> b = 6;
> match exp(x + 3) with
  exp(a + b) : {
    print("Exponential");
    print("a = ", a);
    print("b = ", b);
  }
  sin(x) : {
    print("Sine of x");
  }
Exponential
a = x
b = 3
> print("a = ", a, ", b = ", b);
a = 5 , b = 6
>
> a = 5;
> b = 6;
> match exp(x + 3) with
  exp(a + b) : {
    var a, c;
    a = 17;
    c = "Hallo";
    print("Exponential");
    print("a = ", a);
    print("b = ", b);
    print("c = ", c);
  }
  sin(x) : {
    print("Sine of x");
  }
Exponential
a = 17
b = 3
c = Hallo
> print("a = ", a, ", b = ", b);
a = 5 , b = 6
```

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Pattern matching is meant to be a means to decompose expressions structurally. For this reason and in an analogous way to variables, no evaluation is performed at all on (sub-)expressions that form constant functions. As a consequence, patterns match constant expressions only if they are structurally identical. For example, $5 + 1$ only matches $5 + 1$ and not $1 + 5$, $3 + 3$, or $6$.

This general rule on constant expressions admits one exception. Intervals in Sollya can be defined using constant expressions as bounds. These bounds are immediately evaluated to floating-point constants, though. In order to permit pattern matching on intervals, constant expressions given as bounds of intervals that form patterns are evaluated before pattern matching. However, in order not conflict with the rules of no evaluation of variables, these constant expressions as bounds of intervals in patterns must not contain free variables.
The Sollya keyword `default` has a special meaning in patterns. It acts like a wild-card, matching any (sub-)expression, as long as the whole expression stays correctly typed. Upon matching with `default`, no variable gets bound. This feature is illustrated in the next example:
In Sollya, pattern matching is possible on the following Sollya types and operations defined on them:

- Expressions that define univariate functions, as explained above,
- Intervals with one, two or no bound defined in the pattern by a variable,
- Character sequences, literate or defined using the \@ operator, possibly with a variable on one of the sides of the \@ operator,
- Lists, literate, literate with variables or defined using the \.: \.: and \@ operators, possibly with a variable on one of the sides of the \@ operator or one or two variables for \.: and \.:,
- Structures, literate or literate with variables, and
- All other Sollya objects, matchable with themselves (DE matches DE, on matches on, perturb matches perturb etc.)
procedure detector(obj) {
  match obj with
  exp(a * x) : { "Exponential of ", a, " times x"; };
  [ a; 17 ] : { "An interval from ", a, " to 17"; };
  [] : { "Empty list"; };
  [ [ a, b, 2, exp(c) ]] : { "A list of ", a, ", ", b, ", ", 2 and ",
    "exponential of ", c; };
  a @ [ [ 2, 3 ] ] : { "Concatenation of the list ", a, " and ",
    "the list of 2 and 3"; };
  a : [ [ 9 ... ] ] : { a, " prepended to all integers >= 9"; };
  "Hello" @ w : { "Hello concatenated with ", w; };
  { .a = sin(b); .b = [c;d] } : { "A structure containing as .a the ",
    "sine of ", b,
    " and as .b the range from ", c,
    " to ", d; };
  perturb : { "The special object perturb"; };
  default : { "Something else"; };
};

> detector(exp(5 * x));
Exponential of 5 times x
> detector([3.25;17]);
An interval from 3.25 to 17
> detector([]);
Empty list
> detector([ [ sin(x), nearestint(x), 2, exp(5 * atan(x)) ]]);
A list of \(\sin(x)\), \(\text{nearestint}(x)\), 2 and \(e^{5 \cdot \text{atan}(x)}\)
> detector([ [ sin(x), cos(5 * x), "foo", 2, 3 ]]);
Concatenation of the list \([\sin(x), \cos(5 \cdot x), "foo"]\) and the list of 2 and 3
> detector([ [ DE, 9... ]]);
doubleextended prepended to all integers >= 9
> detector("Hello world");
Hello concatenated with world
> detector({ .a = sin(x); .c = "Hello"; .b = [9;10] });
A structure containing as .a the sine of \(x\) and as .b the range from \(9\) to \(10\)
> detector(perturb);
The special object perturb
> detector([13;19]);
Something else

Concerning intervals, please pay attention to the fact that expressions involving intervals are immediately evaluated and that structural pattern matching on functions on intervals is not possible. This point is illustrated in the next example:
With respect to pattern matching on lists or character sequences defined using the \( \oplus \) operator, the following is to be mentioned:

- Patterns like \( a \oplus b \) are not allowed as they would need to perform an ambiguous cut of the list or character sequence to be matched. This restriction is maintained even if the variables (here \( a \) and \( b \)) are constrained by other occurrences in the pattern (for example in a list) which would make the cut unambiguous.

- Recursive use of the \( \oplus \) operator (even mixed with the operators \( :, \) and \( :: \)) is possible under the condition that there must not exist any other parenthesizing of the term in concatenations (\( \oplus \)) such that the rule of one single variable for \( \oplus \) above gets violated. For instance, \( (\text{[1;1] \oplus a} \oplus (\text{b \oplus [4;1]})) \) is not possible as it can be re-parenthesized \( \text{[1;1] \oplus (a \oplus b} \oplus [4;1]) \), which exhibits the ambiguous case.

These points are illustrated in this example:
As mentioned above, pattern matching on Sollya structures is possible. Patterns for such a match are given in a literately, i.e., using the syntax \{
  \text{.} a = \text{exprA}, \text{.} b = \text{exprB}, \ldots
\}. A structure pattern \(sp\) will be matched by a structure \(s\) iff that structure \(s\) contains at least all the elements (like \(\text{.} a\), \(\text{.} b\) etc.) of the structure pattern \(sp\) and iff each of the elements of the structure \(s\) matches the pattern in the corresponding element of the structure pattern \(sp\). The user should be aware of the fact that the structure to be matched is only supposed to have at least the elements of the pattern but that it may contain more elements is a particular Sollya feature. For instance with pattern matching, it is hence possible to ensure that access to particular elements will be possible in a particular code segment. The following example is meant to clarify this point:
8 Commands and functions

8.1 abs

Name: abs

the absolute value.

Library names: abs

Exponential, 1, 2, 2 + x
#absolute

Name: absolute
indicates an absolute error for externalplot, fpminimax or supnorm

Library names:
  sollya_obj_t sollya_lib_absolute()
  int sollya_lib_is_absolute(sollya_obj_t)

Usage:

  absolute : absolute|relative

Description:
• The use of absolute in the command externalplot indicates that during plotting in externalplot an absolute error is to be considered.
  See externalplot for details.
• Used with fpminimax, absolute indicates that fpminimax must try to minimize the absolute error.
  See fpminimax for details.
• When given in argument to supnorm, absolute indicates that an absolute error is to be considered for supremum norm computation.
  See supnorm for details.

Example 1:

  > bashexecute("gcc -fPIC -c externalplotexample.c");
  > bashexecute("gcc -shared -o externalplotexample externalplotexample.o -lgmp -lm
  mpfr");
  > externalplot("./externalplotexample",absolute,exp(x),[-1/2;1/2],12,perturb);

See also: externalplot [8.63], fpminimax [8.71], relative [8.154], bashexecute [8.18], supnorm [8.180]

#accurateinfnorm

Name: accurateinfnorm
computes a faithful rounding of the infinity norm of a function

Usage:

  accurateinfnorm(function,range,constant) : (function, range, constant) → constant
  accurateinfnorm(function,range,constant,exclusion range 1,...,exclusion range n) : (function, range, constant, range, ..., range) → constant

Parameters:
• function represents the function whose infinity norm is to be computed
• range represents the infinity norm is to be considered on
• **constant** represents the number of bits in the significant of the result

• **exclusion range** 1 through **exclusion range** n represent ranges to be excluded

**Description:**

• The command **accurateinfnorm** computes an upper bound to the infinity norm of function **function** in **range**. This upper bound is the least floating-point number greater than the value of the infinity norm that lies in the set of dyadic floating point numbers having **constant** significant mantissa bits. This means the value **accurateinfnorm** evaluates to is at the time an upper bound and a faithful rounding to **constant** bits of the infinity norm of function **function** on range **range**.

If given, the fourth and further arguments of the command **accurateinfnorm**, **exclusion range** 1 through **exclusion range** n the infinity norm of the function **function** is not to be considered on.

• The command **accurateinfnorm** is now considered **DEPRECATED** in **Sollya**. Users should be aware about the fact that the algorithm behind **accurateinfnorm** is highly inefficient and that other, better suited algorithms, such as **supnorm**, are available inside **Sollya**. As a matter of fact, while **accurateinfnorm** is maintained for compatibility reasons with legacy **Sollya** codes, users are advised to avoid using **accurateinfnorm** in new **Sollya** scripts and to replace it, where possible, by the **supnorm** command.

**Example 1:**

```
> p = remez(exp(x), 5, [-1;1]);
> accurateinfnorm(p - exp(x), [-1;1], 20);
4.52055246569216251373291015625e-5
> accurateinfnorm(p - exp(x), [-1;1], 30);
4.52055246569216251373291015625e-5
> accurateinfnorm(p - exp(x), [-1;1], 40);
4.52055246569216251373291015625e-5
```

**Example 2:**

```
> p = remez(exp(x), 5, [-1;1]);
> midpointmode = on!;
> infnorm(p - exp(x), [-1;1]);
0.452055246569216251373291015625e-5
> accurateinfnorm(p - exp(x), [-1;1], 40);
4.52055246569216251373291015625e-5
```

See also: **infnorm** (8.91), **dirtyinfnorm** (8.43), **supnorm** (8.180), **checkinfnorm** (8.25), **remez** (8.155), **diam** (8.39)

### 8.4 acos

**Name:** acos

the arccosine function.

**Library names:**

```
sollya_obj_t sollya_lib_acos(sollya_obj_t) 
sollya_obj_t sollya_lib_build_function_acos(sollya_obj_t) 
#define SOLLYA_ACOS(x) sollya_lib_build_function_acos(x)
```

**Description:**

• **acos** is the inverse of the function **cos**: **acos**(y) is the unique number x ∈ [0; π] such that **cos**(x)=y.

• It is defined only for y ∈ [-1; 1].

See also: **cos** (8.30)
8.5 acosh

Name: acosh
the arg-hyperbolic cosine function.

Library names:
sollya_obj_t sollya_lib_acosh(sollya_obj_t)
sollya_obj_t sollya_lib_build_function_acosh(sollya_obj_t)
#define SOLLYA_ACOSH(x) sollya_lib_build_function_acosh(x)

Description:

- *acosh* is the inverse of the function *cosh*: *acosh*(y) is the unique number \( x \in [0; +\infty] \) such that \( \cosh(x) = y \).
- It is defined only for \( y \in [0; +\infty] \).

See also: *cosh* [8.31]

8.6 &&

Name: &&
boolean AND operator

Library name:
sollya_obj_t sollya_lib_and(sollya_obj_t, sollya_obj_t)

Usage:

\[ expr1 \&\& expr2 : (\text{boolean, boolean}) \rightarrow \text{boolean} \]

Parameters:

- *expr1* and *expr2* represent boolean expressions

Description:

- && evaluates to the boolean AND of the two boolean expressions *expr1* and *expr2*. && evaluates to true iff both *expr1* and *expr2* evaluate to true.

Example 1:

```
> true && false;
false
```

Example 2:

```
> (1 == exp(0)) && (0 == log(1));
true
```

See also: || (8.124), ! (8.117)

8.7 annotatefunction

Name: annotatefunction
Annotates a Sollya function object with an approximation that is faster to evaluate

Library names:
sollya_obj_t sollya_lib_annotatefunction(sollya_obj_t, sollya_obj_t, sollya_obj_t, ...);
sollya_obj_t sollya_lib_v_annotatefunction(sollya_obj_t, sollya_obj_t, sollya_obj_t, va_list);

Usage:
annotatefunction\((f, g, I, d) : (\text{function}, \text{function}, \text{range}, \text{range}) \rightarrow \text{function}\)\n
annotatefunction\((f, g, I, d, x_0) : (\text{function}, \text{function}, \text{range}, \text{range}, \text{constant}) \rightarrow \text{function}\)\n
Parameters:
- \(f\) is a function.
- \(g\) is a function, in most cases a polynomial.
- \(I\) is an interval.
- \(d\) is an interval.
- \(x_0\) is a constant (default value is 0 when not provided).

Description:
- When a given function \(f\) is to be evaluated at several points of a given interval \(I\) to a given precision, it might be useful to precompute a good approximant \(g\) of \(f\) and further evaluate it instead of \(f\) when the approximation is good enough to provide the desire precision. If \(f\) is a complicated expression, whereas \(g\) is, e.g., a polynomial of low degree, the cost of precomputing \(g\) can be well compensated by the gain of time in each subsequent evaluation. The purpose of \texttt{annotatefunction} is to provide such a mechanism to the user.

- When using \texttt{annotatefunction}(\(f, g, I, d, x_0\)), resp. \texttt{annotatefunction}(\(f, g, I, d\)) (where \(x_0\) is assumed to be zero), it is assumed that
\[
\forall x \in I, f(x) - g(x - x_0) \in d.
\]
It is the user responsibility to ensure this property. Otherwise, any subsequent use of \(f\) on points of \(I\) might lead to incorrect values.

- A call to \texttt{annotatefunction}(\(f, g, I, d, x_0\)) annotates the given Sollya function object \(f\) with the approximation \(g\). In further use, when asked to evaluate \(f\) on a point \(x\) of \(I\), Sollya will first evaluate \(g\) on \(x - x_0\) and check if the result is accurate enough in the given context (accounting for the fact that the error of approximation between the true value and \(g(x - x_0)\) belongs to \(d\)). If not (and only in this case), an evaluation of the expression of \(f\) on \(x\) is performed.

- The approximation \(g\) can be any Sollya function but particular performance is expected when \(g\) is a polynomial. Upon annotation with a polynomial, precomputations are performed to analyze certain properties of the given approximation polynomial.

- \texttt{annotatefunction} updates the internal representation of \(f\) so as to persistently keep this information attached with the Sollya object representing \(f\). In particular, the annotation is persistent through copy or use of \(f\) as a subexpression to build up bigger expressions. Notice however, that there is no way of deducing an annotation for the derivative of \(f\) from an annotation of \(f\). So, in general, it should not be expected that \texttt{diff}(\(f\)) will be automatically annotated (notice, however that \(f\) might be a subexpression of its derivative, e.g., for \(f=\text{exp}\) or \(f=\text{tan}\), in which case the corresponding subexpressions of the derivative could inherit the annotations from \(f\). It is currently not specified whether Sollya does this automatically or not).

- \texttt{annotatefunction} really is an imperative statement that modifies the internal representation of \(f\). However, for convenience \texttt{annotatefunction} returns \(f\) itself.

- Sollya function objects can be annotated more than once with different approximations on different domains, that do not need to be disjoint. Upon evaluation of the annotated function object, Sollya chooses an approximation annotation (if any) that provides for sufficient accuracy at the evaluation point. It is not specified in which order Sollya tries different possible annotations when several are available for a given point \(x\).

Example 1:
> verbosity=1;
> procedure EXP(X,n,p) {
> var res, oldPrec;
> oldPrec = prec;
> prec = p;
> "Using procedure function exponential with X=" @ X @ ", n=" @ n @ ",
> and p=" @ p;
> res = exp(X);
> prec = oldPrec!
> return res;
> }
>
> g = function(EXP);
> p = 4676805239458893382516870161332864698044514954899b-165 + x * (23384026197
294446691258465802074096632225783601255b-164 + x * (5846006549323611672948266
13035653821819225877423b-163 + x * (38973376995490744862767964908061513731982
1946501b-164 + x * (779467539909814871742274462137143438304888817417b-167 + x
* (29492961277114075921122941174178949425280985636737b-171 + x * (83143204257
04876115638389001050597456456371179471b-172 + x * (19004160973097013175793569
91645932289422670402995b-176 + x * (190041609726693241489121222544499121560039
26801563b-179 + x * (3378517506254259726738679493857229456702396042255b-183 +
* (6757035113643674373936259882649268861986066989b-184 + x * (9828414707
5112527699089206114426276633532289937b-188 + x * (26208861080003813314724515
323358473870696162212965b-193 + x * (322570642533259543159374239699456577223
350602741b-197 + x * (5784290865768956703059185903214676926704485495b-195 +
* (24678854217667568523627105540999778984959471957b-201))))))))));
> h = annotatefunction(g, p, [-1/2;1/2], [-475294848522543b-124;475294848522543b
-124]);
> h == g;
> h == g;
true
> prec = 24;
The precision has been set to 24 bits.
> h(0.25);
Warning: rounding has happened. The value displayed is a faithful rounding to 24
bits of the true result.
1.2840254
> prec = 165;
The precision has been set to 165 bits.
> h(0.25);
Using procedure function exponential with X=[0.25;0.25], n=0, and p=185
Warning: rounding has happened. The value displayed is a faithful rounding to 16
5 bits of the true result.
1.28402541668774148407342056806243645833628086528147

See also: chebyshevform [8.24], taylorform [8.180], remez [8.155], supnorm [8.180], infnorm [8.91]

8.8 :.
Name: :.
add an element at the end of a list.

Library name:
  sollya_obj_t sollya_lib_append(sollya_obj_t, sollya_obj_t)

Usage:

L:.x : (list, any type) → list
Parameters:

- $L$ is a list (possibly empty).
- $x$ is an object of any type.

Description:

- :: adds the element $x$ at the end of the list $L$.
- Note that since $x$ may be of any type, it can in particular be a list.

Example 1:

```
> [2,3,4]:.5;
[2, 3, 4, 5]
```

Example 2:

```
> [1,2,3]:.[4,5,6];
[1, 2, 3, [4, 5, 6]]
```

Example 3:

```
> [[]]:.1;
[1]
```

See also: :: [8.137], @ [8.28]

8.9 ~

Name: ~

floating-point evaluation of a constant expression

Library name:

```
sollya_obj_t sollya_lib_approx(sollya_obj_t)
```

Usage:

```
~ expression : function → constant
~ something : any type → any type
```

Parameters:

- $expression$ stands for an expression that is a constant
- $something$ stands for some language element that is not a constant expression

Description:

- $~ expression$ evaluates the expression that is a constant term to a floating-point constant. The evaluation may involve a rounding. If $expression$ is not a constant, the evaluated constant is a faithful rounding of $expression$ with precision bits, unless the $expression$ is exactly 0 as a result of cancellation. In the latter case, a floating-point approximation of some (unknown) accuracy is returned.
- $~$ does not do anything on all language elements that are not a constant expression. In other words, it behaves like the identity function on any type that is not a constant expression. It can hence be used in any place where one wants to be sure that expressions are simplified using floating-point computations to constants of a known precision, regardless of the type of actual language elements.
- $~$ error evaluates to error and provokes a warning.
• ~ is a prefix operator not requiring parentheses. Its precedence is the same as for the unary + and - operators. It cannot be repeatedly used without brackets.

Example 1:

```plaintext
> print(exp(5));
exp(5)
> print(~ exp(5));
148.4131591025766034211558004055227962348766759388
```

Example 2:

```plaintext
> autosimplify = off!
```

Example 3:

```plaintext
> print(~sin(5 * pi));
0
```

Example 4:

```plaintext
> print(~exp(x));
expx
> print(~ "Hello");
Hello
```

Example 5:

```plaintext
> print(~exp(x*5*Pi));
exppi5x
> print(exp(x* ~(5*Pi)));
expx15.7079632679489661923132169163975144209858469968757
```

Example 6:

```plaintext
> print(~exp(5)*x);
148.4131591025766034211558004055227962348766759388 * x
> print( (~exp(5))*x);
148.4131591025766034211558004055227962348766759388 * x
> print(~(exp(5)*x));
expx5
```

See also: evaluate [8.57], prec [8.135], error [8.56]

8.10 asciiplot

Name: asciiplot

plots a function in a range using ASCII characters

Library name:

```c
void sollya_lib_asciiplot(sollya_obj_t, sollya_obj_t)
```

Usage:

```c
asciiplot(function, range) : (function, range) → void
```

Parameters:

• `function` represents a function to be plotted

46
• range represents a range the function is to be plotted in

Description:

• asciiplot plots the function function in range range using ASCII characters. On systems that provide the necessary TIOCGWINSZ ioctl, Sollya determines the size of the terminal for the plot size if connected to a terminal. If it is not connected to a terminal or if the test is not possible, the plot is of fixed size 77 × 25 characters. The function is evaluated on a number of points equal to the number of columns available. Its value is rounded to the next integer in the range of lines available. A letter x is written at this place. If zero is in the hull of the image domain of the function, an x-axis is displayed. If zero is in range, a y-axis is displayed. If the function is constant or if the range is reduced to one point, the function is evaluated to a constant and the constant is displayed instead of a plot.

Example 1:

```
> asciiplot(exp(x),[1;2]);
```

Example 2:
Example 3:

```latex
> asciiplot(5, [-1; 1];)  
5
```

Example 4:

```latex
> asciiplot(exp(x), [1; 1];)  
2.7182818284590452353602874713526624977572570937
```

See also: `plot` [8.128], `externalplot` [8.63]

### 8.11 asin

Name: **asin**

the arcsine function.

Library names:

- `sollya_obj_t` `sollya_lib_asin(sollya_obj_t)`
- `sollya_obj_t` `sollya_lib_build_function_asin(sollya_obj_t)`
- `

  #define SOLLYA_ASIN(x) sollya_lib_build_function_asin(x)

Description:

- **asin** is the inverse of the function **sin**: `asin(y)` is the unique number `x` in `[-\pi/2; \pi/2]` such that `sin(x) = y`.
- It is defined only for `y` in `[-1; 1]`.

See also: `sin` [8.171]
8.12 asinh

Name: asinh
the arg-hyperbolic sine function.

Library names:

- `sollya_obj_t sollya_lib_asinh(sollya_obj_t)`
- `sollya_obj_t sollya_lib_build_function_asinh(sollya_obj_t)`
- `#define SOLLYA_ASINH(x) sollya_lib_build_function_asinh(x)`

Description:

- **asinh** is the inverse of the function **sinh**: **asinh**\( y \) is the unique number \( x \in [-\infty; +\infty] \) such that \( \sinh(x)=y \).
- It is defined for every real number \( y \).

See also: **sinh** (8.173)

8.13 atan

Name: atan
the arctangent function.

Library names:

- `sollya_obj_t sollya_lib_atan(sollya_obj_t)`
- `sollya_obj_t sollya_lib_build_function_atan(sollya_obj_t)`
- `#define SOLLYA_ATAN(x) sollya_lib_build_function_atan(x)`

Description:

- **atan** is the inverse of the function **tan**: **atan**\( y \) is the unique number \( x \in [-\pi/2; +\pi/2] \) such that \( \tan(x)=y \).
- It is defined for every real number \( y \).

See also: **tan** (8.183)

8.14 atanh

Name: atanh
the hyperbolic arctangent function.

Library names:

- `sollya_obj_t sollya_lib_atanh(sollya_obj_t)`
- `sollya_obj_t sollya_lib_build_function_atanh(sollya_obj_t)`
- `#define SOLLYA_ATANH(x) sollya_lib_build_function_atanh(x)`

Description:

- **atanh** is the inverse of the function **tanh**: **atanh**\( y \) is the unique number \( x \in [-\infty; +\infty] \) such that \( \tanh(x)=y \).
- It is defined only for \( y \in [-1; 1] \).

See also: **tanh** (8.184)

8.15 autodiff

Name: autodiff
Computes the first \( n \) derivatives of a function at a point or over an interval.

Library name:

- `sollya_obj_t sollya_lib_autodiff(sollya_obj_t, sollya_obj_t, sollya_obj_t)`

Usage:
autodiff\((f, n, x_0)\) : (function, integer, constant) → list

autodiff\((f, n, I)\) : (function, integer, range) → list

Parameters:

- \(f\) is the function to be differentiated.
- \(n\) is the order of differentiation.
- \(x_0\) is the point at which the function is differentiated.
- \(I\) is the interval over which the function is differentiated.

Description:

- \textbf{autodiff} computes the first \(n\) derivatives of \(f\) at point \(x_0\). The computation is performed numerically, without symbolically differentiating the expression of \(f\). Yet, the computation is safe since small interval enclosures are produced. More precisely, \textbf{autodiff} returns a list \([f_0, \ldots, f_n]\) such that, for each \(i\), \(f_i\) is a small interval enclosing the exact value of \(f^{(i)}(x_0)\).
- Since it does not perform any symbolic differentiation, \textbf{autodiff} is much more efficient than \textbf{diff} and should be preferred when only numerical values are necessary.
- If an interval \(I\) is provided instead of a point \(x_0\), the list returned by \textbf{autodiff} satisfies: \(\forall i, f^{(i)}(I) \subseteq f_i\). A particular use is when one wants to know the successive derivatives of a function at a non representable point such as \(\pi\). In this case, it suffices to call \textbf{autodiff} with the (almost) point interval \(I = [\pi]\).
- When \(I\) is almost a point interval, the returned enclosures \(f_i\) are also almost point intervals. However, when the interval \(I\) begins to be fairly large, the enclosures can be deeply overestimated due to the dependency phenomenon present with interval arithmetic.
- As a particular case, \(f_0\) is an enclosure of the image of \(f\) over \(I\). However, since the algorithm is not specially designed for this purpose it is not very efficient for this particular task. In particular, it is not able to return a finite enclosure for functions with removable singularities (e.g. \(\sin(x)/x\) at \(0\)). The command \textbf{evaluate} is much more efficient for computing an accurate enclosure of the image of a function over an interval.

Example 1:

```
> L = autodiff(exp(cos(x))+sin(exp(x)), 5, 0);
> midpointmode = on!
> for f_i in L do f_i;
0.3559752813266941742012789792982961497379810154498~2/4~e1
0.5403023058681397174009366074429766037323104206179~0/3~
-0.3019450507398802024611853185539884893647499733880~6/2~e1
-0.252441295442368951995750696489089699886768918239~6/4~e1
0.3122798756481033145214529184139729746320579069~1/3~e1
-0.16634307959006696033484053579339956883955954978~3/1~e2
```

Example 2:
Example 3:

```plaintext
> L = autodiff(sin(x)/x, 0, [-1,1]);
> L[0];
[-infty;infty]
> evaluate(sin(x)/x, [-1,1]);
[0.5403023058681397174009366074429766037323104206179;1]
```

See also: `diff (8.41)`, `evaluate (8.57)`

### 8.16 autosimplify

**Name:** autosimplify

activates, deactivates or inspects the value of the automatic simplification state variable

**Library names:**

- `void sollya_lib_set_autosimplify_and_print(sollya_obj_t)`
- `void sollya_lib_set_autosimplify(sollya_obj_t)`
- `sollya_obj_t sollya_lib_get_autosimplify()`

**Usage:**

```plaintext
autosimplify = activation value : on|off → void
autosimplify = activation value ! : on|off → void
autosimplify : on|off
```

**Parameters:**

- `activation value` represents **on** or **off**, i.e. activation or deactivation

**Description:**

- An assignment `autosimplify = activation value`, where `activation value` is one of **on** or **off**, activates respectively deactivates the automatic safe simplification of expressions of functions generated by the evaluation of commands or in argument of other commands.

Sollya commands like `remez`, `taylor` or `rationalapprox` sometimes produce expressions that can be simplified. Constant subexpressions can be evaluated to dyadic floating-point numbers, monomials with coefficients 0 can be eliminated. Further, expressions indicated by the user perform better in many commands when simplified before being passed in argument to a command. When the automatic simplification of expressions is activated, Sollya automatically performs a safe (not value changing) simplification process on such expressions.

The automatic generation of subexpressions can be annoying, in particular if it takes too much time for not enough benefit. Further the user might want to inspect the structure of the expression tree returned by a command. In this case, the automatic simplification should be deactivated.
If the assignment `autosimplify = activation value` is followed by an exclamation mark, no message indicating the new state is displayed. Otherwise the user is informed of the new state of the global mode by an indication.

Example 1:

```
> autosimplify = on !;
> print(x - x);
0
> autosimplify = off ;
Automatic pure tree simplification has been deactivated.
> print(x - x);
x - x
```

Example 2:

```
> autosimplify = on !;
> print(rationalapprox(sin(pi/5.9),7));
33 / 65
> autosimplify = off !;
> print(rationalapprox(sin(pi/5.9),7));
33 / 65
```

See also: `print`, `==`, `! =`, `prec`, `points`, `diam`, `display`, `verbosity`, `canonical`, `taylorrecursions`, `timing`, `fullparentheses`, `midpointmode`, `hopitalrecursions`, `remez`, `rationalapprox`, `taylor`

8.17 bashevaluate

Name: `bashevaluate`

executes a shell command and returns its output as a string

Library names:

```
sollya_obj_t sollya_lib_bashevaluate(sollya_obj_t, ...)
sollya_obj_t sollya_lib_v_bashevaluate(sollya_obj_t, va_list)
```

Usage:

```
bashevaluate(command) : string → string
bashevaluate(command,input) : (string, string) → string
```

Parameters:

- `command` is a command to be interpreted by the shell.
- `input` is an optional character sequence to be fed to the command.

Description:

- `bashevaluate(command)` will execute the shell command `command` in a shell. All output on the command’s standard output is collected and returned as a character sequence.

- If an additional argument `input` is given in a call to `bashevaluate(command,input)`, this character sequence is written to the standard input of the command `command` that gets executed.

- All characters output by `command` are included in the character sequence to which `bashevaluate` evaluates but two exceptions. Every NULL character (‘\0’) in the output is replaced with ‘?’ as Sollya is unable to handle character sequences containing that character. Additionally, if the output ends in a newline character (‘\n’), this character is stripped off. Other newline characters which are not at the end of the output are left as such.
Example 1:

```bash
> bashevaluate("LANG=C date");
Thu Sep 20 12:14:35 CEST 2018
```

Example 2:

```bash
> [[ bashevaluate("echo Hello") ]];
["Hello"]
```

Example 3:

```bash
> a = bashevaluate("sed -e 's/a/e/g;'", "Hallo");
> a;
Hello
```

See also: `bashexecute` (8.18)

8.18 `bashexecute`

Name: `bashexecute`

executes a shell command.

Library names:

- void `sollya_lib_bashexecute(sollya_obj_t)`

Usage:

```c
bashexecute(command) : string → void
```

Parameters:

- `command` is a command to be interpreted by the shell.

Description:

- `bashexecute(command)` lets the shell interpret `command`. It is useful to execute some external code within Sollya.
- `bashexecute` does not return anything. It just executes its argument. However, if `command` produces an output in a file, this result can be imported in Sollya with help of commands like `execute`, `readfile` and `parse`.

Example 1:

```bash
> bashexecute("LANG=C date");
Thu Sep 20 12:14:39 CEST 2018
```

See also: `execute` (8.58), `readfile` (8.152), `parse` (8.125), `bashevaluate` (8.17)

8.19 `binary`

Name: `binary`

special value for global state `display`

Library names:

- `sollya_obj_t sollya_lib_binary()`
- `int sollya_lib_is_binary(sollya_obj_t)`

Description:

- `binary` is a special value used for the global state `display`. If the global state `display` is equal to `binary`, all data will be output in binary notation.

As any value it can be affected to a variable and stored in lists.

See also: `decimal` (8.35), `dyadic` (8.52), `powers` (8.134), `hexadecimal` (8.82), `display` (8.46)
8.20  bind

Name: bind
  partially applies a procedure to an argument, returning a procedure with one argument less

Usage:

```
bind(proc, ident, obj) : (procedure, identifier type, any type) → procedure
```

Parameters:

- `proc` is a procedure to be partially applied to an argument
- `ident` is one of the formal arguments of `proc`
- `obj` is any Sollya object `ident` is to be bound to

Description:

- `bind` allows a formal parameter `ident` of a procedure `proc` to be bound to an object `obj`, hence `proc` to be partially applied. The result of this curried application, returned by `bind`, is a procedure with one argument less. This way, `bind` permits specialization of a generic procedure, parameterized e.g. by a function or range.

- In the case when `proc` does not have a formal parameter named `ident`, `bind` prints a warning and returns the procedure `proc` unmodified.

- `bind` always returns a procedure, even if `proc` only has one argument, which gets bound to `ident`. In this case, `bind` returns a procedure which does not take any argument. Hence evaluation, which might provoke side effects, is only performed once the procedure gets used.

- `bind` does not work on procedures with an arbitrary number of arguments.

Example 1:

```
> procedure add(X,Y) { return X + Y; };
> succ = bind(add,X,1);
> succ(5);
6
> succ;
proc(Y)
{
  nop;
  return (proc(X, Y)
  {
    nop;
    return (X) + (Y);
  })(1, Y);
}
```

Example 2:
> procedure add(X, Y) { return X + Y; }
> succ = bind(add, X, 1);
> five = bind(succ, Y, 4);
> five();
5
> five;
proc()
{
nop;
return (proc(Y)
{
nop;
return (proc(X, Y)
{
nop;
return (X) + (Y);
})(1, Y);
})(4);
}

Example 3:

> verbosity = 1!
> procedure add(X, Y) { return X + Y; }
> foo = bind(add, R, 1);
Warning: the given procedure has no argument named "R". The procedure is returned unchanged.
> foo;
proc(X, Y)
{
nop;
return (X) + (Y);
}

See also: procedure [8.144], proc [8.143], function [8.73], @ [8.28]

8.21 boolean

Name: boolean
keyword representing a boolean type

Library name:
SOLLYA_EXTERNALPROC_TYPE_BOOLEAN

Usage:

    boolean : type type

Description:

- boolean represents the boolean type for declarations of external procedures by means of externalproc.

Remark that in contrast to other indicators, type indicators like boolean cannot be handled outside the externalproc context. In particular, they cannot be assigned to variables.

See also: externalproc [8.64], constant [8.29], function [8.73], integer [8.92], list of [8.100], range [8.148], string [8.176], object [8.120]
8.22 canonical

Name: canonical
brings all polynomial subexpressions of an expression to canonical form or activates, deactivates or checks canonical form printing

Library names:
void sollya_lib_set_canonical_and_print(sollya_obj_t)
void sollya_lib_set_canonical(sollya_obj_t)
sollya_obj_t sollya_lib_canonical(sollya_obj_t)
sollya_obj_t sollya_lib_get_canonical()

Usage:

canonical(function) : function → function
canonical = activation value : on|off → void
canonical = activation value ! : on|off → void

Parameters:
• function represents the expression to be rewritten in canonical form
• activation value represents on or off, i.e. activation or deactivation

Description:
• The command canonical rewrites the expression representing the function function in a way such that all polynomial subexpressions (or the whole expression itself, if it is a polynomial) are written in canonical form, i.e. as a sum of monomials in the canonical base. The canonical base is the base of the integer powers of the global free variable. The command canonical does not endanger the safety of computations even in Sollya's floating-point environment: the function returned is mathematically equal to the function function.

• An assignment canonical = activation value, where activation value is one of on or off, activates respectively deactivates the automatic printing of polynomial expressions in canonical form, i.e. as a sum of monomials in the canonical base. If automatic printing in canonical form is deactivated, automatic printing yields to displaying polynomial subexpressions in Horner form.

If the assignment canonical = activation value is followed by an exclamation mark, no message indicating the new state is displayed. Otherwise the user is informed of the new state of the global mode by an indication.

Example 1:

> print(canonical(1 + x * (x + 3 * x^2)));
1 + x^2 + 3 * x^3
> print(canonical((x + 1)^7));
1 + 7 * x + 21 * x^2 + 35 * x^3 + 35 * x^4 + 21 * x^5 + 7 * x^6 + x^7

Example 2:

> print(canonical(exp((x + 1)^5) - log(asin(((x + 2) + x)^4 * (x + 1)) + x)));
exp(1 + 5 * x + 10 * x^2 + 10 * x^3 + 5 * x^4 + x^5) - log(asin(16 + 80 * x + 160 * x^3 + 80 * x^4 + 16 * x^5) + x)

Example 3:
> canonical; off
(x + 2)^9; 512 + x * (2304 + x * (4608 + x * (5376 + x * (4032 + x * (672 + x *
(144 + x * (18 + x)))))),)
> canonical = on;
Canonical automatic printing output has been activated.
(x + 2)^9; 512 + 2304 * x + 4608 * x^2 + 5376 * x^3 + 4032 * x^4 + 2016 * x^5 + 672 * x^6 +
144 * x^7 + 18 * x^8 + x^9
> canonical; on
> canonical = off!;
(x + 2)^9; 512 + x * (2304 + x * (4608 + x * (5376 + x * (4032 + x * (2016 + x * (672 + x *
(144 + x * (18 + x)))))))))

See also: horner [8.85], print [8.138], autosimplify [8.16]

8.23 ceil

Name: ceil
the usual function ceil.

Library names:
sollya_obj_t sollya_lib_ceil(sollya_obj_t)
sollya_obj_t sollya_lib_build_function_ceil(sollya_obj_t)
#define SOLLYA_CEIL(x) sollya_lib_build_function_ceil(x)

Description:
- ceil is defined as usual: ceil(x) is the smallest integer y such that y ≥ x.
- It is defined for every real number x.

See also: floor [8.70], nearestint [8.114], round [8.161], RU [8.165]

8.24 chebyshevform

Name: chebyshevform
computes a rigorous polynomial approximation

Library name:
sollya_obj_t sollya_lib_chebyshevform(sollya_obj_t, sollya_obj_t, sollya_obj_t);

Usage:
chebyshevform(f, n, I) : (function, integer, range) → list

Parameters:
- f is the function to be approximated.
- n is the degree of the polynomial that must approximate f.
- I is the interval over which the function is to be approximated. This interval cannot be a point
  interval, i.e. its endpoints have to be different.

Description:
WARNING: chebyshevform is a certified command, not difficult to use but not completely straightforward to use either. In order to be sure to use it correctly, the reader is invited to carefully read this documentation entirely.

- chebyshevform computes an approximation polynomial and an interval error bound for a given function $f$.
  More precisely, it returns a list $L = [p, coeffsErrors, \Delta, chebCoeffs]$ where:
  - $p$ is an approximation polynomial of degree $n$ which is roughly speaking a numerical Chebyshev interpolation polynomial of $f$ over $I$ represented in monomial basis.
  - coeffsErrors is a list of $n+1$ intervals. Each interval coeffsErrors[i] contains an enclosure of all the errors accumulated when computing the $i$-th coefficient of $p$.
  - $\Delta$ is an interval that provides a bound for the approximation error between $p$ and $f$. See details below.
  - chebCoeffs is a list of $n+1$ intervals. These are the interval coefficients obtained for the representation of interpolation polynomial considered in Chebyshev basis. See details below.
  
- The polynomial $p$ and the bound $\Delta$ are obtained using Chebyshev Models principles.

- More formally, the mathematical property ensured by the algorithm may be stated as follows:
  Using monomial basis representation given by $p$: there exist (small) values $\varepsilon_i \in \text{coeffsErrors}[i]$ such that:
  $$\forall x \in I, \exists \delta \in \Delta, f(x) - p(x) = \sum_{i=0}^{n} \varepsilon_i x^i + \delta.$$ 
  Using Chebyshev basis representation given by chebCoeffs: there exist values $\alpha_i \in \text{chebCoeffs}[i]$ such that:
  $$\forall x \in I, \exists \delta \in \Delta, f(x) - \sum_{i=0}^{n} \alpha_i T_i(y) = \delta,$$
  where $[a, b] = I, y = (2x - b - a)/(b - a)$ and $T_i(y)$ is the $i$-th Chebyshev polynomial over $[-1, 1]$.

- The algorithm does not guarantee that by increasing the degree of the approximation, the remainder bound will become smaller. Moreover, it may even become larger due to the dependency phenomenon present with interval arithmetic. In order to reduce this phenomenon, a possible solution is to split the definition domain $I$ into several smaller intervals.

Example 1:

```plaintext
> TL=chebyshevform(exp(x), 10, [-1,1]);
> p=TL[0];
> Delta=TL[2];
> p; Delta;
```

See also: taylorform, diff, autodiff, taylor, remez

8.25 checkinfnorm

Name: checkinfnorm

checks whether the infinity norm of a function is bounded by a value
Library name:

```
sollya_obj_t sollya_lib_checkinfnorm(sollya_obj_t, sollya_obj_t, sollya_obj_t)
```

Usage:
```
checkinfnorm(function,range,constant) : (function, range, constant) → boolean
```

Parameters:
- `function` represents the function whose infinity norm is to be checked
- `range` represents the infinity norm is to be considered on
- `constant` represents the upper bound the infinity norm is to be checked to

Description:
- The command `checkinfnorm` checks whether the infinity norm of the given function `function` in the range `range` can be proven (by Sollya) to be less than the given bound `bound`. This means, if `checkinfnorm` evaluates to `true`, the infinity norm has been proven (by Sollya’s interval arithmetic) to be less than the bound. If `checkinfnorm` evaluates to `false`, there are two possibilities: either the bound is less than or equal to the infinity norm of the function or the bound is greater than the infinity norm but Sollya could not conclude using its internal interval arithmetic.

`checkinfnorm` is sensitive to the global variable `diam`. The smaller `diam`, the more time Sollya will spend on the evaluation of `checkinfnorm` in order to prove the bound before returning `false` although the infinity norm is bounded by the bound. If `diam` is equal to 0, Sollya will eventually spend infinite time on instances where the given bound `bound` is less or equal to the infinity norm of the function `function` in range `range`. In contrast, with `diam` being zero, `checkinfnorm` evaluates to `true` iff the infinity norm of the function in the range is bounded by the given bound.

Example 1:
```
> checkinfnorm(sin(x),[0;1.75], 1);
true
> checkinfnorm(sin(x),[0;1.75], 1/2); checkinfnorm(sin(x),[0;20/39],1/2);
false true
```

Example 2:
```
> p = remez(exp(x), 5, [-1;1]);
> b = dirtyinfnorm(p - exp(x), [-1;1]);
> checkinfnorm(p - exp(x), [-1;1], b);
false
> b1 = round(b, 15, RU);
> checkinfnorm(p - exp(x), [-1;1], b1);
true
> b2 = round(b, 25, RU);
> checkinfnorm(p - exp(x), [-1;1], b2);
false
> diam = 1b-20!;
> checkinfnorm(p - exp(x), [-1;1], b2);
true
```

See also: `infnorm (8.91)`, `dirtyinfnorm (8.43)`, `supnorm (8.180)`, `accurateinfnorm (8.3)`, `remez (8.155)`, `diam (8.39)`
8.26  coeff

Name: coeff
gives the coefficient of degree $n$ of a polynomial

Library name:
  sollya_obj_t sollya_lib_coeff(sollya_obj_t, sollya_obj_t)

Usage:
  coeff(f, n) : (function, integer) → constant

Parameters:
  • $f$ is a function (usually a polynomial).
  • $n$ is an integer

Description:
  • If $f$ is a polynomial, coeff($f$, $n$) returns the coefficient of degree $n$ in $f$.
  • If $f$ is a function that is not a polynomial, coeff($f$, $n$) returns 0.

Example 1:
  > coeff((1+x)^5,3);
  10

Example 2:
  > coeff(sin(x),0);
  0

See also: degree [8.37], roundcoefficients [8.162], subpoly [8.177]

8.27  composepolynomials

Name: composepolynomials
  computes an approximation to the composition of two polynomials and bounds the error

Library name:
  sollya_obj_t sollya_lib_composepolynomials(sollya_obj_t, sollya_obj_t)

Usage:
  composepolynomials($p$, $q$) : (function, function) → structure

Parameters:
  • $p$ and $q$ are polynomials

Description:
  • Given two polynomials $p$ and $q$, composepolynomials($p$, $q$) computes an approximation $r$ to the polynomial ($p \circ q$) and bounds the error polynomial $r - (p \circ q)$ using interval arithmetic.

  • composepolynomials always returns a structure containing two elements, poly and radii. The element poly contains the approximate composed polynomial $r$. The element radii contains a list of $n + 1$ intervals $a_i$ bounding the coefficients of the error polynomial, which is of the same degree $n$ as is the composed polynomial ($p \circ q$). This is, there exist $\alpha_i \in a_i$ such that

$$\sum_{i=0}^{n} \alpha_i x^i = r(x) - (p \circ q)(x).$$
In the case when either of \( p \) or \( q \) is not a polynomial, \texttt{composepolynomials} behaves like \texttt{substitute} used in a literate structure. The list of intervals bounding the coefficients of the error polynomial is returned empty.

Example 1:

```plaintext
> composepolynomials(1 + 2 * x + 3 * x^2 + 4 * x^3, 5 + 6 * x + 7 * x^2);
{ .radii = [1[0;0], [0;0], [0;0], [0;0], [0;0], [0;0], [0;0]], .poly = 586 + x * (1992 + x * (4592 + x * (6156 + x * (6111 + x * (3528 + x * 1372)))) ) }
```

Example 2:

```plaintext
> print(composepolynomials(1/5 * x + exp(17) + log(2) * x^2, x^4 + 1/3 * x^2));
{ .radii = [1[-3.5873240686715317015647747332221852960774705712039e-43;3.5873240686715317015647747332221852960774705712039e-43], [0;0], [-2.672764710092195646140364671514818788151968010505e-51;2.672764710092195646140364671514818788151968010505e-51], [0;0], [-1.06910588403687825845621458686059275152607875204202e-50;1.06910588403687825845621458686059275152607875204202e-50], [0;0], [-2.138211768073756169124917372118550305215750408404e-50;2.138211768073756169124917372118550305215750408404e-50], [0;0], [-1.38211768073756169124917372118550305215750408404e-50;1.38211768073756169124917372118550305215750408404e-50], [0;0], [-2.349527535752928147754351803858238798675673527228e7; + x^2 * (0.27701635339554974882413690238423184089777927067 + x^2 * (0.462098120373296879482141430545104538366675624017 + x^2 * 0.69314718055994530941723212145817656807550013436026))) ]
```

Example 3:

```plaintext
> composepolynomials(sin(x),x + x^2);
{ .radii = [1[1;1]], .poly = sin(x * (1 + x)) }
```

See also: \texttt{substitute} \cite{8.178}

### 8.28 \texttt{@}

Name: \texttt{@}

concatenates two lists or strings or applies a list as arguments to a procedure

Library name: \texttt{sollya_obj_t sollya_lib_concat(sollya_obj_t, sollya_obj_t)}

Usage:

\[
L1@L2 : (\text{list, list}) \rightarrow \text{list} \tag{8.178} \\
string1@string2 : (\text{string, string}) \rightarrow \text{string} \\
proc@L1 : (\text{procedure, list}) \rightarrow \text{any type}
\]

Parameters:

- \( L1 \) and \( L2 \) are two lists.

- \( string1 \) and \( string2 \) are two strings.

- \( proc \) is a procedure or an external procedure.

Description:

- \( L1\@L2 \) are two lists.

\[ string1\@string2 \] are strings.

\[ proc\@L1 \] is a procedure or an external procedure.
In its second usage form, @ applies the elements of a list as arguments to a procedure or an external procedure. In the case when proc is a procedure or external procedure with a fixed number of arguments, a check is done if the number of elements in the list corresponds to the number of formal parameters of proc. An empty list can therefore be applied only to a procedure that does not take any argument. In the case when proc accepts an arbitrary number of arguments, no such check is performed.

Example 1:

```plaintext
> [|1,...,3|]@[|7,8,9|];
[1, 2, 3, 7, 8, 9]
```

Example 2:

```plaintext
> "Hello "@"World!";
Hello World!
```

Example 3:

```plaintext
> procedure cool(a,b,c) {
    write(a", ", b," and ",c," are cool guys.\n");
};
> cool @ [| "Christoph", "Mioara", "Sylvain" |];
Christoph, Mioara and Sylvain are cool guys.
```

Example 4:

```plaintext
> procedure sayhello() {
    "Hello! how are you?";
};
> sayhello();
Hello! how are you?
> sayhello @ [||];
Hello! how are you?
```

Example 5:

```plaintext
> bashexecute("gcc -fPIC -Wall -c externalprocexample.c");
> bashexecute("gcc -fPIC -shared -o externalprocexample externalprocexample.o");
> externalproc(foo, "./externalprocexample", (integer, integer) -> integer);
> foo; 
foo
> foo @ [|5, 6|];
11
```

Example 6:
procedure add(L = ...) {
    var acc, i;
    acc = 0;
    for i in L do acc = i + acc;
    return acc;
};
> add(1,2);
3
> add(1,2,3);
6
> add @ [1, 2];
3
> add @ [1, 2, 3];
6
> add @ [ ];
0

See also: procedure 8.144, externalproc 8.64, proc 8.143, bind 8.20, getbacktrace 8.76

8.29 constant

Name: constant
    keyword representing a constant type

Library name:
    SOLLYA_EXTERNALPROC_TYPE_CONSTANT

Usage:

    constant : type type

Description:

- constant represents the constant type for declarations of external procedures externalproc.

Remark that in contrast to other indicators, type indicators like constant cannot be handled outside the externalproc context. In particular, they cannot be assigned to variables.

See also: externalproc 8.64, boolean 8.21, function 8.73, integer 8.92, list of 8.100, range 8.148, string 8.176, object 8.120

8.30 cos

Name: cos
    the cosine function.

Library names:
    sollya_obj_t sollya_lib_cos(sollya_obj_t)
sollya_obj_t sollya_lib_build_function_cos(sollya_obj_t)
#define SOLLYA_COS(x) sollya_lib_build_function_cos(x)

Description:

- cos is the usual cosine function.
- It is defined for every real number x.

See also: acos 8.4, sin 8.171, tan 8.183
8.31 cosh

Name: cosh

the hyperbolic cosine function.

Library names:
sollya_obj_t sollya_lib_cosh(sollya_obj_t)
sollya_obj_t sollya_lib_build_function_cosh(sollya_obj_t)
#define SOLLYA_COSH(x) sollya_lib_build_function_cosh(x)

Description:

- cosh is the usual hyperbolic function: \( \cosh(x) = \frac{e^x + e^{-x}}{2} \).
- It is defined for every real number \( x \).

See also: acosh (8.5), sinh (8.173), tanh (8.184), exp (8.59)

8.32 D

Name: D

short form for double

See also: double (8.49)

8.33 DD

Name: DD

short form for doubledouble

See also: doubledouble (8.50)

8.34 DE

Name: DE

short form for doubleextended

See also: doubleextended (8.51)

8.35 decimal

Name: decimal

special value for global state display

Library names:
sollya_obj_t sollya_lib_decimal()
int sollya_lib_is_decimal(sollya_obj_t)

Description:

- decimal is a special value used for the global state display. If the global state display is equal to decimal, all data will be output in decimal notation.
  As any value it can be affected to a variable and stored in lists.

See also: dyadic (8.52), powers (8.134), hexadecimal (8.82), binary (8.19), display (8.46)

8.36 default

Name: default

default value for some commands.

Library names:
sollya_obj_t sollya_lib_default()
int sollya_lib_is_default(sollya_obj_t)

Description:

- **default** is a special value and is replaced by something depending on the context where it is used. It can often be used as a joker, when you want to specify one of the optional parameters of a command and not the others: set the value of uninteresting parameters to **default**.

- Global variables can be reset by affecting them the special value **default**.

Example 1:

```plaintext
> p = remez(exp(x),5,[0;1],default,1e-5);
> q = remez(exp(x),5,[0;1],1,1e-5);
> p==q;
true
```

Example 2:

```plaintext
> prec;
165
> prec=200;
The precision has been set to 200 bits.
```

### 8.37 degree

**Name:** degree

gives the degree of a polynomial.

**Library name:**

```
sollya_obj_t sollya_lib_degree(sollya_obj_t)
```

**Usage:**

given an integer function `f`, `degree(f)` returns the degree of `f`.

**Parameters:**

- `f` is a function (usually a polynomial).

**Description:**

- If `f` is a polynomial, `degree(f)` returns the degree of `f`.
- Contrary to the usage, Sollya considers that the degree of the null polynomial is 0.
- If `f` is a function that is not a polynomial, `degree(f)` returns -1.

**Example 1:**

```plaintext
> degree((1+x)*(2+5*x^2));
3
> degree(0);
0
```

**Example 2:**

```plaintext
> degree(sin(x));
-1
```

See also: coeff [8.26], subpoly [8.177], roundcoefficients [8.162]
8.38 denominator

Name: denominator

gives the denominator of an expression

Library name:

sollya_obj_t sollya_lib_denominator(sollya_obj_t)

Usage:

denominator(expr) : function → function

Parameters:

- expr represents an expression

Description:

- If expr represents a fraction expr1/expr2, denominator(expr) returns the denominator of this fraction, i.e. expr2.
- If expr represents something else, denominator(expr) returns 1.
- Note that for all expressions expr, numerator(expr) / denominator(expr) is equal to expr.

Example 1:

```plaintext
> denominator(5/3);
3
```

Example 2:

```plaintext
> denominator(exp(x));
1
```

Example 3:

```plaintext
> a = 5/3;
> b = numerator(a)/denominator(a);
> print(a);
5 / 3
> print(b);
5 / 3
```

Example 4:

```plaintext
> a = exp(x/3);
> b = numerator(a)/denominator(a);
> print(a);
exp(x / 3)
> print(b);
exp(x / 3)
```

See also: numerator [8.119], rationalmode [8.150]

8.39 diam

Name: diam

- parameter used in safe algorithms of Sollya and controlling the maximal length of the involved intervals.

Library names:

void sollya_lib_set_diam_and_print(sollya_obj_t)
void sollya_lib_set_diam(sollya_obj_t)
sollya_obj_t sollya_lib_get_diam()

Usage:

\[
\begin{align*}
\text{diam} &= \text{width : constant} \rightarrow \text{void} \\
\text{diam} &= \text{width ! : constant} \rightarrow \text{void} \\
\text{diam} &= \text{constant}
\end{align*}
\]

Parameters:

- \textit{width} represents the maximal relative width of the intervals used

Description:

- \textit{diam} is a global variable. Its value represents the maximal width allowed for intervals involved in safe algorithms of Sollya (namely \textit{infnorm}, \textit{checkinfnorm}, \textit{accurateinfnorm}, \textit{integral}, \textit{findzeros}, \textit{supnorm}).

- More precisely, \textit{diam} is relative to the width of the input interval of the command. For instance, suppose that \textit{diam}=1e-5: if \textit{infnorm} is called on interval \([0, 1]\), the maximal width of an interval will be 1e-5. But if it is called on interval \([0, 1e-3]\), the maximal width will be 1e-8.

See also: \textit{infnorm} (8.91), \textit{checkinfnorm} (8.25), \textit{accurateinfnorm} (8.3), \textit{integral} (8.93), \textit{findzeros} (8.67), \textit{supnorm} (8.180)

8.40 \hspace{1em} \textit{dieonerrormode}

Name: \textit{dieonerrormode}

global variable controlling if Sollya is exited on an error or not.

Library names:

void sollya_lib_set_dieonerrormode_and_print(sollya_obj_t)
void sollya_lib_set_dieonerrormode(sollya_obj_t)
sollya_obj_t sollya_lib_get_dieonerrormode()

Usage:

\[
\begin{align*}
\text{dieonerrormode} &= \text{activation value : on|off} \rightarrow \text{void} \\
\text{dieonerrormode} &= \text{activation value ! : on|off} \rightarrow \text{void} \\
\text{dieonerrormode} &= \text{on|off}
\end{align*}
\]

Parameters:

- \textit{activation value} controls if Sollya is exited on an error or not.

Description:

- \textit{dieonerrormode} is a global variable. When its value is \textit{off}, which is the default, Sollya will not exit on any syntax, typing, side-effect errors. These errors will be caught by the tool, even if a memory might be leaked at that point. On evaluation, the \textit{error} special value will be produced.

- When the value of the \textit{dieonerrormode} variable is \textit{on}, Sollya will exit on any syntax, typing, side-effect errors. A warning message will be printed in these cases at appropriate \textit{verbosity} levels.

Example 1:

```
> verbosity = 1!;
> dieonerrormode = off;
Die-on-error mode has been deactivated.
> for i from true to false do i + "Salut";
Warning: one of the arguments of the for loop does not evaluate to a constant.
The for loop will not be executed.
> exp(17);  
Warning: rounding has happened. The value displayed is a faithful rounding to 16 
5 bits of the true result.
2.41549527535752982147754351803858238798675673527224e7
```
Example 2:

```plaintext
> verbosity = 1 !;
> dieonerrormode = off !;
> 5 */ 4;
Warning: syntax error, unexpected "/.
The last symbol read has been "/".
Will skip input until next semicolon after the unexpected token. May leak memory
. 
exp(17);
Warning: rounding has happened. The value displayed is a faithful rounding to 16
5 bits of the true result.
2.41549527535752982147754351803858238798675673527224e7
```

Example 3:

```plaintext
> verbosity = 1 !;
> dieonerrormode;
off
> dieonerrormode = on !;
> dieonerrormode;
on
> for i from true to false do i + "Salut";
Warning: one of the arguments of the for loop does not evaluate to a constant.
The for loop will not be executed.
Warning: some syntax, typing or side-effect error has occurred.
As the die-on-error mode is activated, the tool will be exited.
```

Example 4:

```plaintext
> verbosity = 1 !;
> dieonerrormode = on !;
> 5 */ 4;
Warning: syntax error, unexpected "/.
The last symbol read has been "/".
Will skip input until next semicolon after the unexpected token. May leak memory
. 
Warning: some syntax, typing or side-effect error has occurred.
As the die-on-error mode is activated, the tool will be exited.
```

Example 5:

```plaintext
> verbosity = 0 !;
> dieonerrormode = on !;
> 5 */ 4;
```

See also: on [8.123], off [8.122], verbosity [8.195], error [8.56]

8.41 diff

Name: diff
differentiation operator

Library name:
sollya_obj_t sollya_lib_diff(sollya_obj_t)

Usage:

```
diff(function) : function → function
```

68
Parameters:

- function represents a function

Description:

- **diff**(function) returns the symbolic derivative of the function function by the global free variable.
  
  If function represents a function symbol that is externally bound to some code by library, the derivative is performed as a symbolic annotation to the returned expression tree.

Example 1:

```
> diff(sin(x));
cos(x)
```

Example 2:

```
> diff(x);
1
```

Example 3:

```
> diff(x^x);
x^x * (1 + log(x))
```

See also: library [8.98], autodiff [8.15], taylor [8.185], taylorform [8.186]

### 8.42 dirtyfindzeros

**Name:** dirtyfindzeros  

gives a list of numerical values listing the zeros of a function on an interval.

**Library name:**  
sollya_obj_t sollya_lib_dirtyfindzeros(sollya_obj_t, sollya_obj_t)

**Usage:**  
dirtyfindzeros(f,I) : (function, range) → list

**Parameters:**

- f is a function.
- I is an interval.

**Description:**

- **dirtyfindzeros**(f,I) returns a list containing some zeros of f in the interval I. The values in the list are numerical approximation of the exact zeros. The precision of these approximations is approximately the precision stored in prec. If f does not have two zeros very close to each other, it can be expected that all zeros are listed. However, some zeros may be forgotten. This command should be considered as a numerical algorithm and should not be used if safety is critical.

- More precisely, the algorithm relies on global variables prec and points and it performs the following steps: let n be the value of variable points and t be the value of variable prec.
  
  - Evaluate |f| at n evenly distributed points in the interval I. The working precision to be used is automatically chosen in order to ensure that the sign is correct.
  
  - Whenever f changes its sign for two consecutive points, find an approximation x of its zero with precision t using Newton’s algorithm. The number of steps in Newton’s iteration depends on t: the precision of the approximation is supposed to be doubled at each step.
Add this value to the list.

The user should be aware that the list returned by dirtyfindzeros may contain a certain floating-point number twice. These repetitions reflect the existence of different zeros of the function the value of which rounds to the same floating-point number in the current working precision. In this case, increasing the working precision will end up making the two zeros distinguishable even in rounded floating-point arithmetic.

Example 1:

```plaintext
> dirtyfindzeros(sin(x),[-5;5]);
[|-3.1415926535897932384626433832795028841971693993751, 0, 3.1415926535897932384626433832795028841971693993751|
```

Example 2:

```plaintext
> L1=dirtyfindzeros(x^2*sin(1/x),[0;1]);
> points=1000!
> L2=dirtyfindzeros(x^2*sin(1/x),[0;1]);
> length(L1); length(L2);
18
25
```

See also: prec (8.135), points (8.130), findzeros (8.67), dirtyinfnorm (8.43), numberroots (8.118)

### 8.43 dirtyinfnorm

**Name:** dirtyinfnorm

computes a numerical approximation of the infinity norm of a function on an interval.

**Library name:**

sollya_obj_t sollya_lib_dirtyinfnorm(sollya_obj_t, sollya_obj_t)

**Usage:**

```plaintext
dirtyinfnorm(f,I) : (function, range) \rightarrow constant
```

**Parameters:**

- f is a function.
- I is an interval.

**Description:**

- dirtyinfnorm(f,I) computes an approximation of the infinity norm of the given function f on the interval I, e.g. \( \max_{x \in I} \{|f(x)|\} \).
- The interval must be bound. If the interval contains one of -Inf or +Inf, the result of dirtyinfnorm is NaN.
- The result of this command depends on the global variables prec and points. Therefore, the returned result is generally a good approximation of the exact infinity norm, with precision prec. However, the result is generally underestimated and should not be used when safety is critical. Use infnorm instead.
- The following algorithm is used: let n be the value of variable points and t be the value of variable prec.
  - Evaluate \(|f|\) at n evenly distributed points in the interval I. The evaluation are faithful roundings of the exact results at precision t.
Whenever the derivative of \( f \) changes its sign for two consecutive points, find an approximation \( x \) of its zero with precision \( t \). Then compute a faithful rounding of \(|f(x)|\) at precision \( t \).

Return the maximum of all computed values.

Example 1:

```
> dirtyinfnorm(sin(x),[-10;10]);
1
```

Example 2:

```
> prec=15!;
> dirtyinfnorm(exp(cos(x))*sin(x),[0;5]);
1.45856
> prec=40!;
> dirtyinfnorm(exp(cos(x))*sin(x),[0;5]);
1.458528537136
> prec=100!;
> dirtyinfnorm(exp(cos(x))*sin(x),[0;5]);
1.458528537136237644438147455025
> prec=200!;
> dirtyinfnorm(exp(cos(x))*sin(x),[0;5]);
1.458528537136237644438147455023841718299214087993682374094153
```

Example 3:

```
> dirtyinfnorm(x^2, [log(0);log(1)));
NaN
```

See also: prec [8.135], points [8.130], infnorm [8.91], checkinfnorm [8.25], supnorm [8.180]

8.44 dirtyintegral

Name: dirtyintegral

computes a numerical approximation of the integral of a function on an interval.

Library name:

```
sollya_obj_t sollya_lib_dirtyintegral(sollya_obj_t, sollya_obj_t)
```

Usage:

```
dirtyintegral(f,I) : (function, range) → constant
```

Parameters:

- \( f \) is a function.
- \( I \) is an interval.

Description:

- \( dirtyintegral(f,I) \) computes an approximation of the integral of \( f \) on \( I \).
- The interval must be bound. If the interval contains one of \(-\text{Inf}\) or \(+\text{Inf}\), the result of \( dirtyintegral \) is NaN, even if the integral has a meaning.
- The result of this command depends on the global variables \texttt{prec} and \texttt{points}. The method used is the trapezium rule applied at \( n \) evenly distributed points in the interval, where \( n \) is the value of global variable \texttt{points}.
- This command computes a numerical approximation of the exact value of the integral. It should not be used if safety is critical. In this case, use command \texttt{integral} instead.
• Warning: this command is currently known to be unsatisfactory. If you really need to compute integrals, think of using another tool or report a feature request to sylvain.chevillard@ens-lyon.org.

Example 1:

```plaintext
> sin(10);
-0.54402111088936981340474766185137728168364301291622
> dirtyintegral(cos(x),[0;10]);
-0.5440304905152629822448058882475382036536298356282
> points=2000!;
> dirtyintegral(cos(x),[0;10]);
-0.54401997751158321972222697312583199035995837926893
```

See also: prec [8.135], points [8.130], integral [8.93]

8.45 dirtysimplify

Name: dirtysimplify
simplifies an expression representing a function

Library name:
sollya_obj_t sollya_lib_dirtysimplify(sollya_obj_t)

Usage:

dirtysimplify(function) : function -> function

Parameters:
• function represents the expression to be simplified

Description:
• The command dirtysimplify simplifies constant subexpressions of the expression given in argument representing the function function. Those constant subexpressions are evaluated using floating-point arithmetic with the global precision prec.

Example 1:

```plaintext
> print(dirtysimplify(sin(pi * x)));
sin(3.14159265358979323846264338327950288419716939993751 * x)
> print(dirtysimplify(erf(exp(3) + x * log(4))));
erf(20.08553692318766774925629856581717899879078385544 + x * 1.3862943611198906188344642429163531361510002687205)
```

Example 2:

```plaintext
> prec = 20!;
> t = erf(0.5);
> s = dirtysimplify(erf(0.5));
> prec = 200!;
> t;
0.520499877813046537682746653891964528736451575757963700058806
> s;
0.52050018310546875
```

See also: simplify [8.170], autosimplify [8.16], prec [8.135], evaluate [8.57], horner [8.85], rationalmode [8.150]
8.46 display

Name: **display**
  sets or inspects the global variable specifying number notation

Library names:
  void sollya_lib_set_display_and_print(sollya_obj_t)
  void sollya_lib_set_display(sollya_obj_t)
  sollya_obj_t sollya_lib_get_display()

Usage:
  display = *notation value* : decimal|binary|dyadic|powers|hexadecimal → void
  display = *notation value* ! : decimal|binary|dyadic|powers|hexadecimal → void
  display : decimal|binary|dyadic|powers|hexadecimal

Parameters:
  * notation value represents a variable of type decimal|binary|dyadic|powers|hexadecimal

Description:
  An assignment display = *notation value*, where *notation value* is one of decimal, dyadic, powers, binary or hexadecimal, activates the corresponding notation for output of values in print, write or at the Sollya prompt.

If the global notation variable **display** is **decimal**, all numbers will be output in scientific decimal notation. If the global notation variable **display** is **dyadic**, all numbers will be output as dyadic numbers with Gappa notation. If the global notation variable **display** is **powers**, all numbers will be output as dyadic numbers with a notation compatible with Maple and PARI/GP. If the global notation variable **display** is **binary**, all numbers will be output in binary notation. If the global notation variable **display** is **hexadecimal**, all numbers will be output in C99/IEEE754-2008 notation. All output notations can be parsed back by Sollya, inducing no error if the input and output precisions are the same (see prec).

If the assignment **display** = *notation value* is followed by an exclamation mark, no message indicating the new state is displayed. Otherwise the user is informed of the new state of the global mode by an indication.

Example 1:
> display = decimal;
Display mode is decimal numbers.
> a = evaluate(sin(pi * x), 0.25);
> a;
0.7071067811865475244008436210484903928483593768847
> display = binary;
Display mode is binary numbers.
> a;
1.011010000001001110011100010001100010111110101101100101100010001000110001
0010001_2 * 2^(-1)
> display = hexadecimal;
Display mode is hexadecimal numbers.
> a;
0x1.6a09e667f3bccc908b2fb1366ea957d3e3adec1751p-1
> display = dyadic;
Display mode is dyadic numbers.
> a;
3307000699110158613323983488220944360067107133265b-165
> display = powers;
Display mode is dyadic numbers in integer-power-of-2 notation.
> a;
3307000699110158613323983488220944360067107133265 * 2^(-165)

See also: print [8.138], write [8.198], decimal [8.35], dyadic [8.32], powers [8.134], binary [8.19], hexadecimal [8.82], prec [8.135]

8.47  div

Name:  div

  Computes the euclidian division of polynomials or numbers and returns the quotient

Library name:
sollya_obj_t sollya_lib_euclidian_div(sollya_obj_t, sollya_obj_t)

Usage:

\[
\text{div}(a, b) : (\text{function}, \text{function}) \rightarrow \text{function}
\]

Parameters:

- \(a\) is a constant or a polynomial.
- \(b\) is a constant or a polynomial.

Description:

- When both \(a\) and \(b\) are constants, \(\text{div}(a, b)\) computes \(\text{floor}(a / b)\). In other words, it returns the quotient of the Euclidian division of \(a\) by \(b\).

- When both \(a\) and \(b\) are polynomials with at least one being non-constant, \(\text{div}(a, b)\) computes a polynomial \(q\) such that the polynomial \(r\) equal to \(a - qb\) is of degree strictly smaller than the degree of \(b\) (see exception below). In order to recover \(r\), use the \text{mod} command.

- \text{div} works on polynomials whose coefficients are constant expressions that cannot be simplified (by the tool) to rational numbers. In most cases, the tool is able to perform the Euclidian polynomial division for such polynomials and stop the Euclidian division algorithm only when \(r\) is of degree strictly smaller than the degree of \(b\). In certain cases, when the polynomials involve coefficients given as constant expressions that are mathematically zero but for which the tool is unable to detect this fact, the tool may be unable to correctly determine that \(r\) is actually of degree strictly
smaller than the degree of $b$. The issue arises in particular for polynomials whose leading coefficient is a constant expression which is zero without the tool being able to detect this. In these cases, \texttt{div}, together with \texttt{mod}, just guarantee that $q$ and $r$, as returned by the two commands, satisfy that $r$ added to the product of $q$ and $b$ yields $a$, and that $r$ is of the smallest degree the tool can admit. However, there might exist another pair of a quotient and remainder polynomial for which the remainder polynomial is of a degree less than the one of $r$.

- When at least one of $a$ or $b$ is a function that is no polynomial, \texttt{div}(a,b) returns 0.

Example 1:

```
> div(1001, 231);
4
> div(13, 17);
0
> div(-14, 15);
-1
> div(-213, -5);
42
> div(23/13, 11/17);
2
> div(exp(13), -sin(17));
460177
```

Example 2:

```
> div(24 + 68 * x + 74 * x^2 + 39 * x^3 + 10 * x^4 + x^5, 4 + 4 * x + x^2);
6 + x * (11 + x * (6 + x))
> div(24 + 68 * x + 74 * x^2 + 39 * x^3 + 10 * x^4 + x^5, 2 * x^3);
19.5 + x * (5 + x * 0.5)
> div(x^2, x^3);
0
```

Example 3:

```
> div(exp(x), x^2);
0
```

See also: \texttt{gcd (8.74)}, \texttt{mod (8.112)}, \texttt{numberroots (8.118)}

8.48 /

Name: / division function

Library names:

- \texttt{sollya_obj_t sollya_lib_div(sollya_obj_t, sollya_obj_t)}
- \texttt{sollya_obj_t sollya_lib_build_function_div(sollya_obj_t, sollya_obj_t)}
- \#define SOLLYA_DIV(x,y) sollya_lib_build_function_div((x), (y))

Usage:

- \texttt{function1 / function2 : (function, function) \rightarrow function}
- \texttt{interval1 / interval2 : (range, range) \rightarrow range}
- \texttt{interval1 / constant : (range, constant) \rightarrow range}
- \texttt{interval1 / constant : (constant, range) \rightarrow range}

Parameters:

- \texttt{function1} and \texttt{function2} represent functions
• **interval1** and **interval2** represent intervals (ranges)

• **constant** represents a constant or constant expression

Description:

• `/` represents the division (function) on reals. The expression \( \text{function1} / \text{function2} \) stands for the function composed of the division function and the two functions \( \text{function1} \) and \( \text{function2} \), where \( \text{function1} \) is the numerator and \( \text{function2} \) the denominator.

• `/` can be used for interval arithmetic on intervals (ranges). `/` will evaluate to an interval that safely encompasses all images of the division function with arguments varying in the given intervals. If the intervals given contain points where the division function is not defined, infinities and NaNs will be produced in the output interval. Any combination of intervals with intervals or constants (resp. constant expressions) is supported. However, it is not possible to represent families of functions using an interval as one argument and a function (varying in the free variable) as the other one.

Example 1:

```plaintext
> 5 / 2;
2.5
```

Example 2:

```plaintext
> x / 2;
x * 0.5
```

Example 3:

```plaintext
> x / x;
1
```

Example 4:

```plaintext
> 3 / 0;
NaN
```

Example 5:

```plaintext
> diff(sin(x) / exp(x));
(exp(x) * cos(x) - sin(x) * exp(x)) / exp(x)^2
```

Example 6:

```plaintext
> [1;2] / [3;4];
[0.25;0.66666666666666666666666666666666666666666666666668]
> [1;2] / 17;
[5.8823529411764705882352941176470588235294117647059e-2;0.1176470588235294117647058823529412]
> -13 / [4;17];
[-3.25;-0.764705882352941176470588235294175]
```

See also: + (8.129), − (8.111), * (8.113), ^ (8.133)
8.49  double

Names:  double, D

rounding to the nearest IEEE 754 double (binary64).

Library names:

sollya_obj_t sollya_lib_double(sollya_obj_t)
sollya_obj_t sollya_lib_double_obj()
int sollya_lib_is_double_obj(sollya_obj_t)
sollya_obj_t sollya_lib_build_function_double(sollya_obj_t)
#define SOLLYA_D(x) sollya_lib_build_function_double(x)

Description:

- **double** is both a function and a constant.
- As a function, it rounds its argument to the nearest IEEE 754 double precision (i.e. IEEE754-2008 binary64) number. Subnormal numbers are supported as well as standard numbers: it is the real rounding described in the standard.
- As a constant, it symbolizes the double precision format. It is used in contexts when a precision format is necessary, e.g. in the commands round, roundcoefficients and implementpoly. See the corresponding help pages for examples.

Example 1:

```plaintext
> display=binary!;
> D(0.1);
1.100110011001100110011001100110011001100110011001101_2 * 2^(-4)
> D(4.17);
1.000010101110000101000111101011100001010001111010111_2 * 2^(2)
> D(1.011_2 * 2^(-1073));
1.1_2 * 2^(-1073)
```

See also: halfprecision [8.80], single [8.172], doubleextended [8.51], doubledouble [8.50], quad [8.146], trippledouble [8.191], roundcoefficients [8.162], implementpoly [8.88], round [8.161], printdouble [8.139]

8.50  doubledouble

Names:  doubledouble, DD

represents a number as the sum of two IEEE doubles.

Library names:

sollya_obj_t sollya_lib_double_double(sollya_obj_t)
sollya_obj_t sollya_lib_double_double_obj()
int sollya_lib_is_double_double_obj(sollya_obj_t)
sollya_obj_t sollya_lib_build_function_double_double(sollya_obj_t)
#define SOLLYA_DD(x) sollya_lib_build_function_double_double(x)

Description:

- **doubledouble** is both a function and a constant.
- As a function, it rounds its argument to the nearest number that can be written as the sum of two double precision numbers.
- The algorithm used to compute **doubledouble**(x) is the following: let \(x_h = \text{double}(x)\) and let \(x_l = \text{double}(x - x_h)\). Return the number \(x_h + x_l\). Note that if the current precision is not sufficient to exactly represent \(x_h + x_l\), a rounding will occur and the result of **doubledouble**(x) will be useless.
• As a constant, it symbolizes the double-double precision format. It is used in contexts when a precision format is necessary, e.g. in the commands `round`, `roundcoefficients` and `implementpoly`. See the corresponding help pages for examples.

Example 1:

```plaintext
> verbosity=1!
> a = 1 + 2^(-100);
> DD(a);
1.0000000000000000000000000000007888609052210118054
> prec=50!;
> DD(a);
1.000000000000000000000000000000788860905
```

See also: `halfprecision (8.80)`, `single (8.172)`, `double (8.49)`, `doubleextended (8.51)`, `quad (8.146)`, `tripledouble (8.191)`, `roundcoefficients (8.162)`, `implementpoly (8.88)`, `round (8.161)`

### 8.51 doubleextended

**Names:** `doubleextended`, DE

computes the nearest number with 64 bits of mantissa.

**Library names:**

- `sollya_obj_t sollya_lib_doubleextended(sollya_obj_t)`
- `sollya_obj_t sollya_lib_doubleextended_obj()`
- `int sollya_lib_is_doubleextended_obj(sollya_obj_t)`
- `sollya_obj_t sollya_lib_build_function_doubleextended(sollya_obj_t)`
- `#define SOLLYA_DE(x) sollya_lib_build_function_doubleextended(x)`

**Description:**

- `doubleextended` is a function that computes the nearest floating-point number with 64 bits of mantissa to a given number. Since it is a function, it can be composed with other Sollya functions such as `exp`, `sin`, etc.

- `doubleextended` now does handle subnormal numbers for a presumed exponent width of the double-extended format of 15 bits. This means, with respect to rounding, `doubleextended` behaves as a IEEE 754-2008 binary79 with a 64 bit significand (with a hidden bit normal range), one sign bit and a 15 bit exponent field would behave. This behavior may be different from the one observed on Intel-based IA32/Intel64 processors (or compatible versions from other vendors). However it is the one seen on HP/Intel Itanium when the precision specifier is double-extended and pseudo-denormals are activated.

- Since it is a function and not a command, its behavior is a bit different from the behavior of `round(x,64,RN)` even if the result is exactly the same. `round(x,64,RN)` is immediately evaluated whereas `doubleextended(x)` can be composed with other functions (and thus be plotted and so on).

Example 1:

```plaintext
> display=binary!;
> DE(0.1);
1.100110011001100110011001100110011001100110011001100110011001101_2 * 2^-4
> round(0.1,64,RN);
1.100110011001100110011001100110011001100110011001100110011001101_2 * 2^-4
```

Example 2:
Example 3:

```
> verbosity=1;
> f = sin(DE(x));
> f(pi);
Warning: rounding has happened. The value displayed is a faithful rounding to 16
5 bits of the true result.
-5.0165576126683320323557327080330757013831561670255e-20
> g = sin(round(x,64,RN));
Warning: at least one of the given expressions or a subexpression is not correct
ly typed
or its evaluation has failed because of some error on a side-effect.
```

See also: roundcoefficients (8.162), halfprecision (8.80), single (8.172), double (8.49), doubledouble (8.50), quad (8.146), tripledouble (8.191), round (8.161)

8.52 dyadic

Name: dyadic

special value for global state display

Library names:
sollya_obj_t sollya_lib_dyadic()
int sollya_lib_is_dyadic(sollya_obj_t)

Description:

- **dyadic** is a special value used for the global state display. If the global state display is equal to **dyadic**, all data will be output in dyadic notation with numbers displayed in Gappa format.

As any value it can be affected to a variable and stored in lists.

See also: decimal (8.35), powers (8.134), hexadecimal (8.82), binary (8.19), display (8.46)

8.53 ==

Name: ==

equality test operator

Library name:
sollya_obj_t sollya_lib_cmp_equal(sollya_obj_t, sollya_obj_t)

Usage:

```
expr1 == expr2 : (any type, any type) → boolean
```

Parameters:

- **expr1** and **expr2** represent expressions

Description:

- The test **expr1 == expr2** returns **true** when **expr1** and **expr2** are syntactically equal and different from **error**, @NaN@ and [@NaN@, @NaN@]. Conversely if **expr1** and **expr2** are objects that are mathematically different and Sollya manages to figure it out, the test returns **false**. In between these two cases, there is the grey zone of expressions that are not syntactically equal but are mathematically equal. In such a case, Sollya normally tries to determine if the expressions are
mathematically equal and if it manages to prove it, it returns **true**, without a warning. In the case when `expr1` and `expr2` are two constant expressions, `Sollya` will in particular try to evaluate their difference: in the case when the difference is 0 or is so small that `Sollya` does not manage to obtain a faithful rounding of the real value, it will return **true** (with a warning if it has not been possible to actually prove that the real value is 0). In any other case, when both expressions are not syntactically equal and `Sollya` has not been able to prove that they are mathematically equal, it returns **false**.

- The level of simplifications performed by `Sollya` to determine if expressions are mathematically equal depends on the value of `autosimplify`. If it is **off**, no formal simplification is performed, hence expression trees as simple as `x+1` and `1+x` will be considered not equal. Conversely, if `autosimplify` is set to **on**, polynomial subexpressions that are mathematically equal will in general be recognized as being equal.

- The user should always keep in mind that a literal constant written in decimal arithmetic (such as 0.1 for instance) is not considered as an exact constant by `Sollya` (unless it is exactly representable in binary without requiring too much precision) and is first correctly rounded at precision `prec`, prior to any other operation. Of course, this leads to a rounding warning, but it is important to remember that this is done before the expression trees are compared, possibly leading to two expressions comparing equal, while they are obviously mathematically different, just because they contain different constants that have been rounded to the same value at precision `prec`. As a general rule, to avoid this behavior, the user should represent constants in an exact format such as hexadecimal or represent decimal constants as integer fractions (e.g., 0.1 represented by the constant expression `1/10`).

- Notice that `@NaN@`, `[@NaN, @NaN@]` and `error` share the property that they compare not equal to anything, including themselves. This means if a variable `a` contains `@NaN@`, `[@NaN, @NaN@]` or `error` and whatever the content of variable `b` is, the test `a == b` returns **false**. The standard way of testing if `a` contains `@NaN@`, `[@NaN, @NaN@]` or `error` is indeed to check if `a == a` returns false. `error` can be distinguished from `@NaN@` and `[@NaN, @NaN@]` using the `!=` operator. In order to distinguish `@NaN@` from `[@NaN, @NaN@]`, a match ... with ... construct must be used.

Example 1:

```plaintext
> "Hello" == "Hello";
true
> "Hello" == "Salut";
false
> "Hello" == 5;
false
> 5 + x == 5 + x;
true
```

Example 2:

```plaintext
> verbosity = 1!;
> asin(1) * 2 == pi;
true
> cos(3)^2 == 1 - sin(3)^2;
Warning: the tool is unable to decide an equality test by evaluation even though faithful evaluation of the terms has been possible. The terms will be considered to be equal.
true
> exp(5) == log(4);
false
```

Example 3:
Example 4:

```plaintext
> autosimplify=off;
Automatic pure tree simplification has been deactivated.
> exp(1+x) == exp(x+1);
false
> autosimplify=on;
Automatic pure tree simplification has been activated.
> exp(1+x) == exp(x+1);
false
> (1/3+x)^2 == x^2 + 1/9 + (5-3)*x/3;
true
> log(x)/log(10) == log10(x);
false
```

Example 5:

```plaintext
> prec = 12;
The precision has been set to 12 bits.
> verbosity = 1!;
> 16384.1 == 16385.1;
Warning: Rounding occurred when converting the constant "16384.1" to floating-point with 12 bits.
If safe computation is needed, try to increase the precision.
Warning: Rounding occurred when converting the constant "16385.1" to floating-point with 12 bits.
If safe computation is needed, try to increase the precision.
true
> 16384 == 16384.25;
false
> 0.1 == 1/10;
Warning: Rounding occurred when converting the constant "0.1" to floating-point with 12 bits.
If safe computation is needed, try to increase the precision.
false
> 0.1 == round(1/10, prec, RN);
Warning: Rounding occurred when converting the constant "0.1" to floating-point with 12 bits.
If safe computation is needed, try to increase the precision.
true
```
> error == error;
false
> error != error;
false
> @NaN@ == @NaN@;
false
> @NaN@ != @NaN@;
true
> [@NaN@,@NaN@] == [@NaN@,@NaN@];
false
> [@NaN@,@NaN@] != [@NaN@,@NaN@];
true
> error == @NaN@;
false
> error != @NaN@;
false
> a = error;
> match a with
  @NaN@ : ("a contains @NaN@")
  [@NaN@, @NaN@] : ("a contains [@NaN@, @NaN@]")
  default: ("a contains something else");
error
> a = @NaN@;
> match a with
  @NaN@ : ("a contains @NaN@")
  [@NaN@, @NaN@] : ("a contains [@NaN@, @NaN@]")
  default: ("a contains something else");
a contains @NaN@
> a = [@NaN@, @NaN@];
> match a with
  @NaN@ : ("a contains @NaN@")
  [@NaN@, @NaN@] : ("a contains [@NaN@, @NaN@]")
  default: ("a contains something else");
a contains [@NaN@, @NaN@]
See also: != (8.115), > (8.78), >= (8.75), <= (8.96), < (8.105), in (8.89), ! (8.117), && (8.6), || (8.124), error (8.50), prec (8.135), autosimplify (8.16)

8.54 \texttt{erf}

Name: \texttt{erf}

the error function.

Library names:

sollya_obj_t sollya_lib_erf(sollya_obj_t)
sollya_obj_t sollya_lib_build_function_erf(sollya_obj_t)
#define SOLLYA_ERF(x) sollya_lib_build_function_erf(x)

Description:

- **\texttt{erf}** is the error function defined by:

\[
erf(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt.
\]

- It is defined for every real number \( x \).

See also: **\texttt{erfc} (8.55)**, **\texttt{exp} (8.59)**
8.55 erfc

Name: erfc
the complementary error function.

Library names:

sollya_obj_t sollya_lib_erfc(sollya_obj_t)
sollya_obj_t sollya_lib_build_function_erfc(sollya_obj_t)
#define SOLLYA_ERFC(x) sollya_lib_build_function_erfc(x)

Description:

- erfc is the complementary error function defined by erfc(x) = 1 − erf(x).
- It is defined for every real number x.

See also: erf

8.56 error

Name: error
expression representing an input that is wrongly typed or that cannot be executed

Library names:

sollya_obj_t sollya_lib_error()
int sollya_lib_obj_is_error(sollya_obj_t)

Usage:

error : error

Description:

- The variable error represents an input during the evaluation of which a type or execution error has been detected or is to be detected. Inputs that are syntactically correct but wrongly typed evaluate to error at some stage. Inputs that are correctly typed but containing commands that depend on side-effects that cannot be performed or inputs that are wrongly typed at meta-level (cf. parse), evaluate to error.

Remark that in contrast to all other elements of the Sollya language, error compares neither equal nor unequal to itself. This provides a means of detecting syntax errors inside the Sollya language itself without introducing issues of two different wrongly typed inputs being equal.

Example 1:

> print(5 + "foo");
error

Example 2:

> error;
error

Example 3:

> error == error;
false
> error != error;
false

Example 4:
> correct = 5 + 6;
> incorrect = 5 + "foo";
> correct == correct;
true
> incorrect == incorrect;
false
> errorhappened = !(incorrect == incorrect);
> errorhappened;
true

See also: void [8.196], parse [8.125], == [8.53], != [8.115]

8.57 evaluate

Name: evaluate

evaluates a function at a constant point or in a range

Library name:
sollya_obj_t sollya_lib_evaluate(sollya_obj_t, sollya_obj_t)

Usage:

\[
\text{evaluate}(\text{function}, \text{constant}) : (\text{function}, \text{constant}) \rightarrow \text{constant} | \text{range}
\]

\[
\text{evaluate}(\text{function}, \text{range}) : (\text{function}, \text{range}) \rightarrow \text{range}
\]

\[
\text{evaluate}(\text{function}, \text{function2}) : (\text{function}, \text{function}) \rightarrow \text{function}
\]

Parameters:

- function represents a function
- constant represents a constant point
- range represents a range
- function2 represents a function that is not constant

Description:

- If its second argument is a constant constant, evaluate evaluates its first argument function at the point indicated by constant. This evaluation is performed in a way that the result is a faithful rounding of the real value of the function at constant to the current global precision. If such a faithful rounding is not possible, evaluate returns a range surely encompassing the real value of the function function at constant. If even interval evaluation is not possible because the expression is undefined or numerically unstable, NaN will be produced.

- If its second argument is a range range, evaluate evaluates its first argument function by interval evaluation on this range range. This ensures that the image domain of the function function on the preimage domain range is surely enclosed in the returned range.

- In the case when the second argument is a range that is reduced to a single point (such that [1; 1] for instance), the evaluation is performed in the same way as when the second argument is a constant but it produces a range as a result: evaluate automatically adjusts the precision of the intern computations and returns a range that contains at most three floating-point consecutive numbers in precision prec. This corresponds to the same accuracy as a faithful rounding of the actual result. If such a faithful rounding is not possible, evaluate has the same behavior as in the case when the second argument is a constant.

- If its second argument is a function function2 that is not a constant, evaluate replaces all occurrences of the free variable in function function by function function2.

Example 1:
Example 2:

```plaintext
> print(evaluate(sin(pi * x), 2));
[-3.100365765139897619749121887390789523854170596558e-13490;5.3002401585857127605350842426029223241500776302528e-13489]
```

Example 3:

```plaintext
> print(evaluate(sin(pi * x), [2, 2.25]));
[-5.143390272677254630046998919961912407349224165421e-50;0.7071067811865475244008443621048903928483593768866]
```

Example 4:

```plaintext
> print(evaluate(sin(pi * x), 2 + 0.25 * x));
sin((pi) * 2 + x * (pi) * 0.25)
```

Example 5:

```plaintext
> print(evaluate(sin(pi * 1/x), 0));
[-1;1]
```

See also: ```isevaluable [8.05]```

### 8.58 execute

**Name:** `execute`

executes the content of a file

**Library name:**
```c
void sollya_lib_execute(sollya_obj_t)
```

**Usage:**
```plaintext
execute(filename) : string → void
```

**Parameters:**
- `filename` is a string representing a file name

**Description:**
- `execute` opens the file indicated by `filename`, and executes the sequence of commands it contains. This command is evaluated at execution time: this way you can modify the file `filename` (for instance using `bashexecute`) and execute it just after.
- If `filename` contains a command `execute`, it will be executed recursively.
- If `filename` contains a call to `restart`, it will be neglected.
- If `filename` contains a call to `quit`, the commands following `quit` in `filename` will be neglected.

**Example 1:**

```plaintext
> execute("execute_nested_solutions.sollya");
```

85
```plaintext
> a=2;
> a;
2
> print("a=1;") > "example.sollya";
> execute("example.sollya");
> a;
1
```

Example 2:

```plaintext
> verbosity=1!;
> print("a=1; restart; a=2;") > "example.sollya";
> execute("example.sollya");
Warning: a restart command has been used in a file read into another. This restart command will be neglected.
> a;
2
```

Example 3:

```plaintext
> verbosity=1!;
> print("a=1; quit; a=2;") > "example.sollya";
> execute("example.sollya");
Warning: the execution of a file read by execute demanded stopping the interpretation but it is not stopped.
> a;
1
```

See also: parse [8.125], readfile [8.152], write [8.198], print [8.138], bashexecute [8.18], quit [8.147], restart [8.157]

8.59 exp

Name: **exp**

the exponential function.

Library names:

- sollya_obj_t sollya_lib_exp(sollya_obj_t)
- sollya_obj_t sollya_lib_build_function_exp(sollya_obj_t)

```plaintext
#define SOLLYA_EXP(x) sollya_lib_build_function_exp(x)
```

Description:

- **exp** is the usual exponential function defined as the solution of the ordinary differential equation $y' = y$ with $y(0) = 1$.

- **exp(x)** is defined for every real number $x$.

See also: exp [8.59], log [8.101]

8.60 expand

Name: **expand**

expands polynomial subexpressions

Library name:

- sollya_obj_t sollya_lib_expand(sollya_obj_t)

Usage:
**expand**(*function*): function → function

Parameters:

- *function* represents a function

Description:

- **expand**(*function*) expands all polynomial subexpressions in function *function* as far as possible. Factors of sums are multiplied out, power operators with constant positive integer exponents are replaced by multiplications.

Example 1:

```plaintext
> print(expand(x^3));
x * x * x
```

Example 2:

```plaintext
> print(expand((x + 2)^3 + 2 * x));
8 + 12 * x + 6 * x * x + x * x * x + 2 * x
```

Example 3:

```plaintext
> print(expand(exp((x + (x + 3))^5)));
exp(243 + 405 * x + 270 * x * x + 90 * x * x * x * x + 15 * x * x * x * x * x + x + x * x * x * x * 405 + 108 * x * 5 * x + 54 * x * x * 5 * x + 12 * x * x * x * 5 * x
* x + x * x * x * 5 * x + x * x * x * 270 + 27 * x * x * x * 10 + 9 * x * x * x * x * x * x * 10 + x
* x * x * x * x * x + x * 10 + x * x * x * x * x * x * 10 + x
* x * x * x * x * x * x * x * x * x * x * x * x * x * x * x * x * x)
```

See also: dirtysimplify (8.45), simplify (8.170), horner (8.85), coeff (8.26), degree (8.37)

### 8.61 expm1

**Name:** expm1

shifted exponential function.

**Library names:**

```plaintext
sollya_obj_t sollya_lib_expm1(sollya_obj_t)
sollya_obj_t sollya_lib_build_function_expm1(sollya_obj_t)
#define SOLLYA_EXPM1(x) sollya_lib_build_function_expm1(x)
```

**Description:**

- **expm1** is defined by \( \expm1(x) = \exp(x) - 1 \).
- It is defined for every real number \( x \).

See also: exp (8.59)

### 8.62 exponent

**Name:** exponent

returns the scaled binary exponent of a number.

**Library name:**

```plaintext
sollya_obj_t sollya_lib_exponent(sollya_obj_t)
```

**Usage:**
exponent(x) : constant → integer

Parameters:

• x is a dyadic number.

Description:

• exponent(x) is by definition 0 if x is one of 0, NaN, or Inf.
• If x is not zero, it can be uniquely written as \(x = m \cdot 2^e\) where m is an odd integer and e is an integer. exponent(x) returns e.

Example 1:

```plaintext
> a=round(Pi,20,RN);
> e=exponent(a);
> e;
-17
> m=mantissa(a);
> a-m*2^e;
0
```

See also: mantissa (8.106), precision (8.136)

8.63 externalplot

Name: externalplot

plots the error of an external code with regard to a function

Library names:

```plaintext
void sollya_lib_externalplot(sollya_obj_t, sollya_obj_t, sollya_obj_t,
                           sollya_obj_t, sollya_obj_t, ...)
void sollya_lib_v_externalplot(sollya_obj_t, sollya_obj_t, sollya_obj_t,
                               sollya_obj_t, sollya_obj_t, va_list)
```

Usage:

```plaintext
externalplot(filename, mode, function, range, precision) : (string, absolute|relative, function, range, integer) → void
externalplot(filename, mode, function, range, precision, perturb) : (string, absolute|relative, function, range, integer, perturb) → void
externalplot(filename, mode, function, range, precision, plot mode, result filename) : (string, absolute|relative, function, range, integer, file|postscript|postscriptfile, string) → void
externalplot(filename, mode, function, range, precision, perturb, plot mode, result filename) : (string, absolute|relative, function, range, integer, perturb, file|postscript|postscriptfile, string) → void
```

Description:

• The command externalplot plots the error of an external function evaluation code sequence implemented in the object file named filename with regard to the function function. If mode evaluates to absolute, the difference of both functions is considered as an error function; if mode evaluates to relative, the difference is divided by the function function. The resulting error function is plotted on all floating-point numbers with precision significant mantissa bits in the range range.

If the sixth argument of the command externalplot is given and evaluates to perturb, each of the floating-point numbers the function is evaluated at gets perturbed by a random value that is uniformly distributed in ±1 ulp around the original precision bit floating-point variable.

If a sixth and seventh argument, respectively a seventh and eighth argument in the presence of perturb as a sixth argument, are given that evaluate to a variable of type file|postscript|postscriptfile
respectively to a character sequence of type string, externalplot will plot (additionally) to a file in the same way as the command plot does. See plot for details.

The external function evaluation code given in the object file name filename is supposed to define a function name f as follows (here in C syntax): void f(mpfr_t rop, mpfr_t op). This function is supposed to evaluate op with an accuracy corresponding to the precision of rop and assign this value to rop.

Example 1:

```
> bashexecute("gcc -fPIC -c externalplotexample.c");
> bashexecute("gcc -shared -o externalplotexample externalplotexample.o -lgmp -l mpfr");
> externalplot("./externalplotexample",relative,exp(x),[-1/2;1/2],12,perturb);
```

See also: plot [8.128], asciiplot [8.10], perturb [8.126], absolute [8.2], relative [8.154], file [8.66], postscript [8.131], postscriptfile [8.132], bashexecute [8.18], externalproc [8.64], library [8.98]

### 8.64 externalproc

**Name:** externalproc

binds an external code to a Sollya procedure

**Library names:**

```
sollya_obj_t sollya_lib_externalprocedure(sollya_externalprocedure_type_t, sollya_externalprocedure_type_t *, int, char *, void *);
sollya_obj_t sollya_lib_externalprocedure_with_data(sollya_externalprocedure_type_t, sollya_externalprocedure_type_t *, int, char *, void *, void *, void (*)(void *));
```

**Usage:**

```
externalproc(identifier, filename, argumenttype -> resulttype) : (identifier type, string, type type, type type) -> void
```

**Parameters:**

- `identifier` represents the identifier the code is to be bound to
- `filename` of type `string` represents the name of the object file where the code of procedure can be found
- `argumenttype` represents a definition of the types of the arguments of the Sollya procedure and the external code
- `resulttype` represents a definition of the result type of the external code

**Description:**

- `externalproc` allows for binding the Sollya identifier `identifier` to an external code. After this binding, when Sollya encounters `identifier` applied to a list of actual parameters, it will evaluate these parameters and call the external code with these parameters. If the external code indicated success, it will receive the result produced by the external code, transform it to Sollya’s internal representation and return it.

In order to allow correct evaluation and typing of the data in parameter and in result to be passed to and received from the external code, externalproc has a third parameter `argumenttype -> resulttype`. Both `argumenttype` and `resulttype` are one of `void, constant, function, object`, respectively.
range, integer, string, boolean, list of constant, list of function, list of object, list of range, list of integer, list of string, list of boolean.

It is worth mentioning that the difference between the data and result type function and the type object is minimal and due to support of legacy Sollya code. Both Sollya functions and Sollya objects are transferred from and to the external procedure thru the C type sollya_obj_t. The difference is that Sollya will check that a certain object is a mathematical function when function is used as a type, and will skip this test if the object type is used. Similarly, Sollya relies on an object produced by the external procedure to be a mathematical function when function is used and will not make this assumption for object.

If upon a usage of a procedure bound to an external procedure the type of the actual parameters given or its number is not correct, Sollya produces a type error. An external function not applied to arguments represents itself and prints out with its argument and result types.

The external function is supposed to return an integer indicating success. It returns its result depending on its Sollya result type as follows. Here, the external procedure is assumed to be implemented as a C function.

- If the Sollya result type is void, the C function has no pointer argument for the result.
- If the Sollya result type is constant, the first argument of the C function is of C type mpfr_t *, the result is returned by affecting the MPFR variable.
- If the Sollya result type is function, the first argument of the C function is of C type sollya_obj_t *, the result is returned by affecting the sollya_obj_t variable.
- If the Sollya result type is object, the first argument of the C function is of C type sollya_obj_t *, the result is returned by affecting the sollya_obj_t variable.
- If the Sollya result type is range, the first argument of the C function is of C type mpfi_t *, the result is returned by affecting the MPFI variable.
- If the Sollya result type is integer, the first argument of the C function is of C type int *, the result is returned by affecting the int variable.
- If the Sollya result type is string, the first argument of the C function is of C type char **, the result is returned by the char * pointed with a new char *.
- If the Sollya result type is boolean, the first argument of the C function is of C type int *, the result is returned by affecting the int variable with a boolean value.
- If the Sollya result type is list of type, the first argument of the C function is of a C type depending on the Sollya return type:
  * For a list of constant: sollya_constant_list_t *
  * For a list of function: sollya_obj_list_t *
  * For a list of object: sollya_obj_list_t *
  * For a list of range: sollya_constant_list_t *
  * For a list of integer: sollya_int_list_t *
  * For a list of string: sollya_string_list_t *
  * For a list of boolean: sollya_boolean_list_t *

The external procedure affects its possible pointer argument if and only if it succeeds. This means, if the function returns an integer indicating failure, it does not leak any memory to the encompassing environment.

The external procedure receives its arguments as follows: If the Sollya argument type is void, no argument array is given. Otherwise the C function receives a C void ** argument representing an array of size equal to the arity of the function where each entry (of C type void *) represents a value with a C type depending on the corresponding Sollya type.

- If the Sollya type is constant, the void * is to be cast to mpfr_t *.
- If the Sollya type is function, the void * is to be cast to sollya_obj_t.
If the Sollya type is **object**, the \texttt{void *} is to be cast to \texttt{sollya_obj_t}.

If the Sollya type is **range**, the \texttt{void *} is to be cast to \texttt{mpfi_t *}.

If the Sollya type is **integer**, the \texttt{void *} is to be cast to \texttt{int *}.

If the Sollya type is **string**, the \texttt{void *} is to be cast to \texttt{char *}.

If the Sollya type is **boolean**, the \texttt{void *} is to be cast to \texttt{int *}.

If the Sollya type is **list of** type, the \texttt{void *} is to be cast to a list of a type depending on the type of the list argument:

- For a list of **constant**: \texttt{sollya_constant_list_t}
- For a list of **function**: \texttt{sollya_obj_list_t}
- For a list of **object**: \texttt{sollya_obj_list_t}
- For a list of **range**: \texttt{sollya_interval_list_t}
- For a list of **integer**: \texttt{sollya_int_list_t}
- For a list of **string**: \texttt{sollya_string_list_t}
- For a list of **boolean**: \texttt{sollya_boolean_list_t}

The external procedure is not supposed to alter the memory pointed by its array argument \texttt{void **}.

In both directions (argument and result values), empty lists are represented by \texttt{NULL} pointers.

Similarly to internal procedures, externally bounded procedures can be considered to be objects inside Sollya that can be assigned to other variables, stored in list etc.

- The user should be aware that they may use the Sollya library in external codes to be dynamically bound to Sollya using \texttt{externalproc}. On most systems, it suffices to include the header of the Sollya library into the source code of the external procedure. Linking with the actual Sollya library is not necessary on most systems; as the interactive Sollya executable contains a superset of the Sollya library functions. On some systems, linking with the Sollya library or some of its dependencies may be necessary.

In particular, the Sollya library – and, of course, its header file – contain a certain set of functions to manipulate lists with elements of certain types, such as \texttt{sollya_constant_list_t}, \texttt{sollya_obj_list_t} and so on. As explained above, these types are passed in argument to (and received back thru a reference from) an external procedure. These list manipulation functions are not strictly necessary to the use of the Sollya library in free-standing applications that do not use the functionality provided with \texttt{externalproc}. They are therefore provided as-is without any further documentation, besides the comments given in the Sollya library header file.

- The dynamic object file whose name is given to \texttt{externalproc} for binding of an external procedure may also define a destructor function \texttt{int sollya_external_lib_close(void)}. If Sollya finds such a destructor function in the dynamic object file, it will call that function when closing the dynamic object file again. This happens when Sollya is terminated or when the current Sollya session is restarted using \texttt{restart}. The purpose of the destructor function is to allow the dynamically bound code to free any memory that it might have allocated before Sollya is terminated or restarted.

The dynamic object file is not necessarily needed to define a destructor function. This ensure backward compatibility with older Sollya external library function object files.

When defined, the destructor function is supposed to return an integer value indicating if an error has happened. Upon success, the destructor functions is to return a zero value, upon error a non-zero value.

Example 1:
> bashexecute("gcc -fPIC -Wall -c externalprocexample.c");
> bashexecute("gcc -fPIC -shared -o externalprocexample externalprocexample.o");
> externalproc(foo, "/.externalprocexample", (integer, integer) -> integer);
> foo;
> foo(5, 6);
11
> verbosity = 1!;
> foo();
Warning: at least one of the given expressions or a subexpression is not correctly typed
or its evaluation has failed because of some error on a side-effect.
error
> a = foo;
> a(5,6);
11

See also: library (8.98), libraryconstant (8.99), externalplot (8.63), bashexecute (8.18), void (8.196), constant (8.29), function (8.73), range (8.148), integer (8.92), string (8.176), boolean (8.21), list of (8.100), object (8.120)

8.65 false
Name: false
the boolean value representing the false.

Library names:
  sollya_obj_t sollya_lib_false()
  int sollya_lib_is_false(sollya_obj_t)

Description:
  • false is the usual boolean value.

Example 1:

> true && false;
false
> 2<1;
false

See also: true (8.192), && (8.6), || (8.124)

8.66 file
Name: file
  special value for commands plot and externalplot

Library names:
  sollya_obj_t sollya_lib_file()
  int sollya_lib_is_file(sollya_obj_t)

Description:
  • file is a special value used in commands plot and externalplot to save the result of the command in a data file.
  • As any value it can be affected to a variable and stored in lists.
Example 1:

```plaintext
> savemode=file;
> name="plotSinCos";
> plot(sin(x),0,cos(x),[-Pi,Pi],savemode, name);
```

See also: externalplot [8.63], plot [8.128], postscript [8.131], postscriptfile [8.132]

8.67 findzeros

Name: findzeros

gives a list of intervals containing all zeros of a function on an interval.

Library name:

```
sollya_obj_t sollya_lib_findzeros(sollya_obj_t, sollya_obj_t)
```

Usage:

```
findzeros(f,I) : (function, range) → list
```

Parameters:

- $f$ is a function.
- $I$ is an interval.

Description:

- $\text{findzeros}(f,I)$ returns a list of intervals $I_1,\ldots,I_n$ such that, for every zero $z$ of $f$, there exists some $k$ such that $z \in I_k$.
- The list may contain intervals $I_k$ that do not contain any zero of $f$. An interval $I_k$ may contain many zeros of $f$.
- This command is meant for cases when safety is critical. If you want to be sure not to forget any zero, use \texttt{findzeros}. However, if you just want to know numerical values for the zeros of $f$, \texttt{dirtyfindzeros} should be quite satisfactory and a lot faster.
- If $\delta$ denotes the value of global variable \texttt{diam}, the algorithm ensures that for each $k$, $|I_k| \leq \delta \cdot |I|$.
- The algorithm used is basically a bisection algorithm. It is the same algorithm that the one used for \texttt{infnorm}. See the help page of this command for more details. In short, the behavior of the algorithm depends on global variables \texttt{prec}, \texttt{diam}, \texttt{taylorrecursions} and \texttt{hopitalrecursions}.

Example 1:

```plaintext
> findzeros(sin(x),[-5;5]);
[[[-3.14208984375; -3.140869140625], [-1.220703125e-3; 1.220703125e-3], [3.140869140625; 3.14208984375]]]
> diam=1e-10!;
> findzeros(sin(x),[-5;5]);
[[[-3.14159265370108187198638916015625; -3.141592653692865371041015625], [-1.16415321826934814453125e-9; 1.16415321826934814453125e-9], [3.141592653692865371041015625; 3.14159265370108187198638916015625]]]
```

See also: dirtyfindzeros [8.42], infnorm [8.91], prec [8.135], diam [8.39], taylorrecursions [8.187], hopitalrecursions [8.84], numberroots [8.118]
8.68 fixed

Name: fixed
indicates that fixed-point formats should be used for \texttt{fpminimax}

Library names:

\begin{verbatim}
sollya_obj_t sollya_lib_fixed() int sollya_lib_is_fixed(sollya_obj_t)
\end{verbatim}

Usage:

\begin{verbatim}
 fixed : fixed|floating
\end{verbatim}

Description:

\begin{itemize}
  \item The use of \texttt{fixed} in the command \texttt{fpminimax} indicates that the list of formats given as argument is to be considered to be a list of fixed-point formats. See \texttt{fpminimax} for details.
\end{itemize}

Example 1:

\begin{verbatim}
> fpminimax(cos(x),6,[[32,32,32,32,32,32],[1;1],fixed);
0.999999748077243566130615234375 \times 2^{-2} \times (-0.4999928693287074565887451171875 + \times 2^{2} \times (4.163351492024958133697509765625e-2 + \times 2^{2} \times (-1.338223926723003387451171875e-3)))
\end{verbatim}

See also: \texttt{fpminimax} \((8.71)\), \texttt{floating} \((8.69)\)

8.69 floating

Name: floating
indicates that floating-point formats should be used for \texttt{fpminimax}

Library names:

\begin{verbatim}
sollya_obj_t sollya_lib_floating() int sollya_lib_is_floating(sollya_obj_t)
\end{verbatim}

Usage:

\begin{verbatim}
 floating : fixed|floating
\end{verbatim}

Description:

\begin{itemize}
  \item The use of \texttt{floating} in the command \texttt{fpminimax} indicates that the list of formats given as argument is to be considered to be a list of floating-point formats. See \texttt{fpminimax} for details.
\end{itemize}

Example 1:

\begin{verbatim}
> fpminimax(cos(x),6,[[D...],[1;1],floating);
0.99999974816012215939053930924274027347564697265625 + x \times (-2.795931796958502334402306951076556592020898992465e-15 + x \times (-0.49999286980201401719980935922649223357439041137695 + x \times (4.0484539189054105169841244454207387920433372507922e-14 + x \times (-4.1633515528919168291466235132247675210237503051758e-2 + x \times (-4.01585881874373375878949218474363725507386355118e-14 + x \times (-1.338224088548378102464520019493892988434603214264e-3))))))
\end{verbatim}

See also: \texttt{fpminimax} \((8.71)\), \texttt{fixed} \((8.68)\)

8.70 floor

Name: floor
the usual function floor.

Library names:
sollya_obj_t sollya_lib_floor(sollya_obj_t)
sollya_obj_t sollya_lib_build_function_floor(sollya_obj_t)
#define SOLLYA_FLOOR(x) sollya_lib_build_function_floor(x)

Description:
- floor is defined as usual: floor(x) is the greatest integer y such that y ≤ x.
- It is defined for every real number x.

See also: ceil [8.23], nearestint [8.114], round [8.161], RD [8.151]

8.71 fpminimax

Name: fpminimax
computes a good polynomial approximation with fixed-point or floating-point coefficients

Library names:
sollya_obj_t sollya_lib_fpminimax(sollya_obj_t, sollya_obj_t, sollya_obj_t,
                                      sollya_obj_t, ...)
sollya_obj_t sollya_lib_v_fpminimax(sollya_obj_t, sollya_obj_t,
                                               sollya_obj_t, sollya_obj_t, va_list)

Usage:

fpminimax(f, n, formats, range, indic1, indic2, indic3, P) : (function, integer, list, range,
            absolute|relative | fixed|floating | function, absolute|relative | fixed|floating | function, absolute|relative | fixed|floating | function, function) → function
fpminimax(f, monomials, formats, range, indic1, indic2, indic3, P) : (function, list, list, range,
            absolute|relative | fixed|floating | function, absolute|relative | fixed|floating | function, absolute|relative | fixed|floating | function, function) → function
fpminimax(f, n, formats, L, indic1, indic2, indic3, P) : (function, integer, list, list,
            absolute|relative | fixed|floating | function, absolute|relative | fixed|floating | function, absolute|relative | fixed|floating | function, function) → function
fpminimax(f, monomials, formats, L, indic1, indic2, indic3, P) : (function, list, list, list,
            absolute|relative | fixed|floating | function, absolute|relative | fixed|floating | function, absolute|relative | fixed|floating | function, function) → function

Parameters:
- f is the function to be approximated
- n is the degree of the polynomial that must approximate f
- monomials is a list of integers or a list of function. It indicates the basis for the approximation of f
- formats is a list indicating the formats that the coefficients of the polynomial must have
- range is the interval where the function must be approximated
- L is a list of interpolation points used by the method
- indic1 (optional) is one of the optional indication parameters. See the detailed description below.
- indic2 (optional) is one of the optional indication parameters. See the detailed description below.
- indic3 (optional) is one of the optional indication parameters. See the detailed description below.
- P (optional) is the minimax polynomial to be considered for solving the problem.

Description:
• **fpminimax** uses a heuristic (but practically efficient) method to find a good polynomial approximation of a function \( f \) on an interval range. It implements the method published in the article: Efficient polynomial \( L^\infty \)-approximations
Nicolas Brisebarre and Sylvain Chevillard

• The basic usage of this command is **fpminimax**(\( f, n, \text{formats, range} \)). It computes a polynomial approximation of \( f \) with degree at most \( n \) on the interval range. \text{formats} is a list of integers or format types (such as double, doubledouble, etc.). The polynomial returned by the command has its coefficients that fit the formats indications. For instance, if \text{formats}[0] is 35, the coefficient of degree 0 of the polynomial will fit a floating-point format of 35 bits. If \text{formats}[1] is D, the coefficient of degree 1 will be representable by a floating-point number with a precision of 53 bits (which is not necessarily an IEEE 754 double precision number. See the remark below), etc.

• The second argument may be either an integer, a list of integers or a list of functions. An integer indicates the degree of the desired polynomial approximation. A list of integers indicates the list of desired monomials. For instance, the list \([0, 2, 4, 6]\) indicates that the polynomial must be even and of degree at most 6. Giving an integer \( n \) as second argument is equivalent as giving \([0, \ldots, n]\]. Finally, a list of function \( g_k \) indicates that the desired approximation must be a linear combination of the \( g_k \).

The list of formats is interpreted with respect to the list of monomials. For instance, if the list of monomials is \([0, 2, 4, 6]\) and the list of formats is \([161, 107, 53, 24]\), the coefficients of degree 0 is searched as a floating-point number with precision 161, the coefficient of degree 2 is searched as a number of precision 107, and so on.

• The list of formats may contain either integers or format types (halfprecision, single, double, doubledouble, tripledouble, doubleextended and quad). The list may be too large or even infinite. Only the first indications will be considered. For instance, for a degree \( n \) polynomial, formats\([n + 1]\) and above will be discarded. This lets one use elliptical indications for the last coefficients.

• The floating-point coefficients considered by **fpminimax** do not have an exponent range. In particular, in the format list, double is an exact synonym for 53. Currently, **fpminimax** only ensures that the corresponding coefficient has at most 53 bits of mantissa. It does not imply that it is an IEEE-754 double.

• By default, the list of formats is interpreted as a list of floating-point formats. This may be changed by passing **fixed** as an optional argument (see below). Let us take an example: **fpminimax**(\( f, 2, \[[107, DD, 53]\], [0; 1])\). Here the optional argument is missing (we could have set it to floating). Thus, **fpminimax** will search for a polynomial of degree 2 with a constant coefficient that is a 107 bits floating-point number, etc.

Currently, doubledouble is just a synonym for 107 and tripledouble a synonym for 161. This behavior may change in the future (taking into account the fact that some double-doubles are not representable with 107 bits).

Second example: **fpminimax**(\( f, 2, [[25, 18, 30]], [0; 1], fixed \)). In this case, **fpminimax** will search for a polynomial of degree 2 with a constant coefficient of the form \( m/2^25 \) where \( m \) is an integer. In other words, it is a fixed-point number with 25 bits after the point. Note that even with argument fixed, the formats list is allowed to contain halfprecision, single, double, doubleextended, doubledouble, quad or tripledouble. In this this case, it is just a synonym for 11, 24, 53, 64, 107, 113 or 161. This is deprecated and may change in the future.

• The fourth argument may be a range or a list. Lists are for advanced users that know what they are doing. The core of the method is a kind of approximated interpolation. The list given here is a list of points that must be considered for the interpolation. It must contain at least as many points as unknown coefficients. If you give a list, it is also recommended that you provide the minimax polynomial as last argument. If you give a range, the list of points will be automatically computed.
• The fifth, sixth and seventh arguments are optional. By default, \texttt{fpminimax} will approximate \( f \) while optimizing the relative error, and interpreting the list of formats as a list of floating-point formats.

This default behavior may be changed with these optional arguments. You may provide zero, one, two or three of the arguments in any order. This lets the user indicate only the non-default arguments.

The three possible arguments are:

- \texttt{relative} or \texttt{absolute}: the error to be optimized;
- \texttt{floating} or \texttt{fixed}: formats of the coefficients;
- a constrained part \( q \).

The constrained part lets the user assign in advance some of the coefficients. For instance, for approximating \( \exp(x) \), it may be interesting to search for a polynomial \( p \) of the form

\[
p = 1 + x + \frac{x^2}{2} + a_3x^3 + a_4x^4.
\]

Thus, there is a constrained part \( q = 1 + x + x^2/2 \) and the unknown polynomial should be considered in the monomial basis \([3, 4]\). Calling \texttt{fpminimax} with monomial basis \([3, 4]\) and constrained part \( q \), will return a polynomial with the right form.

• The last argument is for advanced users. It is the minimax polynomial that approximates the function \( f \) in the given basis. If it is not given this polynomial will be automatically computed by \texttt{fpminimax}.

This minimax polynomial is used to compute the list of interpolation points required by the method. It is also used, when floating-point coefficients are desired, to give an initial assumption for the exponents of the coefficients. In general, you do not have to provide this argument. But if you want to obtain several polynomials of the same degree that approximate the same function on the same range, just changing the formats, you should probably consider computing only once the minimax polynomial and the list of points instead of letting \texttt{fpminimax} recompute them each time.

Note that in the case when a constrained part is given, the minimax polynomial must take that into account. For instance, in the previous example, the minimax would be obtained by the following command:

\[
P = \text{remez}(1-(1+x+x^2/2)/\exp(x), [3,4], \text{range, } 1/\exp(x));
\]

Note that the constrained part is not to be added to \( P \).

In the case when the second argument is an integer or a list of integers, there is no restriction for \( P \), as long as it is a polynomial. However, when the second argument is a list of functions, and even if these functions are all polynomials, \( P \) must be expanded in the given basis. For instance, if the second argument is 2 or \([0, 1, 2]\), \( P \) can be given in Horner form. However, if the second argument is \([1, x, x^2]\), \( P \) must be written as a linear combination of 1, \( x \) and \( x^2 \), otherwise, the algorithm will fail to recover the coefficients of \( P \) and will fail with an error message.

Please also note that recovering the coefficients of \( P \) in an arbitrary basis is performed heuristically and no verification is performed to check that \( P \) does not contain other functions than the functions of the basis.

• Note that \texttt{fpminimax} internally computes a minimax polynomial (using the same algorithm as \texttt{remez} command). Thus \texttt{fpminimax} may encounter the same problems as \texttt{remez}. In particular, it may be very slow when Haar condition is not fulfilled. Another consequence is that currently \texttt{fpminimax} has to be run with a sufficiently high working precision.

Example 1:

\[
\begin{align*}
> P &= \text{fpminimax}(\cos(x), 6, [[DD, DD, D...]], [-1b-5; 1b-5]); \\
> \text{printexpansion}(P); \\
(0x3ff0000000000000 + 0xbc09fda15e029b00) + x * ((0x3af9eb57163024a8 + 0x37942c2f3e3839) + x * (0xbf56c138142da5b0))
\end{align*}
\]
Example 2:

```plaintext
> P = fpminimax(sin(x),6,[-32...],[1b-5;1b-5], fixed, absolute);
> display = powers!;
> P;
  x * (1 + x^2 * (-357913941 * 2^(-31) + x^2 * (35789873 * 2^(-32))))
```

Example 3:

```plaintext
> P = fpminimax(exp(x), [3,4], [D,24], [-1/256; 1/246], 1+x+x^2/2);
> display = powers!;
> P;
  1 + x * (1 + x * (1 * 2^(-1) + x * (375300225001191 * 2^(-51) + x * (5592621 * 2^(-27)))))
```

Example 4:

```plaintext
> f = cos(exp(x));
> pstar = remez(f, 5, [-1b-7;1b-7]);
> listpoints = dirtyfindzeros(f-pstar, [-1b-7; 1b-7]);
> P1 = fpminimax(f, 5, [DD...], listpoints, absolute, default, default, pstar);
> P2 = fpminimax(f, 5, [D...], listpoints, absolute, default, default, pstar);
> P3 = fpminimax(f, 5, [D, D, D, 24...], listpoints, absolute, default, default, default, pstar);
> print("Error of pstar: ", dirtyinfnorm(f-pstar, [-1b-7; 1b-7]));
  Error of pstar: 7.9048441259903026332577436001060063099817726177425e-16
> print("Error of P1: ", dirtyinfnorm(f-P1, [-1b-7; 1b-7]));
  Error of P1: 7.9048441259903026358081299123420463921479618202064e-16
> print("Error of P2: ", dirtyinfnorm(f-P2, [-1b-7; 1b-7]));
  Error of P2: 8.247714457950871737109573536791331686347620955985e-16
> print("Error of P3: ", dirtyinfnorm(f-P3, [-1b-7; 1b-7]));
  Error of P3: 1.08454277156993282593701165841863009789063333951055e-15
```

Example 5:

```plaintext
> L = [exp(x), sin(x), cos(x)-1, sin(x^3)];
> g = (2^x-1)/x;
> p = fpminimax(g, L, [D...], [-1/16;1/16],absolute);
> display = powers!;
> p;
  -3267884797436153 * 2^(-54) * sin(x^3) + 5247089102535885 * 2^(-53) * (cos(x) - 1) + 815995033730771 * 2^(-54) * sin(x) + 6243315658446641 * 2^(-53) * exp(x)
```

Example 6:
> n = 9;
> T = [[1, x]];  
> for i from 2 to n do T[i] = canonical(2*x*T[i-1] - T[i-2]);
> g = (2^x - 1)/x;
> PCheb = fpminimax(g, T, [[DD, DE...]], [-1/16; 1/16], absolute);
> display = dyadic!
> print(PCheb);

8733930098894247371b-98 * (9 * x + -120 * x^3 + 432 * x^5 + -576 * x^7 + 256 * x^9) + 15750497046710770365b-94 * (1 + -32 * x^2 + 160 * x^4 + -256 * x^6 + 128 * x^8) + 646738030985872933b-88 * (-7 * x + 56 * x^3 + -112 * x^5 + 64 * x^7) + 934272606926218927b-84 * (-1 + 18 * x^2 + -48 * x^4 + 32 * x^6) + 11814521367456461131b-80 * (5 * x + -20 * x^3 + 16 * x^5) + 640547947432857093b-75 * (1 + -8 * x^2 + 8 * x^4) + 11584457324781948899b-72 * (-3 * x + 4 * x^3) + 16779705312447201161b-69 * (-1 + 2 * x^2) + 18265014280997359319b-66 * x + 117054497448175143902009975397253b-107

See also: remez [8.155], dirtyfindzeros [8.42], absolute [8.2], relative [8.154], fixed [8.68], floating [8.69], default [8.36], halfprecision [8.80], single [8.172], double [8.49], doubleextended [8.51], doubledouble [8.50], quad [8.146], tripledouble [8.191], implementpoly [8.88], coeff [8.20], degree [8.37], roundcoefficients [8.162], guessdegree [8.79]

8.72 fullparentheses

Name: fullparentheses

activates, deactivates or inspects the state variable controlling output with full parenthesising

Library names:

void sollya_lib_set_fullparentheses_and_print(sollya_obj_t);
void sollya_lib_set_fullparentheses(sollya_obj_t);
sollya_obj_t sollya_lib_get_fullparentheses();

Usage:

fullparentheses = activation value : on|off → void
fullparentheses = activation value ! : on|off → void

Parameters:

- *activation value* represents on or off, i.e. activation or deactivation

Description:

- An assignment fullparentheses = activation value, where activation value is one of on or off, activates respectively deactivates the output of expressions with full parenthesising. In full parenthesising mode, Sollya commands like print, write and the implicit command when an expression is given at the prompt will output expressions with parenthesising at all places where it is necessary for expressions containing infix operators to be parsed back with the same result. Otherwise parentheses around associative operators are omitted.

If the assignment fullparentheses = activation value is followed by an exclamation mark, no message indicating the new state is displayed. Otherwise the user is informed of the new state of the global mode by an indication.

Example 1:
> autosimplify = off!
> fullparentheses = off;
Full parentheses mode has been deactivated.
> print(1 + 2 + 3);
1 + 2 + 3
> fullparentheses = on;
Full parentheses mode has been activated.
> print(1 + 2 + 3);
(1 + 2) + 3

See also: print [8.138], write [8.198], autosimplify [8.16]

8.73 function

Name: function
keyword for declaring a procedure-based function or a keyword representing a function type

Library names:
sollya_obj_t sollya_lib_procedurefunction(sollya_obj_t, sollya_obj_t)
sollya_obj_t sollya_lib_build_function_procedurefunction(sollya_obj_t, sollya_obj_t)

SOLLYA_EXTERNALPROC_TYPE_FUNCTION

Usage:

function(procedure) : procedure → function
function : type type

Parameters:
• procedure is a procedure of type (range, integer, integer) → range

Description:
• For the sake of safety and mathematical consistency, Sollya distinguishes clearly between functions, seen in the mathematical sense of the term, i.e. mappings, and procedures, seen in the sense Computer Science gives to functions, i.e. pieces of code that compute results for arguments following an algorithm. In some cases however, it is interesting to use such Computer Science procedures as realisations of mathematical functions, e.g. in order to plot them or even to perform polynomial approximation on them. The function keyword allows for such a transformation of a Sollya procedure into a Sollya function.

• The procedure to be used as a function through function(procedure) must be of type (range, integer, integer) → range. This means it must take in argument an interval \( X \), a degree of differentiation \( n \) and a working precision \( p \). It must return in result an interval \( Y \) encompassing the image \( f^{(n)}(X) \) of the \( n \)-th derivative of the implemented function \( f \), i.e. \( f^{(n)}(X) \subseteq Y \). In order to allow Sollya’s algorithms to work properly, the procedure must ensure that, whenever \( (p, \text{diam}(X)) \) tends to \( (+\infty, 0) \), the computed over-estimated bounding \( Y \) tends to the actual image \( f^{(n)}(X) \).

• The user must be aware that they are responsible of the correctness of the procedure. If, for some \( n \) and \( X \), procedure returns an interval \( Y \) such that \( f^{(n)}(X) \not\subseteq Y \), function will successfully return a function without any complain, but this function might behave inconsistently in further computations.

• For cases when the procedure does not have the correct signature or does not return a finite interval as a result function(procedure) evaluates to Not-A-Number (resp. to an interval of Not-A-Numbers for interval evaluation).

• function also represents the function type for declarations of external procedures by means of externalproc.

Remark that in contrast to other indicators, type indicators like function cannot be handled outside the externalproc context. In particular, they cannot be assigned to variables.
Example 1:
> procedure EXP(X,n,p) {
   var res, oldPrec;
   oldPrec = prec;
   prec = p!;
   res = exp(X);
   prec = oldPrec!;
   return res;
};
> f = function(EXP);
> f(1);
2.7182818284590452353602874713526624977572470937
> exp(1);
2.7182818284590452353602874713526624977572470937
> f(x + 3);
(function(proc(X, n, p)
{
   var res, oldPrec;
   oldPrec = prec;
   prec = p!;
   res = exp(X);
   prec = oldPrec!;
   return res;
}))(3 + x)
> diff(f);
(diff(function(proc(X, n, p)
{
   var res, oldPrec;
   oldPrec = prec;
   prec = p!;
   res = exp(X);
   prec = oldPrec!;
   return res;
}))(3 + x)
>
> (diff(f))(0);
1
> g = f(sin(x));
> g(17);
0.38235816999386683402690554641655641359573468342088
> diff(g);
(diff(function(proc(X, n, p)
{
   var res, oldPrec;
   oldPrec = prec;
   prec = p!;
   res = exp(X);
   prec = oldPrec!;
   return res;
}))(sin(x)) * cos(x)
>
> (diff(g))(1);
1.2538076749344683697237458088447611474812675164344
> p = remez(f,3,[-1/2;1/2]);
> p;
0.9997120901420646830335493949039176881764871951833 + x * (0.999737029835711401
34762682913614052309208076875596 + x * (0.51049729360282624921622721654643510358
3073053437 + x * 0.169814324607133287588897694747370380479108785868016))
8.74  \texttt{gcd}

\textbf{Name:} \texttt{gcd}

Computes the greatest common divisor of polynomials or numbers.

\textbf{Library name:}

\texttt{sollya\_obj\_t sollya\_lib\_gcd(sollya\_obj\_t, sollya\_obj\_t)}

\textbf{Usage:}

\texttt{gcd(p, q) : (function, function) \rightarrow function}

\textbf{Parameters:}

- \textit{p} is a constant or a polynomial.
- \textit{q} is a constant or a polynomial.

\textbf{Description:}

- When both \textit{p} and \textit{q} are integers, \texttt{gcd(p,q)} computes the greatest common divisor of these two integers, i.e. the greatest non-negative integer dividing both \textit{p} and \textit{q}.
- When both \textit{p} and \textit{q} are rational numbers, say \(a/b\) and \(c/d\), \texttt{gcd(p,q)} computes the greatest common divisor of \(a \cdot d\) and \(b \cdot c\), divided by the product of the denominators, \(b \cdot d\).
- When both \textit{p} and \textit{q} are constants but at least one of them is no rational number, \texttt{gcd(p,q)} returns 1.
- When both \textit{p} and \textit{q} are polynomials with at least one being non-constant, \texttt{gcd(p,q)} returns the polynomial of greatest degree dividing both \textit{p} and \textit{q}, and whose leading coefficient is the greatest common divisor of the leading coefficients of \textit{p} and \textit{q}.
- Similarly to the cases documented for \texttt{div} and \texttt{mod}, \texttt{gcd} may fail to return the unique polynomial of largest degree dividing both \textit{p} and \textit{q} in cases when certain coefficients of either \textit{p} or \textit{q} are constant expressions for which the tool is unable to determine whether they are zero or not. These cases typically involve polynomials whose leading coefficient is zero but the tool is unable to detect this fact.
- When at least one of \textit{p} or \textit{q} is a function that is no polynomial, \texttt{gcd(p,q)} returns 1.

\textbf{Example 1:}

\begin{verbatim}
> gcd(1001, 231);
77
> gcd(13, 17);
1
> gcd(-210, 462);
42
\end{verbatim}

\textbf{Example 2:}

\begin{verbatim}
> rationalmode = on!;
> gcd(6/7, 33/13);
3 / 91
\end{verbatim}

\textbf{Example 3:}

\begin{verbatim}
> gcd(exp(13),sin(17));
1
\end{verbatim}
Example 4:

```
> gcd(24 + 68 * x + 74 * x^2 + 39 * x^3 + 10 * x^4 + x^5, 480 + 776 * x + 476 * x^2 + 138 * x^3 + 19 * x^4 + x^5);
4 + x * (4 + x)
```

```
> gcd(1001 * x^2, 231 * x);
x * 77
```

Example 5:

```
> gcd(exp(x), x^2);
1
```

See also:  
[div](8.47),  
[mod](8.112),  
[numberroots](8.118)  

8.75  

>=

Name: >=  
greater-than-or-equal-to operator

Library name:  
sollya_obj_t sollya_lib_cmp_greater_equal(sollya_obj_t, sollya_obj_t)

Usage:  

```
expr1 >= expr2 : (constant, constant) -> boolean
```

Parameters:

- `expr1` and `expr2` represent constant expressions

Description:

- The operator `>=` evaluates to true iff its operands `expr1` and `expr2` evaluate to two floating-point numbers $a_1$ respectively $a_2$ with the global precision `prec` and $a_1$ is greater than or equal to $a_2$. The user should be aware of the fact that because of floating-point evaluation, the operator `>=` is not exactly the same as the mathematical operation `greater-than-or-equal-to`.

Example 1:

```
> 5 >= 4;
true
> 5 >= 5;
true
> 5 >= 6;
false
> exp(2) >= exp(1);
true
> log(1) >= exp(2);
false
```

Example 2:

```
> prec = 12;
The precision has been set to 12 bits.
> 16384.1 >= 16385.1;
true
```

See also:  
[==](8.53),  
[!=](8.115),  
[>](8.75),  
[<=](8.96),  
[<](8.105),  
[in](8.89),  
[!](8.117),  
[& &](8.6),  
[||](8.124),  
[prec](8.135),  
[max](8.107),  
[min](8.110)
8.76  getbacktrace

Name: getbacktrace
  returns the list of Sollya procedures currently run

Library name:
  sollya_obj_t sollya_lib_getbacktrace();

Usage:
  getbacktrace() : void → list

Description:

- The getbacktrace command allows the stack of Sollya procedures that are currently run to be inspected. When called, getbacktrace returns an ordered list of structures, each of which contains an element passed_args and an element called_proc. The element calledproc contains the Sollya object representing the procedure being run. The element passed_args contains an ordered list of all effective arguments passed to the procedure when it was called. The procedure called last (i.e., on top of the stack) comes first in the list returned by getbacktrace. When any of the procedure called takes no arguments, the passed_args element of the corresponding structure evaluates to an empty list.

- When called from outside any procedure (at toplevel), getbacktrace returns an empty list.

- When called for a stack containing a call to a variadic procedure that was called with an infinite number of effective arguments, the corresponding passed_args element evaluates to an end-elliptic list.

Example 1:
> procedure testA() {
  "Current backtrace:";
  getbacktrace();
};
> procedure testB(X) {
  "X = ", X;
  testA();
};
> procedure testC(X, Y) {
  "X = ", X, ", Y = ", Y;
  testB(Y);
};
> testC(17, 42);
X = 17, Y = 42
X = 42
Current backtrace:
[[{ .passed_args = [1 | ], .called_proc = proc()
  {
    "Current backtrace:";
    getbacktrace();
    return void;
  } }, { .passed_args = [42], .called_proc = proc(X)
  {
    "X = ", X;
    testA();
    return void;
  } }, { .passed_args = [17, 42], .called_proc = proc(X, Y)
  {
    "X = ", X, ", Y = ", Y;
    testB(Y);
    return void;
  } }]]

Example 2:

> getbacktrace();
[1 1]

Example 3:
> procedure printnumargs(X) {
  var L, t;
  "number of arguments: ", X;
  L = getbacktrace();
  "Backtrace:";
  for t in L do {
    " " @ objectname(t.called_proc) @ ", ", t.passed_args;
  }
};
> procedure numargs(l = ...) {
  "l[17] = ", l[17];
  printnumargs(length(l));
};
> procedure test() {
  numargs @ [|25, 26, 27 ...|];
};
> test();
l[17] = 42
number of arguments: infty
Backtrace: 
  printnumargs, [|infty|]
  numargs, [|25, 26, 27...|]
  test, [| |]

See also: proc [8.143], procedure [8.144], objectname [8.121], bind [8.20], @ [8.28]

8.77 getsuppressedmessages

Name: getsuppressedmessages
returns a list of numbers of messages that have been suppressed from message output

Library name:
sollya_obj_t sollya_lib_getsuppressedmessages();

Usage:

  getsuppressedmessages() : void → list

Description:

- The getsuppressedmessages command allows the user to inspect the state of warning and information message suppression. When called, getsuppressedmessages returns a list of integers numbers that stand for the warning and information messages that have been suppressed. If no message is suppressed, getsuppressedmessages returns an empty list.

- Every Sollya warning or information message (that is not fatal to the tool’s execution) has a message number. By default, these numbers are not displayed when a message is output. When message number displaying is activated using showmessagenumbers, the message numbers are displayed together with the message. This allows the user to match the numbers returned in a list by getsuppressedmessages with the actual warning and information messages.

- The list of message numbers returned by getsuppressedmessages is suitable to be fed into the unsuppressmessage command. This way, the user may unsuppress all warning and information messages that have been suppressed.

Example 1:
> verbosity = 1;
The verbosity level has been set to 1.
> 0.1;
Warning: Rounding occurred when converting the constant "0.1" to floating-point with 165 bits.
If safe computation is needed, try to increase the precision.
0.1
> suppressmessage(174);
> 0.1;
0.1
> suppressmessage(407);
> 0.1;
0.1
> getsuppressedmessages();
[[174, 407]]
> suppressmessage(207, 196);
> getsuppressedmessages();
[[174, 196, 207, 407]]

Example 2:

> suppressmessage(174, 209, 13, 24, 196);
> suppressmessage([| 16, 17 |]);
> suppressmessage(19);
> unsuppressmessage([| 13, 17 |]);
> getsuppressedmessages();
[[16, 19, 24, 174, 196, 209]]
> unsuppressmessage(getsuppressedmessages());
> getsuppressedmessages();
[]

Example 3:

> verbosity = 12;
The verbosity level has been set to 12.
> suppressmessage(174);
> exp(x * 0.1);
Information: no Horner simplification will be performed because the given tree is already in Horner form.
exp(x * 0.1)
> getsuppressedmessages();
[[174]]
> verbosity = 0;
The verbosity level has been set to 0.
> exp(x * 0.1);
exp(x * 0.1)
> getsuppressedmessages();
[[174]]

See also: 
getsuppressedmessages [8.77], suppressmessage [8.181], unsuppressmessage [8.193], 
verbosity [8.195], roundingwarnings [8.164]

8.78  >
Name: >
greater-than operator
Library name:
```c
sollya_obj_t sollya_lib_cmp_greater(sollya_obj_t, sollya_obj_t)
```

Usage:
```
expr1 > expr2 : (constant, constant) → boolean
```

Parameters:
- `expr1` and `expr2` represent constant expressions

Description:
- The operator `>` evaluates to true iff its operands `expr1` and `expr2` evaluate to two floating-point numbers $a_1$ respectively $a_2$ with the global precision `prec` and $a_1$ is greater than $a_2$. The user should be aware of the fact that because of floating-point evaluation, the operator `>` is not exactly the same as the mathematical operation `greater-than`.

Example 1:
```
> 5 > 4;
true
> 5 > 5;
false
> 5 > 6;
false
> exp(2) > exp(1);
true
> log(1) > exp(2);
false
```

Example 2:
```
> prec = 12;
The precision has been set to 12 bits.
> 16385.1 > 16384.1;
false
```

See also: `==` (8.53), `!=` (8.115), `>=` (8.75), `<=` (8.96), `< (8.105), `in` (8.89), `!` (8.117), `&&` (8.6), `||` (8.124), `prec` (8.135), `max` (8.107), `min` (8.110)

8.79 `guessdegree`

Name: `guessdegree`
returns the minimal degree needed for a polynomial to approximate a function with a certain error on an interval.

Library names:
```c
sollya_obj_t sollya_lib_guessdegree(sollya_obj_t, sollya_obj_t, sollya_obj_t, ...)
sollya_obj_t sollya_lib_v_guessdegree(sollya_obj_t, sollya_obj_t, va_list)
```

Usage:
```
guessdegree(f,I,eps,w,bound) : (function, range, constant, function, constant) → range
```

Parameters:
- `f` is the function to be approximated.
- `I` is the interval where the function must be approximated.
- \( eps \) is the maximal acceptable error.
- \( w \) (optional) is a weight function. Default is 1.
- \( bound \) (optional) is a bound on the degree. Default is currently 128.

Description:
- \texttt{guessdegree} tries to find the minimal degree needed to approximate \( f \) on \( I \) by a polynomial with an error \( \epsilon = pw - f \) whose infinity norm not greater than \( eps \). More precisely, it finds \( n \) minimal such that there exists a polynomial \( p \) of degree \( n \) such that \( \|pw - f\|_\infty < \epsilon \).
- \texttt{guessdegree} returns an interval: for common cases, this interval is reduced to a single number (i.e. the minimal degree). But in certain cases, \texttt{guessdegree} does not succeed in finding the minimal degree. In such cases the returned interval is of the form \( [n, p] \) such that:
  - no polynomial of degree \( n - 1 \) gives an error less than \( eps \).
  - there exists a polynomial of degree \( p \) giving an error less than \( eps \).
- The fifth optional argument \texttt{bound} is used to prevent \texttt{guessdegree} from trying to find too large degrees. If \texttt{guessdegree} does not manage to find a degree \( n \) satisfying the error and such that \( n \leq \texttt{bound} \), an interval of the form \( [\cdot, +\infty] \) is returned. Note that \texttt{bound} must be a positive integer.

Example 1:

```
> guessdegree(exp(x),[-1;1],1e-10);
[10;10]
```

Example 2:

```
> guessdegree(exp(x),[-1;1],1e-10,default, 9);
[10;infty]
```

Example 3:

```
> guessdegree(1, [-1;1], 1e-8, 1/exp(x));
[8;9]
```

See also: \texttt{dirtyinfnorm} (8.43), \texttt{remez} (8.155), \texttt{fpminimax} (8.71), \texttt{degree} (8.37)

### 8.80 halfprecision

Names: halfprecision, HP

rounding to the nearest IEEE 754 half-precision number (binary16).

Library names:

- \texttt{sollya_obj_t sollya_lib_halfprecision(sollya_obj_t)}
- \texttt{sollya_obj_t sollya_lib_halfprecision_obj()}\n- \texttt{int sollya_lib_is_halfprecision_obj(sollya_obj_t)}
- \texttt{sollya_obj_t sollya_lib_build_function_halfprecision(sollya_obj_t)}
- \#define SOLLYA_HP(x) sollya_lib_build_function_halfprecision(x)

Description:

- \texttt{halfprecision} is both a function and a constant.
- As a function, it rounds its argument to the nearest IEEE 754 half-precision (i.e. IEEE754-2008 binary16) number. Subnormal numbers are supported as well as standard numbers: it is the real rounding described in the standard.
As a constant, it symbolizes the half-precision format. It is used in contexts when a precision format is necessary, e.g. in the commands \texttt{round} and \texttt{roundcoefficients}. It is not supported for \texttt{implementpoly}. See the corresponding help pages for examples.

Example 1:

```plaintext
> display=binary!;
> HP(0.1);
1.100110011_2 * 2^(-4)
> HP(4.17);
1.00001011_2 * 2^(2)
> HP(1.011_2 * 2^(-23));
1.1_2 * 2^(-23)
```

See also: \texttt{single (8.172)}, \texttt{double (8.49)}, \texttt{doubleextended (8.51)}, \texttt{doubledouble (8.50)}, \texttt{quad (8.146)}, \texttt{tripledouble (8.191)}, \texttt{roundcoefficients (8.162)}, \texttt{fpminimax (8.71)}, \texttt{implementpoly (8.88)}, \texttt{round (8.161)}, \texttt{printsingle (8.141)}

### 8.81 head

Name: \texttt{head}

gives the first element of a list.

Library name:

\begin{verbatim}
sollya_obj_t sollya_lib_head(sollya_obj_t)
\end{verbatim}

Usage:

\begin{verbatim}
head(L) : list → any type
\end{verbatim}

Parameters:

\begin{itemize}
  \item L is a list.
\end{itemize}

Description:

\begin{itemize}
  \item \texttt{head(L)} returns the first element of the list \texttt{L}. It is equivalent to \texttt{L[0]}.
  \item If \texttt{L} is empty, the command will fail with an error.
\end{itemize}

Example 1:

```plaintext
> head([1,2,3]);
1
> head([1,2...]);
1
```

See also: \texttt{tail (8.182)}, \texttt{revert (8.159)}

### 8.82 hexadecimal

Name: \texttt{hexadecimal}

special value for global state \texttt{display}

Library names:

\begin{verbatim}
sollya_obj_t sollya_lib_hexadecimal()
int sollya_lib_is_hexadecimal(sollya_obj_t)
\end{verbatim}

Description:

\begin{itemize}
  \item \texttt{hexadecimal} is a special value used for the global state \texttt{display}. If the global state \texttt{display} is equal to \texttt{hexadecimal}, all data will be output in hexadecimal C99/\ IEEE 754-2008 notation.
  \item As any value it can be affected to a variable and stored in lists.
\end{itemize}

See also: \texttt{decimal (8.35)}, \texttt{dyadic (8.52)}, \texttt{powers (8.134)}, \texttt{binary (8.19)}, \texttt{display (8.46)}
8.83 honorcoeffprec

Name: honorcoeffprec
indicates the (forced) honoring the precision of the coefficients in implementpoly

Library names:

sollya_obj_t sollya_lib_honorcoeffprec()
int sollya_lib_is_honorcoeffprec(sollya_obj_t)

Usage:

honorcoeffprec : honorcoeffprec

Description:

• Used with command implementpoly, honorcoeffprec makes implementpoly honor the precision of the given polynomial. This means if a coefficient needs a double-double or a triple-double to be exactly stored, implementpoly will allocate appropriate space and use a double-double or triple-double operation even if the automatic (heuristic) determination implemented in command implementpoly indicates that the coefficient could be stored on less precision or, respectively, the operation could be performed with less precision. See implementpoly for details.

Example 1:

```plaintext
> verbosity = 1!
> q = implementpoly(1 - dirtysimplify(TD(1/6)) * x^-2,[-1b-10;1b-10],1b-60,DD,"p","implementation.c");
Warning: at least one of the coefficients of the given polynomial has been rounded in a way that the target precision can be achieved at lower cost. Nevertheless, the implemented polynomial is different from the given one.
> printexpansion(q);
0x3ff0000000000000 + x^-2 * 0xbfc5555555555555
> r = implementpoly(1 - dirtysimplify(TD(1/6)) * x^-2,[-1b-10;1b-10],1b-60,DD,"p","implementation.c",honorcoeffprec);
Warning: the inferred precision of the 2th coefficient of the polynomial is greater than the necessary precision computed for this step. This may make the automatic determination of precisions useless.
> printexpansion(r);
0x3ff0000000000000 + x^-2 * (0xbfc5555555555555 + 0xbc65555555555555 + 0xb905555555555555)
```

See also: implementpoly (8.88), printexpansion (8.140), fpminimax (8.71)

8.84 hopitalrecursions

Name: hopitalrecursions
controls the number of recursion steps when applying L’Hopital’s rule.

Library names:

void sollya_lib_set_hopitalrecursions_and_print(sollya_obj_t)
void sollya_lib_set_hopitalrecursions(sollya_obj_t)
sollya_obj_t sollya_lib_get_hopitalrecursions()

Usage:

hopitalrecursions = n : integer → void
hopitalrecursions = n ! : integer → void
hopitalrecursions : integer

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Parameters:

- \( n \) represents the number of recursions

Description:

- **hopitalrecursions** is a global variable. Its value represents the number of steps of recursion that are tried when applying L'Hopital's rule. This rule is applied by the interval evaluator present in the core of Sollya (and particularly visible in commands like `infnorm`).

- If an expression of the form \( f/g \) has to be evaluated by interval arithmetic on an interval \( I \) and if \( f \) and \( g \) have a common zero in \( I \), a direct evaluation leads to NaN. Sollya implements a safe heuristic to avoid this, based on L'Hopital's rule: in such a case, it can be shown that \((f/g)(I) \subseteq (f'/g')(I)\). Since the same problem may exist for \( f'/g' \), the rule is applied recursively. The number of step in this recursion process is controlled by **hopitalrecursions**.

- Setting **hopitalrecursions** to 0 makes Sollya use this rule only once; setting it to 1 makes Sollya use the rule twice, and so on. In particular: the rule is always applied at least once, if necessary.

Example 1:

```plaintext
> hopitalrecursions=0;
The number of recursions for Hopital's rule has been set to 0.
> evaluate(log(1+x)^2/x^2,[-1/2; 1]);
[-infty;infty]
> hopitalrecursions=1;
The number of recursions for Hopital's rule has been set to 1.
> evaluate(log(1+x)^2/x^2,[-1/2; 1]);
[-2.5225887222397812376689284858327062723020005374411; 6.772588722397812376689284858327062723020005374412]
```


### 8.85 horner

**Name:** horner  

Brings all polynomial subexpressions of an expression to Horner form

**Library name:**  
sollya_obj_t sollya_lib_horner(sollya_obj_t)

**Usage:**

```
horner(function) : function \rightarrow function
```

**Parameters:**

- **function** represents the expression to be rewritten in Horner form

**Description:**

- The command **horner** rewrites the expression representing the function **function** in a way such that all polynomial subexpressions (or the whole expression itself, if it is a polynomial) are written in Horner form. The command **horner** does not endanger the safety of computations even in Sollya’s floating-point environment: the function returned is mathematically equal to the function **function**.

**Example 1:**

```plaintext
> print(horner(1 + 2 * x + 3 * x^2));
1 + x * (2 + x * 3)
> print(horner((x + 1)^7));
1 + x * (7 + x * (21 + x * (35 + x * (35 + x * (21 + x * (7 + x))))))
```

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Example 2:

```plaintext
> print(horner(exp((x + 1)^5) - log(asin(x + x^3) + x)));

exp(1 + x * (5 + x * (10 + x * (10 + x * (5 + x))))) - log(asin(x * (1 + x^-2)) + x)
```

See also: canonical [8.22], print [8.138], coeff [8.26], degree [8.37], autosimplify [8.16], simplify [8.170]

8.86 HP

Name: HP
short form for halfprecision

See also: halfprecision [8.80]

8.87 implementconstant

Name: implementconstant
implements a constant in arbitrary precision

Library names:

```plaintext
void sollya_lib_implementconstant(sollya_obj_t, ...);
void sollya_lib_v_implementconstant(sollya_obj_t, va_list);
```

Usage:

```plaintext
implementconstant(expr) : constant → void
implementconstant(expr, filename) : (constant, string) → void
implementconstant(expr, filename, functionname) : (constant, string, string) → void
```

Description:

- The command `implementconstant` implements the constant expression `expr` in arbitrary precision. More precisely, it generates the source code (written in C, and using MPFR) of a C function `const_something` with the following signature:

  ```plaintext
  void const_something (mpfr_ptr y, mp_prec_t prec)
  ```

  Let us denote by `c` the exact mathematical value of the constant defined by the expression `expr`. When called with arguments `y` and `prec` (where the variable `y` is supposed to be already initialized), the function `mpfr_const_something` sets the precision of `y` to a suitable precision and stores in it an approximate value of `c` such that

  ```plaintext
  |y - c| ≤ |c| 2^{1-prec}.
  ```

- When no filename `filename` is given or if `default` is given as `filename`, the source code produced by `implementconstant` is printed on standard output. Otherwise, when `filename` is given as a string of characters, the source code is output to a file named `filename`. If that file cannot be opened and/or written to, `implementconstant` fails and has no other effect.

- When `functionname` is given as an argument to `implementconstant` and `functionname` evaluates to a string of characters, the default name for the C function `const_something` is replaced by `functionname`. When `default` is given as `functionname`, the default name is used nevertheless, as if no `functionname` argument were given. When choosing a character sequence for `functionname`, the user should keep attention to the fact that `functionname` must be a valid C identifier in order to enable error-free compilation of the produced code.

- If `expr` refers to a constant defined with `libraryconstant`, the produced code uses the external code implementing this constant. The user should keep in mind that it is up to them to make sure the symbol for that external code can get resolved when the newly generated code is to be loaded.
• If a subexpression of \( expr \) evaluates to 0, \texttt{implementconstant} will most likely fail with an error message.

• \texttt{implementconstant} is unable to implement constant expressions \( expr \) that contain procedure-based functions, i.e. functions created from \texttt{Sollya} procedures using the \texttt{function} construct. If \( expr \) contains such a procedure-based function, \texttt{implementconstant} prints a warning and fails silently. The reason for this lack of functionality is that the produced C source code, which is supposed to be compiled, would have to call back to the \texttt{Sollya} interpreter in order to evaluate the procedure-based function.

• Similarly, \texttt{implementconstant} is currently unable to implement constant expressions \( expr \) that contain library-based functions, i.e. functions dynamically bound to \texttt{Sollya} using the \texttt{library} construct. If \( expr \) contains such a library-based function, \texttt{implementconstant} prints a warning and fails silently. Support for this feature is in principle feasible from a technical standpoint and might be added in a future release of \texttt{Sollya}.

• Currently, non-differentiable functions such as \texttt{double}, \texttt{doubledouble}, \texttt{tripledouble}, \texttt{single}, \texttt{halfprecision}, \texttt{quad}, \texttt{doubleextended}, \texttt{floor}, \texttt{ceil}, \texttt{nearestint} are not supported by \texttt{implementconstant}. If \texttt{implementconstant} encounters one of them, a warning message is displayed and no code is produced. However, if \texttt{autosimplify} equals on, it is possible that \texttt{Sollya} silently simplifies subexpressions of \( expr \) containing such functions and that \texttt{implementconstant} successfully produces code for evaluating \( expr \).

• While it produces an MPFR-based C source code for \( expr \), \texttt{implementconstant} takes architectural and system-dependent parameters into account. For example, it checks whether literal constants figuring in \( expr \) can be represented on a C \texttt{long int} type or if they must be stored in a different manner not to affect their accuracy. These tests, performed by \texttt{Sollya} during execution of \texttt{implementconstant}, depend themselves on the architecture \texttt{Sollya} is running on. Users should keep this matter in mind, especially when trying to compile source code on one machine whilst it has been produced on another.

Example 1:
void const_something (mpfr_ptr y, mp_prec_t prec)
{
    /* Declarations */
    mpfr_t tmp1;
    mpfr_t tmp2;
    mpfr_t tmp3;
    mpfr_t tmp4;
    mpfr_t tmp5;
    mpfr_t tmp6;
    mpfr_t tmp7;

    /* Initializations */
    mpfr_init2 (tmp2, prec+5);
    mpfr_init2 (tmp1, prec+3);
    mpfr_init2 (tmp4, prec+8);
    mpfr_init2 (tmp3, prec+7);
    mpfr_init2 (tmp6, prec+11);
    mpfr_init2 (tmp7, prec+11);
    mpfr_init2 (tmp5, prec+11);

    /* Core */
    mpfr_set_prec (tmp2, prec+4);
    mpfr_set_ui (tmp2, 1, MPFR_RNDN);
    mpfr_set_prec (tmp1, prec+3);
    mpfr_exp (tmp1, tmp2, MPFR_RNDN);
    mpfr_set_prec (tmp4, prec+8);
    mpfr_set_ui (tmp4, 2, MPFR_RNDN);
    mpfr_set_prec (tmp3, prec+7);
    mpfr_log (tmp3, tmp4, MPFR_RNDN);
    mpfr_set_prec (tmp6, prec+11);
    mpfr_set_ui (tmp6, 1, MPFR_RNDN);
    mpfr_set_prec (tmp7, prec+11);
    mpfr_set_prec (tmp5, prec+11);
    mpfr_div (tmp5, tmp6, tmp7, MPFR_RNDN);
    mpfr_set_prec (tmp4, prec+7);
    mpfr_set_prec (tmp2, prec+5);
    mpfr_div (tmp2, tmp3, tmp4, MPFR_RNDN);
    mpfr_set_prec (y, prec+3);
    mpfr_add (y, tmp1, tmp2, MPFR_RNDN);

    /* Cleaning stuff */
    mpfr_clear(tmp1);
    mpfr_clear(tmp2);
    mpfr_clear(tmp3);
    mpfr_clear(tmp4);
}
Example 2:

```c
#include <mpfr.h>

void const_something (mpfr_ptr y, mp_prec_t prec)
{
    /* Declarations */
    mpfr_t tmp1;
    mpfr_t tmp2;
    mpfr_t tmp3;

    /* Initializations */
    mpfr_init2 (tmp2, prec+6);
    mpfr_init2 (tmp3, prec+6);
    mpfr_init2 (tmp1, prec+6);

    /* Core */
    mpfr_set_prec (tmp2, prec+6);
    mpfr_set_ui (tmp2, 13, MPFR_RNDN);
    mpfr_set_prec (tmp3, prec+6);
    mpfr_set_ui (tmp3, 17, MPFR_RNDN);
    mpfr_set_prec (tmp1, prec+6);
    mpfr_div (tmp1, tmp2, tmp3, MPFR_RNDN);
    mpfr_set_prec (y, prec+2);
    mpfr_sin (y, tmp1, MPFR_RNDN);

    /* Cleaning stuff */
    mpfr_clear(tmp1);
    mpfr_clear(tmp2);
    mpfr_clear(tmp3);
}
```

Example 3:
> implementconstant(asin(1/3 * pi),default,"arcsin_of_one_third_pi");

modify or redistribute this generated code itself, or its skeleton, you may (at your option) remove this special exception, which will cause this generated code and its skeleton and the resulting Sollya output files to be licensed under the CeCILL-C licence without this special exception.

This special exception was added by the Sollya copyright holders in version 4.1 of Sollya.

*/

#include <mpfr.h>

void arcsin_of_one_third_pi (mpfr_ptr y, mp_prec_t prec)
{
    /* Declarations */
    mpfr_t tmp1;
    mpfr_t tmp2;
    mpfr_t tmp3;

    /* Initializations */
    mpfr_init2 (tmp2, prec+8);
    mpfr_init2 (tmp3, prec+8);
    mpfr_init2 (tmp1, prec+8);

    /* Core */
    mpfr_set_prec (tmp2, prec+8);
    mpfr_const_pi (tmp2, MPFR_RNDN);
    mpfr_set_prec (tmp3, prec+8);
    mpfr_set_ui (tmp3, 3, MPFR_RNDN);
    mpfr_set_prec (tmp1, prec+8);
    mpfr_div (tmp1, tmp2, tmp3, MPFR_RNDN);
    mpfr_set_prec (y, prec+2);
    mpfr_asin (y, tmp1, MPFR_RNDN);

    /* Cleaning stuff */
    mpfr_clear(tmp1);
    mpfr_clear(tmp2);
    mpfr_clear(tmp3);
}

Example 4:
Example 5:

```c
> bashexecute("gcc -fPIC -Wall -c libraryconstantexample.c -I$HOME/.local/include");
> bashexecute("gcc -shared -o libraryconstantexample libraryconstantexample.o -l
  gmp -lmpfr");
> euler_gamma = libraryconstant("./libraryconstantexample");
> implementconstant(euler_gamma^(1/3), "euler.c");
> bashevaluate("tail -n -17 euler.c");

void const_something (mpfr_ptr y, mp_prec_t prec)
{
    /* Declarations */
    mpfr_t tmp1;
    /* Initializations */
    mpfr_init2 (tmp1, prec+1);
    /* Core */
    euler_gamma (tmp1, prec+1);
    mpfr_set_prec (y, prec+2);
    mpfr_root (y, tmp1, 3, MPFR_RNDN);
    /* Cleaning stuff */
    mpfr_clear(tmp1);
}
```

See also: implementpoly (8.88), libraryconstant (8.99), library (8.98), function (8.73), bashevaluate (8.17)

### 8.88 implementpoly

**Name:** implementpoly

- implements a polynomial using double, double-double and triple-double arithmetic and generates a Gappa proof

**Library names:**

```c
sollya_obj_t sollya_lib_implementpoly(sollya_obj_t, sollya_obj_t,
  sollya_obj_t, sollya_obj_t,
  sollya_obj_t, sollya_obj_t, ...)
```

```c
sollya_obj_t sollya_lib_v_implementpoly(sollya_obj_t, sollya_obj_t,
  sollya_obj_t, sollya_obj_t,
  sollya_obj_t, sollya_obj_t, va_list)
```

**Usage:**

```c
```
implementpoly\((\text{polynomial}, \text{range}, \text{error bound}, \text{format}, \text{functionname}, \text{filen}\text{ame})\) : (function, range, constant, D|double|DD|doubledouble|TD|tripledouble, string, string) → function

\textbf{implementpoly} (\texttt{polynomial}, \texttt{range}, \texttt{error bound}, \texttt{format}, \texttt{functionname}, \texttt{filename}, honor coefficient precisions) : (function, range, constant, D|double|DD|doubledouble|TD|tripledouble, string, string, honorcoeffprec) → function

\textbf{implementpoly} (\texttt{polynomial}, \texttt{range}, \texttt{error bound}, \texttt{format}, \texttt{functionname}, \texttt{filename}, proof filename) : (function, range, constant, D|double|DD|doubledouble|TD|tripledouble, string, string, proof filename) → function

\textbf{implementpoly} (\texttt{polynomial}, \texttt{range}, \texttt{error bound}, \texttt{format}, \texttt{functionname}, \texttt{filename}, honor coefficient precisions, proof filename) : (function, range, constant, D|double|DD|doubledouble|TD|tripledouble, string, string, honorcoeffprec, string) → function

Description:

- The command \textbf{implementpoly} implements the polynomial \texttt{polynomial} in range \texttt{range} as a function called \texttt{functionname} in C code using double, double-double and triple-double arithmetic in a way that the rounding error (estimated at its first order) is bounded by \texttt{error bound}. The produced code is output in a file named \texttt{filename}. The argument \texttt{format} indicates the double, double-double or triple-double format of the variable in which the polynomial varies, influencing also in the signature of the C function.

If a seventh or eighth argument \texttt{proof filename} is given and if this argument evaluates to a variable of type \texttt{string}, the command \textbf{implementpoly} will produce a \texttt{Gappa} proof that the rounding error is less than the given bound. This proof will be output in \texttt{Gappa} syntax in a file name \texttt{proof filename}.

The command \textbf{implementpoly} returns the polynomial that has been implemented. As the command \textbf{implementpoly} tries to adapt the precision needed in each evaluation step to its strict minimum and as it applies renormalization to double-double and triple-double precision coefficients to bring them to a round-to-nearest expansion form, the returned polynomial may differ from the polynomial \texttt{polynomial}. Nevertheless the difference will be small enough that the rounding error bound with regard to the polynomial \texttt{polynomial} (estimated at its first order) will be less than the given error bound.

If a seventh argument \texttt{honor coefficient precisions} is given and evaluates to a variable \texttt{honorcoeffprec}, \textbf{implementpoly} will honor the precision of the given polynomial \texttt{polynomials}. This means if a coefficient needs a double-double or a triple-double to be exactly stored, \textbf{implementpoly} will allocate appropriate space and use a double-double or triple-double operation even if the automatic (heuristic) determination implemented in command \textbf{implementpoly} indicates that the coefficient could be stored on less precision or, respectively, the operation could be performed with less precision. The use of \texttt{honorcoeffprec} has advantages and disadvantages. If the polynomial \texttt{polynomial} given has not been determined by a process considering directly polynomials with floating-point coefficients, \texttt{honorcoeffprec} should not be indicated. The \textbf{implementpoly} command can then determine the needed precision using the same error estimation as used for the determination of the precisions of the operations. Generally, the coefficients will get rounded to double, double-double and triple-double precision in a way that minimizes their number and respects the rounding error bound \texttt{error bound}. Indicating \texttt{honorcoeffprec} may in this case short-circuit most precision estimations leading to sub-optimal code. On the other hand, if the polynomial \texttt{polynomial} has been determined with floating-point precisions in mind, \texttt{honorcoeffprec} should be indicated because such polynomials often are very sensitive in terms of error propagation with regard to their coefficients' values. Indicating \texttt{honorcoeffprec} prevents the \textbf{implementpoly} command from rounding the coefficients and altering by many orders of magnitude the approximation error of the polynomial with regard to the function it approximates.

The implementer behind the \textbf{implementpoly} command makes some assumptions on its input and verifies them. If some assumption cannot be verified, the implementation will not succeed and \textbf{implementpoly} will evaluate to a variable \texttt{error} of type \texttt{error}. The same behaviour is observed if some file is not writable or some other side-effect fails, e.g. if the implementer runs out of memory. As error estimation is performed only on the first order, the code produced by the \textbf{implementpoly} command should be considered valid iff a \texttt{Gappa} proof has been produced and successfully run in \texttt{Gappa}.
Example 1:

```c
void p(double *p_resh, double x) {
    double p_x_0_pow2h;
    p_x_0_pow2h = x * x;

    double p_t_1_0h;
    double p_t_2_0h;
    double p_t_3_0h;
    double p_t_4_0h;
    double p_t_5_0h;

    p_t_1_0h = p_coeff_4h;
    p_t_2_0h = p_t_1_0h * p_x_0_pow2h;
    p_t_3_0h = p_coeff_2h + p_t_2_0h;
    p_t_4_0h = p_t_3_0h * p_x_0_pow2h;
    p_t_5_0h = p_coeff_0h + p_t_4_0h;
    *p_resh = p_t_5_0h;
}
```

Example 2:

```c
> implementpoly(1 - 1/6 * x^2 + 1/120 * x^4, [-1b-10;1b-10], 1b-30, D, "p","implementation.c","implementation.gappa");
1 + x^2 * (-0.166666666666666657414808128123695496469736099243164 + x^2 * 8.333333333333332176851016015461937058717012405396e-3)
```

Example 3:

```c
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```
> verbosity = 1!
> q = implementpoly(1 - dirtysimplify(TD(1/6)) * x^2, [-1b-10;1b-10], 1b-60, DD, "p",
"implementation.c")
Warning: at least one of the coefficients of the given polynomial has been round
ed in a way
that the target precision can be achieved at lower cost. Nevertheless, the imple-
mented polynomial
is different from the given one.
> printexpansion(q);
0x3ff0000000000000 + x^2 * 0xbfc5555555555555
> r = implementpoly(1 - dirtysimplify(TD(1/6)) * x^2, [-1b-10;1b-10], 1b-60, DD, "p",
"implementation.c", honorcoeffprec);
Warning: the inferred precision of the 2th coefficient of the polynomial is grea-
ter than
the necessary precision computed for this step. This may make the automatic dete-
rmination
of precisions useless.
> printexpansion(r);
0x3ff0000000000000 + x^2 * (0xbfc5555555555555 + 0xbc65555555555555 + 0xb9055555555555555)

Example 4:
> p = 0x3ff0000000000000 + x * (0x3ff0000000000000 + x * (0x3fe0000000000000 + x
* (0x3fc5555555555559 + x * (0x3fa55555555555bd + x * (0x3f81111111106e2 + x
* (0x3f56c16c16bf5eb7 + x * (0x3f2a01a01a292ddc + x * (0x3ef0a01a0218a016a + x
* (0x3ec71de360331aad + x * (0x3e927e42e3823bf3 + x * (0x3e5ae6b2710c2c9a + x
* (0x3e2203730c0a7c1d + x * 0x3de5da557e0781df))))))))));
> q = implementpoly(p, [-1/2;1/2], 1b-60, D, "p", "implementation.c", honorcoeffprec,
implementation.gappa);
> if (q != p) then print("During implementation, rounding has happened.") else pr
int("Polynomial implemented as given.");
Polynomial implemented as given.

See also: honorcoeffprec [8.83], roundcoefficients [8.162], double [8.49], doubledouble [8.50],
tripledouble [8.191], bashevaluate [8.17], printexpansion [8.140], error [8.56], remez [8.155],
fpminimax [8.71], taylor [8.185], implementconstant [8.87]

8.89 in

Name: in

containment test operator

Library name:
sollya_obj_t sollya_lib_cmp_in(sollya_obj_t, sollya_obj_t)

Usage:

expr in range1 : (constant, range) → boolean
range1 in range2 : (range, range) → boolean

Parameters:

- *expr* represents a constant expression

- *range1* and *range2* represent ranges (intervals)

Description:

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• When its first operand is a constant expression \( expr \), the operator \( \text{in} \) evaluates to true iff the constant value of the expression \( expr \) is contained in the interval \( range_1 \).

• When both its operands are ranges (intervals), the operator \( \text{in} \) evaluates to true iff all values in \( range_1 \) are contained in the interval \( range_2 \).

• \( \text{in} \) is also used as a keyword for loops over the different elements of a list.

Example 1:

```
> 5 in [-4;7];
true
> 4 in [-1;1];
false
> 0 in sin([-17;17]);
true
```

Example 2:

```
> [5;7] in [2;8];
true
> [2;3] in [4;5];
false
> [2;3] in [2.5;5];
false
```

Example 3:

```
> for i in [|1,...,5|] do print(i);
1
2
3
4
5
```

See also: \( == \) (8.53), \( != \) (8.115), \( >= \) (8.75), \( > \) (8.78), \( <= \) (8.96), \( < \) (8.105), \( ! \) (8.117), \( && \) (8.60), \( || \) (8.124), \( prec \) (8.135), \( print \) (8.138)

8.90 inf

Name: \( \text{inf} \)

gives the lower bound of an interval.

Library name:

\( \text{sollya_obj_t sollya_lib_inf(sollya_obj_t)} \)

Usage:

\[
\text{inf}(I) : \text{range} \rightarrow \text{constant}
\]
\[
\text{inf}(x) : \text{constant} \rightarrow \text{constant}
\]

Parameters:

• \( I \) is an interval.

• \( x \) is a real number.

Description:

• Returns the lower bound of the interval \( I \). Each bound of an interval has its own precision, so this command is exact, even if the current precision is too small to represent the bound.
When called on a real number \( x \), \( \inf \) behaves like the identity.

Example 1:

\[
\begin{align*}
&> \inf([1;3]); \\
&1 \\
&> \inf(0); \\
&0
\end{align*}
\]

Example 2:

\[
\begin{align*}
&> \text{display=binary!;} \\
&> I=[0.111110000011111_2; 1]; \\
&> \inf(I); \\
&1.11110000011111_2 * 2^{(-1)} \\
&> \text{prec=12!;} \\
&> \inf(I); \\
&1.11110000011111_2 * 2^{(-1)}
\end{align*}
\]

See also: \texttt{mid [8.108], sup [8.179], max [8.107], min [8.110]}

8.91 \texttt{infnorm}

Name: \texttt{infnorm}

computes an interval bounding the infinity norm of a function on an interval.

Library names:

\[
sollya\_obj\_t\ sollya\_lib\_infnorm(sollya\_obj\_t, sollya\_obj\_t, \ldots) \\
sollya\_obj\_t\ sollya\_lib\_v\_infnorm(sollya\_obj\_t, sollya\_obj\_t, va\_list)
\]

Usage:

\[
\texttt{infnorm}(f,I,\text{filename},Ilist) : (\text{function}, \text{range}, \text{string}, \text{list}) \to \text{range}
\]

Parameters:

- \( f \) is a function.
- \( I \) is an interval.
- \texttt{filename} (optional) is the name of the file into a proof will be saved.
- \( IList \) (optional) is a list of intervals to be excluded.

Description:

- \texttt{infnorm}(f,range) computes an interval bounding the infinity norm of the given function \( f \) on the interval \( I \), e.g. computes an interval \( J \) such that \( \max_{x \in I} \{|f(x)|\} \subseteq J \).
- If \texttt{filename} is given, a proof in English will be produced (and stored in file called \texttt{filename}) proving that \( \max_{x \in I} \{|f(x)|\} \subseteq J \).
- If a list \( IList \) of intervals \( I_1, \ldots, I_n \) is given, the infinity norm will be computed on \( I \setminus (I_1 \cup \ldots \cup I_n) \).
- The function \( f \) is assumed to be at least twice continuous on \( I \). More generally, if \( f \) is \( C^k \), global variables \texttt{hopitalrecursions} and \texttt{taylorrecursions} must have values not greater than \( k \).
- If the interval is reduced to a single point, the result of \texttt{infnorm} is an interval containing the exact absolute value of \( f \) at this point.
- If the interval is not bound, the result will be \([0, +\infty]\) which is correct but perfectly useless. \texttt{infnorm} is not meant to be used with infinite intervals.
• The result of this command depends on the global variables \texttt{prec}, \texttt{diam}, \texttt{taylorrecursions} and \texttt{hopitalrecursions}. The contribution of each variable is not easy even to analyse.

  – The algorithm uses interval arithmetic with precision \texttt{prec}. The precision should thus be set high enough to ensure that no critical cancellation will occur.

  – When an evaluation is performed on an interval $[a, b]$, if the result is considered being too large, the interval is split into $[a, \frac{a+b}{2}]$ and $[\frac{a+b}{2}, b]$ and so on recursively. This recursion step is not performed if the $(b - a) < \delta \cdot |I|$ where $\delta$ is the value of variable \texttt{diam}. In other words, \texttt{diam} controls the minimum length of an interval during the algorithm.

  – To perform the evaluation of a function on an interval, Taylor’s rule is applied, e.g. $f([a, b]) \subseteq f(m) + [a - m, b - m] \cdot f'([a, b])$ where $m = \frac{a+b}{2}$. This rule is recursively applied $n$ times where $n$ is the value of variable \texttt{taylorrecursions}. Roughly speaking, the evaluations will avoid decorrelation up to order $n$.

  – When a function of the form $\frac{g}{h}$ has to be evaluated on an interval $[a, b]$ and when $g$ and $h$ vanish at a same point $z$ of the interval, the ratio may be defined even if the expression $\frac{g(z)}{h(z)} = 0$ does not make any sense. In this case, L’Hopital’s rule may be used and $\left(\frac{g}{h}\right)([a, b]) \subseteq \left(\frac{g'}{h'}\right)([a, b])$.

Since the same can occur with the ratio $\frac{g'}{h'}$, the rule is applied recursively. The variable \texttt{hopitalrecursions} controls the number of recursion steps.

• The algorithm used for this command is quite complex to be explained here. Please find a complete description in the following article:

S. Chevillard and C. Lauter
A certified infinity norm for the implementation of elementary functions
LIP Research Report number RR2007-26
http://prunel.ccsd.cnrs.fr/ensl-00119810

• Users should be aware about the fact that the algorithm behind \texttt{infnorm} is inefficient in most cases and that other, better suited algorithms, such as \texttt{supnorm}, are available inside \texttt{Sollya}. As a matter of fact, while \texttt{infnorm} is maintained for compatibility reasons with legacy \texttt{Sollya} codes, users are advised to avoid using \texttt{infnorm} in new \texttt{Sollya} scripts and to replace it, where possible, by the \texttt{supnorm} command.

Example 1:

```plaintext
> infnorm(exp(x),[-2;3]);
[20.08553692318766774092852965481717896987907838554;20.085536923187667740928529654817178969879078385544]
```

Example 2:

```plaintext
> infnorm(exp(x),[-2;3],"proof.txt");
[20.08553692318766774092852965481717896987907838554;20.085536923187667740928529654817178969879078385544]
```

Example 3:

```plaintext
> infnorm(exp(x),[-2;3],[1 \ 0.1, \ [2;2.5] \ ]);
[20.08553692318766774092852965481717896987907838554;20.085536923187667740928529654817178969879078385544]
```

Example 4:

```plaintext
> infnorm(exp(x),[-2;3],"proof.txt", [1 \ 0.1, \ [2;2.5] \ ]);
[20.08553692318766774092852965481717896987907838554;20.085536923187667740928529654817178969879078385544]
```

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Example 5:

```
> infnorm(exp(x), [1;1]);
[2.7182818284590452353602874713526624977572470936999;2.7182818284590452353602874713526624977572470937]
```

Example 6:

```
> infnorm(exp(x), [log(0);log(1)]);
[0;infty]
```

See also: prec (8.135), diam (8.39), hopitalrecursions (8.84), taylorrecursions (8.187), dirty-infnorm (8.43), checkinfnorm (8.25), supnorm (8.180), findzeros (8.67), diff (8.41), taylorrecursions (8.187), autodiff (8.15), numberroots (8.118), taylorform (8.186)

8.92 integer

Name: integer  
keyword representing a machine integer type

Library name: 
SOLLYA_EXTERNALPROC_TYPE_INTEGER

Usage:

```
integer : type type
```

Description:

- integer represents the machine integer type for declarations of external procedures externalproc.
  
Remark that in contrast to other indicators, type indicators like integer cannot be handled outside the externalproc context. In particular, they cannot be assigned to variables.

See also: externalproc (8.64), boolean (8.21), constant (8.29), function (8.73), list of (8.100), range (8.148), string (8.170), object (8.120)

8.93 integral

Name: integral  
computes an interval bounding the integral of a function on an interval.

Library name: 
sollya_obj_t sollya_lib_integral(sollya_obj_t, sollya_obj_t)

Usage:

```
integral(f, I) : (function, range) \rightarrow range
```

Parameters:

- f is a function.
- I is an interval.

Description:

- integral(f, I) returns an interval J such that the exact value of the integral of f on I lies in J.
- This command is safe but very inefficient. Use dirtyintegral if you just want an approximate value.
The result of this command depends on the global variable \texttt{diam}. The method used is the following: \( I \) is cut into intervals of length not greater than \( \delta \cdot |I| \) where \( \delta \) is the value of global variable \texttt{diam}. On each small interval \( J \), an evaluation of \( f \) by interval is performed. The result is multiplied by the length of \( J \). Finally all values are summed.

Example 1:

```plaintext
> sin(10);
-0.54402111088936981340474766185137728168364301291622
> integral(cos(x),[0;10]);
[-0.54710197983579690224097637163525943075698599257333;-0.540940151301183848150540881373370744053741191729]
> diam=1e-5;
> integral(cos(x),[0;10]);
[-0.54432915685955427101857780295936956775293876382777;-0.54371306401249969508039644221927489010425803173555]
```

See also: \texttt{diam} (8.39), \texttt{dirtyintegral} (8.44), \texttt{prec} (8.135)

### 8.94 \texttt{isbound}

**Name:** \texttt{isbound} 
indicates whether a variable is bound or not.

**Usage:**

```plaintext
\texttt{isbound(ident)} : boolean
```

**Parameters:**

- \texttt{ident} is a name.

**Description:**

- \texttt{isbound(ident)} returns a boolean value indicating whether the name \texttt{ident} is used or not to represent a variable. It returns true when \texttt{ident} is the name used to represent the global variable or if the name is currently used to refer to a (possibly local) variable.

- When a variable is defined in a block and has not been defined outside, \texttt{isbound} returns true when called inside the block, and false outside. Note that \texttt{isbound} returns true as soon as a variable has been declared with \texttt{var}, even if no value is actually stored in it.

- If \texttt{ident1} is bound to a variable and if \texttt{ident2} refers to the global variable, the command \texttt{rename(}\texttt{ident2, ident1}) hides the value of \texttt{ident1} which becomes the global variable. However, if the global variable is again renamed, \texttt{ident1} gets its value back. In this case, \texttt{isbound(}\texttt{ident1}) returns true. If \texttt{ident1} was not bound before, \texttt{isbound(}\texttt{ident1}) returns false after that \texttt{ident1} has been renamed.

**Example 1:**

```plaintext
> isbound(x);
false
> isbound(f);
false
> isbound(g);
false
> f=sin(x);
> isbound(x);
true
> isbound(f);
true
> isbound(g);
false
```
Example 2:

```plaintext
> isbound(a);
false
> { var a; isbound(a); }
true
> isbound(a);
false
```

Example 3:

```plaintext
> f=sin(x);
> isbound(x);
true
> rename(x,y);
> isbound(x);
false
```

Example 4:

```plaintext
> x=1;
> f=sin(y);
> rename(y,x);
> f;
sin(x)
> x;
x
> isbound(x);
true
> rename(x,y);
> isbound(x);
true
> x;
1
```

See also: `rename` [8.156]

8.95 `isevaluable`

Name: `isevaluable`

tests whether a function can be evaluated at a point

Usage:

```
isevaluable(function, constant) : (function, constant) → boolean
```

Parameters:

- `function` represents a function
- `constant` represents a constant point

Description:

- `isevaluable` applied to function `function` and a constant `constant` returns a boolean indicating whether or not a subsequent call to `evaluate` on the same function `function` and constant `constant` will produce a numerical result or NaN. This means `isevaluable` returns false iff `evaluate` will return NaN.
• The command `isevaluable` is now considered DEPRECATED in Sollya. As checks for NaNs are now possible in Sollya, the command `isevaluable` can be fully emulated with a call to `evaluate` and a couple of tests, as shown below in the last example.

Example 1:

```
> isevaluable(sin(pi * log(x)), 0.5);
true
> print(evaluate(sin(pi * log(x)), 0.5));
-0.82148283122563882875872566228649962370813607461095
```

Example 2:

```
> isevaluable(sin(pi * log(x)), 0);
true
> print(evaluate(sin(pi * log(x)), 0));
[-1;1]
```

Example 3:

```
> isevaluable(sin(pi * 1/x), 0.5);
true
> print(evaluate(sin(pi * 1/x), 0.5));
[-3.100365765139897619749121887390789523854170596558e-13490;5.3002401585857127605350842426029223241500776302528e-13489]
```

Example 4:

```
> procedure isEvaluableEmulation(f, c) {
    return match evaluate(f, c) with
    NaN : (false)
    [NaN;NaN] : (false)
    default : (true);
};
> isEvaluableEmulation(sin(pi * log(x)), 0.5);
true
> isEvaluableEmulation(sin(pi * log(x)), 0);
true
> isEvaluableEmulation(sin(pi * log(x)), -1);
false
```

See also: `evaluate` [8.57]

### 8.96 \(<=\)

**Name:** \(<=\)

- less-than-or-equal-to operator

**Library name:**

`sollya_obj_t sollya_lib_cmp_less_equal(sollya_obj_t, sollya_obj_t)`

**Usage:**

\[
expr1 <= expr2 : (constant, constant) \rightarrow boolean
\]

**Parameters:**

- \(expr1\) and \(expr2\) represent constant expressions

**Description:**

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• The operator $\leq$ evaluates to true iff its operands $expr1$ and $expr2$ evaluate to two floating-point numbers $a_1$ respectively $a_2$ with the global precision $\text{prec}$ and $a_1$ is less than or equal to $a_2$. The user should be aware of the fact that because of floating-point evaluation, the operator $\leq$ is not exactly the same as the mathematical operation less-than-or-equal-to.

Example 1:

```plaintext
> 5 <= 4;
false
> 5 <= 5;
true
> 5 <= 6;
true
> exp(2) <= exp(1);
false
> log(1) <= exp(2);
true
```

Example 2:

```plaintext
> prec = 12;
The precision has been set to 12 bits.
> 16385.1 <= 16384.1;
true
```

See also: $==$ (8.53), $!=$ (8.115), $>$ (8.75), $>$= (8.78), $<$ (8.105), $\text{in}$ (8.89), $!$ (8.117), $&&$ (8.6), $||$ (8.124), $\text{prec}$ (8.135), $\text{max}$ (8.107), $\text{min}$ (8.110)

8.97  length

Name: length

computes the length of a list or string.

Library name:

```
  sollya_obj_t sollya_lib_length(sollya_obj_t)
```

Usage:

```
  length(L) : list → integer
  length(s) : string → integer
```

Parameters:

• $L$ is a list.

• $s$ is a string.

Description:

• length returns the length of a list or a string, e.g. the number of elements or letters.

• The empty list or string have length 0. If $L$ is an end-elliptic list, length returns $+\text{Inf}$.

Example 1:

```plaintext
> length("Hello World!");
12
```

Example 2:

```plaintext
> length([[1, ..., 5]]);
5
```
8.98 library

Name: library

binds an external mathematical function to a variable in Sollya

Library names:

- `sollya_obj_t sollya_lib_libraryfunction(sollya_obj_t, char *, int (*)(mpfi_t, mpfi_t, int))`
- `sollya_obj_t sollya_lib_build_function_libraryfunction(sollya_obj_t, char *, int (*)(mpfi_t, mpfi_t, int))`
- `sollya_obj_t sollya_lib_libraryfunction_with_data(sollya_obj_t, char *, int (*)(mpfi_t, mpfi_t, int, void *), void *, void (*)(void *))`
- `sollya_obj_t sollya_lib_build_function_libraryfunction_with_data(sollya_obj_t, char *, int (*)(mpfi_t, mpfi_t, int, void *), void *, void (*)(void *))`

Usage:

```
library(path) : string → function
```

Description:

- The command library lets you extend the set of mathematical functions known to Sollya. By default, Sollya knows the most common mathematical functions such as `exp`, `sin`, `erf`, etc. Within Sollya, these functions may be composed. This way, Sollya should satisfy the needs of a lot of users. However, for particular applications, one may want to manipulate other functions such as Bessel functions, or functions defined by an integral or even a particular solution of an ODE.
- library makes it possible to let Sollya know about new functions. In order to let it know, you have to provide an implementation of the function you are interested in. This implementation is a C file containing a function of the form:

  ```c
  int my_ident(sollya_mpfi_t result, sollya_mpfi_t op, int n)
  ```

  The semantic of this function is the following: it is an implementation of the function and its derivatives in interval arithmetic. my_ident(result, I, n) shall store in result an enclosure of the image set of the n-th derivative of the function f over I: f^{(n)}(I) ⊆ result.
- The integer value returned by the function implementation currently has no meaning.
- You do not need to provide a working implementation for any n. Most functions of Sollya requires a relevant implementation only for f, f' and f''. For higher derivatives, its is not so critical and the implementation may just store [−∞, +∞] in result whenever n > 2.
• Note that you should respect somehow interval-arithmetic standards in your implementation: result has its own precision and you should perform the intermediate computations so that result is as tight as possible.

• You can include sollya.h in your implementation and use library functionalities of Sollya for your implementation. However, this requires to have compiled Sollya with -fPIC in order to make the Sollya executable code position independent and to use a system on with programs, using dlopen to open dynamic routines can dynamically open themselves. Important notice: as the code will be run in a context where a sollya session is already opened, the library functions must be used directly, without calling sollya_lib_init and sollya_lib_close (calling these functions would conflict with the current session, leading to weird and hard to debug behaviors).

• To bind your function into Sollya, you must use the same identifier as the function name used in your implementation file (my_ident in the previous example). Once the function code has been bound to an identifier, you can use a simple assignment to assign the bound identifier to yet another identifier. This way, you may use convenient names inside Sollya even if your implementation environment requires you to use a less convenient name.

• The dynamic object file whose name is given to library for binding of an external library function may also define a destructor function int sollya_external_lib_close(void). If Sollya finds such a destructor function in the dynamic object file, it will call that function when closing the dynamic object file again. This happens when Sollya is terminated or when the current Sollya session is restarted using restart. The purpose of the destructor function is to allow the dynamically bound code to free any memory that it might have allocated before Sollya is terminated or restarted. The dynamic object file is not necessarily needed to define a destructor function. This ensure backward compatibility with older Sollya external library function object files. When defined, the destructor function is supposed to return an integer value indicating if an error has happened. Upon success, the destructor functions is to return a zero value, upon error a non-zero value.

Example 1:

```bash
> bashexecute("gcc -fPIC -Wall -c libraryexample.c -I$HOME/.local/include");
> bashexecute("gcc -shared -o libraryexample libraryexample.o -lgmp -lmpr");
> myownlog = library("./libraryexample");
> evaluate(log(x), 2);
0.69314718055994530941723212145817556807550013436025
> evaluate(myownlog(x), 2);
0.69314718055994530941723212145817556807550013436025
```

See also: function (8.73), bashexecute (8.18), externalproc (8.64), externalplot (8.63), diff (8.41), evaluate (8.57), libraryconstant (8.99)

8.99 libraryconstant

Name: libraryconstant

binds an external mathematical constant to a variable in Sollya

Library names:

```c
sollya_obj_t sollya_lib_libraryconstant(char *, void (*)(mpfr_t, mp_prec_t))

sollya_obj_t sollya_lib_build_function_libraryconstant(char *,
    void (*)(mpfr_t,
    mp_prec_t))

sollya_obj_t sollya_lib_libraryconstant_with_data(char *,
    void (*)(mpfr_t,
    mp_prec_t,
    void *),
    void *,
```
void (*)(void *))
sollya_obj_t sollya_lib_build_function_libraryconstant_with_data(
  char *,
  void (*)(mpfr_t,
          mp_prec_t,
          void *),
  void *,
  void (*)(void *))

Usage:

  libraryconstant(path) : string → function

Description:

- The command libraryconstant lets you extend the set of mathematical constants known to Sollya. By default, the only mathematical constant known by Sollya is pi. For particular applications, one may want to manipulate other constants, such as Euler's gamma constant, for instance.

- libraryconstant makes it possible to let Sollya know about new constants. In order to let it know, you have to provide an implementation of the constant you are interested in. This implementation is a C file containing a function of the form:

  void my_ident(mpfr_t result, mp_prec_t prec)

The semantic of this function is the following: it is an implementation of the constant in arbitrary precision. my_ident(result, prec) shall set the precision of the variable result to a suitable precision (the variable is assumed to be already initialized) and store in result an approximate value of the constant with a relative error not greater than $2^{1-\text{prec}}$. More precisely, if $c$ is the exact value of the constant, the value stored in result should satisfy

  $|\text{result} - c| \leq |c| 2^{1-\text{prec}}$.

- You can include sollya.h in your implementation and use library functionalities of Sollya for your implementation. However, this requires to have compiled Sollya with -fPIC in order to make the Sollya executable code position independent and to use a system on with programs, using dlopen to open dynamic routines can dynamically open themselves.

- To bind your constant into Sollya, you must use the same identifier as the function name used in your implementation file (my_ident in the previous example). Once the function code has been bound to an identifier, you can use a simple assignment to assign the bound identifier to yet another identifier. This way, you may use convenient names inside Sollya even if your implementation environment requires you to use a less convenient name.

- Once your constant is bound, it is considered by Sollya as an infinitely accurate constant (i.e. a 0-ary function, exactly like pi).

- The dynamic object file whose name is given to libraryconstant for binding of an external library constant may also define a destructor function int sollya_external_lib_close(void). If Sollya finds such a destructor function in the dynamic object file, it will call that function when closing the dynamic object file again. This happens when Sollya is terminated or when the current Sollya session is restarted using restart. The purpose of the destructor function is to allow the dynamically bound code to free any memory that it might have allocated before Sollya is terminated or restarted. The dynamic object file is not necessarily needed to define a destructor function. This ensure backward compatibility with older Sollya external library function object files. When defined, the destructor function is supposed to return an integer value indicating if an error has happened. Upon success, the destructor functions is to return a zero value, upon error a non-zero value.
Example 1:

```bash
> bashexecute("gcc -fPIC -Wall -c libraryconstantexample.c -I$HOME/.local/include");
> bashexecute("gcc -shared -o libraryconstantexample libraryconstantexample.o -l
gmp -lmpfr");
> euler_gamma = libraryconstant("./libraryconstantexample");
> prec = 20!
> euler_gamma;
0.577215
> prec = 100!
> euler_gamma;
0.577215664901532860606512090082
> midpointmode = on;
Midpoint mode has been activated.
> euler_gamma;
0.57721566490153286060651209008~2/4~
```

See also: bashexecute (8.18), externalproc (8.64), externalplot (8.63), pi (8.127), library (8.98), evaluate (8.57), implementconstant (8.87)

8.100 list of

Name: list of
keyword used in combination with a type keyword

Library names:

- SOLLYA_EXTERNALPROC_TYPE_CONSTANT_LIST
- SOLLYA_EXTERNALPROC_TYPE_FUNCTION_LIST
- SOLLYA_EXTERNALPROC_TYPE_RANGE_LIST
- SOLLYA_EXTERNALPROC_TYPE_INTEGER_LIST
- SOLLYA_EXTERNALPROC_TYPE_STRING_LIST
- SOLLYA_EXTERNALPROC_TYPE_BOOLEAN_LIST
- SOLLYA_EXTERNALPROC_TYPE_OBJECT_LIST

Description:

- list of is used in combination with one of the following keywords for indicating lists of the respective type in declarations of external procedures using externalproc: boolean, constant, function, integer, range, object and string.

See also: externalproc (8.64), boolean (8.21), constant (8.29), function (8.73), integer (8.92), range (8.148), string (8.176), object (8.120)

8.101 log

Name: log
natural logarithm.

Library names:

```c
sollya_obj_t sollya_lib_log(sollya_obj_t)
sollya_obj_t sollya_lib_build_function_log(sollya_obj_t)
#define SOLLYA_LOG(x) sollya_lib_build_function_log(x)
```

Description:

- log is the natural logarithm defined as the inverse of the exponential function: \( \log(y) \) is the unique real number \( x \) such that \( \exp(x) = y \).
- It is defined only for \( y \in [0; +\infty] \).

See also: exp (8.59), log2 (8.104), log10 (8.102)
8.102 \textbf{log10}

Name: \texttt{log10}

decimal logarithm.

Library names:

\begin{verbatim}
  sollya_obj_t sollya_lib_log10(sollya_obj_t)
  sollya_obj_t sollya_lib_build_function_log10(sollya_obj_t)
  #define SOLLYA_LOG10(x) sollya_lib_build_function_log10(x)
\end{verbatim}

Description:

- \texttt{log10} is the decimal logarithm defined by: \( \log_{10}(x) = \log(x)/\log(10) \).
- It is defined only for \( x \in [0; +\infty] \).

See also: \texttt{log} (8.101), \texttt{log2} (8.104)

8.103 \textbf{log1p}

Name: \texttt{log1p}

translated logarithm.

Library names:

\begin{verbatim}
  sollya_obj_t sollya_lib_log1p(sollya_obj_t)
  sollya_obj_t sollya_lib_build_function_log1p(sollya_obj_t)
  #define SOLLYA_LOG1P(x) sollya_lib_build_function_log1p(x)
\end{verbatim}

Description:

- \texttt{log1p} is the function defined by \( \log(1 + x) \).
- It is defined only for \( x \in [-1; +\infty] \).

See also: \texttt{log} (8.101)

8.104 \textbf{log2}

Name: \texttt{log2}

binary logarithm.

Library names:

\begin{verbatim}
  sollya_obj_t sollya_lib_log2(sollya_obj_t)
  sollya_obj_t sollya_lib_build_function_log2(sollya_obj_t)
  #define SOLLYA_LOG2(x) sollya_lib_build_function_log2(x)
\end{verbatim}

Description:

- \texttt{log2} is the binary logarithm defined by: \( \log_{2}(x) = \log(x)/\log(2) \).
- It is defined only for \( x \in [0; +\infty] \).

See also: \texttt{log} (8.101), \texttt{log10} (8.102)

8.105 \textbf{<}

Name: <

less-than operator

Library name:

\begin{verbatim}
  sollya_obj_t sollya_lib_cmp_less(sollya_obj_t, sollya_obj_t)
\end{verbatim}

Usage:
expr1 < expr2 : (constant, constant) → boolean

Parameters:

- expr1 and expr2 represent constant expressions

Description:

- The operator < evaluates to true iff its operands expr1 and expr2 evaluate to two floating-point numbers \( a_1 \) respectively \( a_2 \) with the global precision prec and \( a_1 \) is less than \( a_2 \). The user should be aware of the fact that because of floating-point evaluation, the operator < is not exactly the same as the mathematical operation less-than.

Example 1:

```
> 5 < 4;
false
> 5 < 5;
false
> 5 < 6;
true
> \exp(2) < \exp(1);
false
> \log(1) < \exp(2);
true
```

Example 2:

```
> prec = 12;
The precision has been set to 12 bits.
> 16384.1 < 16385.1;
false
```

See also: == (8.53), ! (8.115), >= (8.75), > (8.78), <= (8.96), in (8.89), ! (8.117), && (8.6), || (8.124), prec (8.135), max (8.107), min (8.110)

8.106 mantissa

Name: mantissa
returns the integer mantissa of a number.

Library name:
sollya_obj_t sollya_lib_mantissa(sollya_obj_t)

Usage:

```c
mantissa(x) : constant → integer
```

Parameters:

- \( x \) is a dyadic number.

Description:

- \( \operatorname{mantissa}(x) \) is by definition \( x \) if \( x \) equals 0, NaN, or Inf.
- If \( x \) is not zero, it can be uniquely written as \( x = m \cdot 2^e \) where \( m \) is an odd integer and \( e \) is an integer. \( \operatorname{mantissa}(x) \) returns \( m \).

Example 1:
\begin{verbatim}
> a=round(Pi,20,RN);
> e=exponent(a);
> m=mantissa(a);
> m;
411775
> a-m*2^e;
0
\end{verbatim}

See also: exponent [8.62], precision [8.136]

8.107 \( \texttt{max} \)

Name: \( \texttt{max} \)

determines which of given constant expressions has maximum value

Library names:
\begin{verbatim}
sollya_obj_t sollya_lib_max(sollya_obj_t, ...)
sollya_obj_t sollya_lib_v_max(sollya_obj_t, va_list)
\end{verbatim}

Usage:
\begin{verbatim}
\texttt{max}((\texttt{expr1,expr2,...,exprn}) : (constant, constant, ..., constant) \rightarrow constant
\texttt{max}(l) : list \rightarrow constant
\end{verbatim}

Parameters:
\begin{itemize}
  \item \textit{expr} are constant expressions.
  \item \textit{l} is a list of constant expressions.
\end{itemize}

Description:
\begin{itemize}
  \item \texttt{max} determines which of a given set of constant expressions \textit{expr} has maximum value. To do so, \texttt{max} tries to increase the precision used for evaluation until it can decide the ordering or some maximum precision is reached. In the latter case, a warning is printed indicating that there might actually be another expression that has a greater value.
  \item Even though \texttt{max} determines the maximum expression by evaluation, it returns the expression that is maximum as is, i.e. as an expression tree that might be evaluated to any accuracy afterwards.
  \item \texttt{max} can be given either an arbitrary number of constant expressions in argument or a list of constant expressions. The list however must not be end-elliptic.
  \item Users should be aware that the behavior of \texttt{max} follows the IEEE 754-2008 standard with respect to NaNs. In particular, \texttt{max} evaluates to NaN if and only if all arguments of \texttt{max} are NaNs. This means that NaNs may disappear during computations.
\end{itemize}

Example 1:
\begin{verbatim}
> max(1,2,3,exp(5),log(0.25));
148.4131591025766034211558004055227962348766759388
> max(17);
17
\end{verbatim}

Example 2:
\begin{verbatim}
> l = [1,2,3,exp(5),log(0.25)];
148.4131591025766034211558004055227962348766759388
> max(l); 17
\end{verbatim}

Example 3:
Example 4:

```plaintext
> verbosity = 1!
> print(max(17 + log2(13)/log2(9),17 + log(13)/log(9)))
Warning: the tool is unable to decide a maximum computation by evaluation even though faithful evaluation of the terms has been possible. The terms will be considered to be equal.
17 + log2(13) / log2(9)
```

See also: **min** (8.110), == (8.53), != (8.115), >= (8.75), > (8.78), < (8.105), <= (8.96), in (8.89), inf (8.90), sup (8.179)

### 8.108 mid

**Name:** mid

gives the middle of an interval.

**Library name:**

```plaintext
sollya_obj_t sollya_lib_mid(sollya_obj_t)
```

**Usage:**

```plaintext
mid(I) : range → constant
mid(x) : constant → constant
```

**Parameters:**

- `I` is an interval.
- `x` is a real number.

**Description:**

- Returns the middle of the interval `I`. If the middle is not exactly representable at the current precision, the value is returned as an unevaluated expression.
- When called on a real number `x`, `mid` behaves like the identity.

**Example 1:**

```plaintext
> mid([1;3]);
2
> mid(17);
17
```

See also: **inf** (8.90), sup (8.179)

### 8.109 midpointmode

**Name:** midpointmode

global variable controlling the way intervals are displayed.

**Library names:**

```plaintext
void sollya_lib_set_midpointmode_and_print(sollya_obj_t)
void sollya_lib_set_midpointmode(sollya_obj_t)
sollya_obj_t sollya_lib_get_midpointmode()
```

**Usage:**

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\texttt{midpointmode} = \textit{activation value} : on\mid off \rightarrow \textit{void}  
\texttt{midpointmode} = \textit{activation value} ! : on\mid off \rightarrow \textit{void}  
\texttt{midpointmode} : on\mid off

Parameters:

- \textit{activation value} enables or disables the mode.

Description:

- \texttt{midpointmode} is a global variable. When its value is \texttt{off}, intervals are displayed as usual (in the form \([a;b]\)). When its value is \texttt{on}, and if \(a\) and \(b\) have the same first significant digits, the interval is displayed in a way that lets one immediately see the common digits of the two bounds.

- This mode is supported only with \texttt{display set to decimal}. In other modes of display, \texttt{midpointmode} value is simply ignored.

Example 1:

\begin{verbatim}
> a = round(Pi,30,RD);
> b = round(Pi,30,RU);
> d = [a,b];
> d;
[3.1415926516056060791015625;3.1415926553308963775634765625]
> midpointmode=on!;
> d;
0.314159265~1/6~e1
\end{verbatim}

See also: \texttt{on} \(^{(8.123)}\), \texttt{off} \(^{(8.122)}\), \texttt{roundingwarnings} \(^{(8.164)}\), \texttt{display} \(^{(8.46)}\), \texttt{decimal} \(^{(8.35)}\)

8.110 \texttt{min}

Name: \texttt{min}

determines which of given constant expressions has minimum value

Library names:

\texttt{sollya\_obj\_t sollya\_lib\_min(sollya\_obj\_t, ...)}
\texttt{sollya\_obj\_t sollya\_lib\_v\_min(sollya\_obj\_t, va\_list)}

Usage:

\texttt{min(expr1,expr2,...,exprn) : (constant, constant, ..., constant) \rightarrow constant}
\texttt{min(l) : list \rightarrow constant}

Parameters:

- \textit{expr} are constant expressions.

- \(l\) is a list of constant expressions.

Description:

- \texttt{min} determines which of a given set of constant expressions \textit{expr} has minimum value. To do so, \texttt{min} tries to increase the precision used for evaluation until it can decide the ordering or some maximum precision is reached. In the latter case, a warning is printed indicating that there might actually be another expression that has a lesser value.

- Even though \texttt{min} determines the minimum expression by evaluation, it returns the expression that is minimum as is, i.e. as an expression tree that might be evaluated to any accuracy afterwards.

- \texttt{min} can be given either an arbitrary number of constant expressions in argument or a list of constant expressions. The list however must not be end-elliptic.
• Users should be aware that the behavior of \texttt{min} follows the IEEE 754-2008 standard with respect to NaNs. In particular, \texttt{min} evaluates to NaN if and only if all arguments of \texttt{min} are NaNs. This means that NaNs may disappear during computations.

Example 1:

\begin{verbatim}
> min(1,2,3,exp(5),log(0.25));
-1.3862943611198906188344642429163531361510002687205
> min(17);
17
\end{verbatim}

Example 2:

\begin{verbatim}
> l = [1,2,3,exp(5),log(0.25)];
> min(l);
-1.3862943611198906188344642429163531361510002687205
\end{verbatim}

Example 3:

\begin{verbatim}
> print(min(exp(17),sin(62)));
\texttt{sin(62)}
\end{verbatim}

Example 4:

\begin{verbatim}
> verbosity = 1!;
> print(min(17 + log2(13)/log2(9),17 + log(13)/log(9)));
Warning: the tool is unable to decide a minimum computation by evaluation even though faithful evaluation of the terms has been possible. The terms will be considered to be equal.
17 + log(13) / log(9)
\end{verbatim}

See also: \texttt{max} (8.107), \texttt{==} (8.53), \texttt{!=} (8.115), \texttt{>=} (8.75), \texttt{>} (8.73), \texttt{<} (8.105), \texttt{<=} (8.96), \texttt{in} (8.89), \texttt{inf} (8.90), \texttt{sup} (8.179)

8.111 –

Name: –
subtraction function

Library names:

\begin{verbatim}
sollya_obj_t sollya_lib_sub(sollya_obj_t, sollya_obj_t)
sollya_obj_t sollya_lib_build_function_sub(sollya_obj_t, sollya_obj_t, sollya_obj_t)
#define SOLLYA_SUB(x,y) sollya_lib_build_function_sub((x), (y))
sollya_obj_t sollya_lib_neg(sollya_obj_t)
sollya_obj_t sollya_lib_build_function_neg(sollya_obj_t)
#define SOLLYA_NEG(x) sollya_lib_build_function_neg(x)
\end{verbatim}

Usage:

\begin{verbatim}
function1 − function2 : (function, function) → function
interval1 − interval2 : (range, range) → range
interval1 − constant : (range, constant) → range
interval1 − constant : (constant, range) → range
    − function1 : function → function
    − interval1 : range → range
\end{verbatim}

Parameters:

• \texttt{function1} and \texttt{function2} represent functions
• \textit{interval1} and \textit{interval2} represent intervals (ranges)

• \textit{constant} represents a constant or constant expression

Description:

• \textit{−} represents the subtraction (function) on reals. The expression \textit{function1} \textit{−} \textit{function2} stands for the function composed of the subtraction function and the two functions \textit{function1} and \textit{function2}, where \textit{function1} is the subtrahend and \textit{function2} the subtractor.

• \textit{−} can be used for interval arithmetic on intervals (ranges). \textit{−} will evaluate to an interval that safely encompasses all images of the subtraction function with arguments varying in the given intervals. Any combination of intervals with intervals or constants (resp. constant expressions) is supported. However, it is not possible to represent families of functions using an interval as one argument and a function (varying in the free variable) as the other one.

• \textit{−} stands also for the negation function.

Example 1:

\begin{verbatim}
> 5 - 2;
3
\end{verbatim}

Example 2:

\begin{verbatim}
> x - 2;
-2 + x
\end{verbatim}

Example 3:

\begin{verbatim}
> x - x;
0
\end{verbatim}

Example 4:

\begin{verbatim}
> diff(sin(x) - exp(x));
cos(x) - exp(x)
\end{verbatim}

Example 5:

\begin{verbatim}
> [1;2] - [3;4];
[-3;-1]
> [1;2] - 17;
[-16;-15]
> 13 - [-4;17];
[-4;17]
\end{verbatim}

Example 6:

\begin{verbatim}
> -exp(x);
-exp(x)
> -13;
-13
> -[13;17];
[-17;-13]
\end{verbatim}

See also: \[ 8.129 \], \[ 8.113 \], \[ 8.48 \], \[ 8.133 \]
8.112  mod

Name: mod
Computes the euclidian division of polynomials or numbers and returns the rest

Library name:
sollya_obj_t sollya_lib_euclidian_mod(sollya_obj_t, sollya_obj_t)

Usage:

\texttt{mod}(a, b) : (\texttt{function}, \texttt{function}) \rightarrow \texttt{function}

Parameters:

- $a$ is a constant or a polynomial.
- $b$ is a constant or a polynomial.

Description:

- \texttt{mod}(a, b) computes $a - (b \times \texttt{div}(a, b))$. In other words, it returns the remainder of the Euclidian division of $a$ by $b$.
- See \texttt{div} for subtle cases involving polynomials whose degree can not easily be computed by the tool as their leading coefficient is given as a constant expression that is mathematically zero but for which the tool is unable to detect this fact.

Example 1:

\begin{verbatim}
> mod(1001, 231);
 77
> mod(13, 17);
 13
> mod(-14, 15); 1
> mod(-213, -5);
-3
> print(mod(23/13, 11/17));
105 / 221
> print(mod(exp(13), -sin(17)));
exp(13) + 460177 * sin(17)
\end{verbatim}

Example 2:

\begin{verbatim}
> mod(24 + 68 * x + 74 * x^2 + 39 * x^3 + 10 * x^4 + x^5, 4 + 4 * x + x^2);
0
> mod(24 + 68 * x + 74 * x^2 + 39 * x^3 + 10 * x^4 + x^5, 2 * x^3);
24 + x * (68 + x * 74)
> mod(x^2, x^3);
x^2
\end{verbatim}

Example 3:

\begin{verbatim}
> mod(exp(x), x^2);
exp(x)
> mod(x^3, sin(x));
x^3
\end{verbatim}

See also: gcd 8.74, div 8.47, numberroots 8.118
8.113  *

Name:  *  
multiplication function

Library names:
- `sollya_obj_t sollya_lib_mul(sollya_obj_t, sollya_obj_t)`
- `sollya_obj_t sollya_lib_build_function_mul(sollya_obj_t, sollya_obj_t)`
- `#define SOLLYA_MUL(x,y) sollya_lib_build_function_mul((x), (y))`

Usage:

- `function1 * function2 : (function, function) → function`
- `interval1 * interval2 : (range, range) → range`
- `interval1 * constant : (range, constant) → range`
- `interval1 * constant : (constant, range) → range`

Parameters:
- `function1` and `function2` represent functions
- `interval1` and `interval2` represent intervals (ranges)
- `constant` represents a constant or constant expression

Description:
- `*` represents the multiplication (function) on reals. The expression `function1 * function2` stands for the function composed of the multiplication function and the two functions `function1` and `function2`.
- `*` can be used for interval arithmetic on intervals (ranges). `*` will evaluate to an interval that safely encompasses all images of the multiplication function with arguments varying in the given intervals. Any combination of intervals with intervals or constants (resp. constant expressions) is supported. However, it is not possible to represent families of functions using an interval as one argument and a function (varying in the free variable) as the other one.

Example 1:

```
> 5 * 2;
10
```

Example 2:

```
> x * 2;
x * 2
```

Example 3:

```
> x * x;
x^2
```

Example 4:

```
> diff(sin(x) * exp(x));
sin(x) * exp(x) + exp(x) * cos(x)
```

Example 5:

```
> [1;2] * [3;4];
[3;8]
> [1;2] * 17;
[17;34]
> 13 * [-4;17];
[-52;221]
```

See also: `+` (8.129), `-` (8.111), `/` (8.48), `^` (8.133)
8.114 nearestint

Name: nearestint

the function mapping the reals to the integers nearest to them.

Library names:

sollya_obj_t sollya_lib_nearestint(sollya_obj_t)
sollya_obj_t sollya_lib_build_function_nearestint(sollya_obj_t)
#define SOLLYA_NEARESTINT(x) sollya_lib_build_function_nearestint(x)

Description:

- nearestint is defined as usual: nearestint(x) is the integer nearest to x, with the special rule that the even integer is chosen if there exist two integers equally near to x.

- It is defined for every real number x.

See also: ceil (8.23), floor (8.70), round (8.161), RN (8.160)

8.115 !=

Name: !=

negated equality test operator

Library name:

sollya_obj_t sollya_lib_cmp_not_equal(sollya_obj_t, sollya_obj_t)

Usage:

expr1 != expr2 : (any type, any type) → boolean

Parameters:

- expr1 and expr2 represent expressions

Description:

- The operator != evaluates to true iff its operands expr1 and expr2 are syntactically unequal and both different from error, constant expressions that are not constants and that evaluate to two different floating-point number with the global precision prec or polynomials that are unequal while automatic expression simplification is activated. The user should be aware of the fact that because of floating-point evaluation, the operator != is not exactly the same as the negation of the mathematical equality. Further, expressions that are polynomials may not be structurally equal when != evaluates to false; in order to obtain purely structural tests, the user should deactivate automatic simplification using autosimplify.

Following the IEEE 754 standard, NaN compares unequal to itself, even though this corresponds to a case when expr1 and expr2 are syntactically equal and different from error. Accordingly, the interval [NaN, NaN] compares unequal to itself.

Note that the expressions !(expr1 != expr2) and expr1 == expr2 do not always evaluate to the same boolean value. See error for details.

Example 1:

```
> "Hello" != "Hello";
false
> "Hello" != "Salut";
true
> "Hello" != 5;
true
> 5 + x != 5 + x;
false
```
Example 2:

```plaintext
> 1 != exp(0);  
false
> asin(1) * 2 != pi;  
false
> exp(5) != log(4);  
true
```

Example 3:

```plaintext
> sin(pi/6) != 1/2 * sqrt(3);  
true
```

Example 4:

```plaintext
> prec = 12;
The precision has been set to 12 bits.
> 16384.1 != 16385.1;
false
```

Example 5:

```plaintext
> NaN != NaN;  
true
> [NaN,NaN] != [NaN,NaN];  
true
> error != error;  
false
```

Example 6:

```plaintext
> p = x + x^2;
> q = x * (1 + x);
> autosimplify = on;
Automatic pure tree simplification has been activated.
> p != q;  
false
> autosimplify = off;
Automatic pure tree simplification has been deactivated.
> p != q;  
true
```

See also: == (8.53), > (8.78), >= (8.75), < (8.105), in (8.89), ! (8.117), && (8.6), || (8.124),
error (8.56), prec (8.135), autosimplify (8.16)

8.116 nop

Name: nop
no operation

Usage:

```plaintext
nop : void → void
nop() : void → void
nop(n) : integer → void
```

Description:

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• The command \texttt{nop} does nothing. This means it is an explicit parse element in the \texttt{Sollya} language that finally does not produce any result or side-effect.

• The command \texttt{nop} may take an optional positive integer argument \(n\). The argument controls how much (useless) multiprecision floating-point multiplications \texttt{Sollya} performs while doing nothing. With this behaviour, \texttt{nop} can be used for calibration of timing tests.

• The keyword \texttt{nop} is implicit in some procedure definitions. Procedures without imperative body get parsed as if they had an imperative body containing one \texttt{nop} statement.

Example 1:

> nop;

Example 2:

> nop(100);

Example 3:

> succ = proc(n) { return n + 1; };
> succ;
proc(n)
{
    nop;
    return (n) + (1);
}
> succ(5);
6

See also: \texttt{proc} \((8.143)\), \texttt{time} \((8.189)\)

8.117 \texttt{!}

Name: \texttt{!}

boolean NOT operator

Library name:

\texttt{sollya Obj T sollya Lib Negate(sollya Obj T)}

Usage:

\texttt{! expr : boolean \rightarrow boolean}

Parameters:

• \texttt{expr} represents a boolean expression

Description:

• \texttt{!} evaluates to the boolean \texttt{NOT} of the boolean expression \texttt{expr}. \texttt{! expr} evaluates to true iff \texttt{expr} does not evaluate to true.

Example 1:

> ! false;
true

Example 2:

> ! (1 == exp(0));
false

See also: \texttt{&&} \((8.6)\), \texttt{||} \((8.124)\)
8.118 numberroots

Name: numberroots
Computes the number of roots of a polynomial in a given range.

Library name:
sollya_obj_t sollya_lib_numberroots(sollya_obj_t, sollya_obj_t)

Usage:

\texttt{numberroots}(p, I) : (\texttt{function}, \texttt{range}) \rightarrow \texttt{integer}

Parameters:
\begin{itemize}
  \item $p$ is a polynomial.
  \item $I$ is an interval.
\end{itemize}

Description:
\begin{itemize}
  \item \texttt{numberroots} rigorously computes the number of roots of polynomial the $p$ in the interval $I$. The technique used is Sturm's algorithm. The value returned is not just a numerical estimation of the number of roots of $p$ in $I$: it is the exact number of roots.
  \item The command \texttt{findzeros} computes safe enclosures of all the zeros of a function, without forgetting any, but it is not guaranteed to separate them all in distinct intervals. \texttt{numberroots} is more accurate since it guarantees the exact number of roots. However, it does not compute them. It may be used, for instance, to certify that \texttt{findzeros} did not put two distinct roots in the same interval.
  \item Multiple roots are counted only once.
  \item The interval $I$ must be bounded. The algorithm cannot handle unbounded intervals. Moreover, the interval is considered as a closed interval: if one (or both) of the endpoints of $I$ are roots of $p$, they are counted.
  \item The argument $p$ can be any expression, but if \texttt{Sollya} fails to prove that it is a polynomial an error is produced. Also, please note that if the coefficients of $p$ or the endpoints of $I$ are not exactly representable, they are first numerically evaluated, before the algorithm is used. In that case, the counted number of roots corresponds to the rounded polynomial on the rounded interval and not to the exact parameters given by the user. A warning is displayed to inform the user.
\end{itemize}

Example 1:

```
> numberroots(1+x-x^2, [1,2]);
1
> findzeros(1+x-x^2, [1,2]);
[|1.617919921875;1.6180419921875|]
```

Example 2:

```
> numberroots((1+x)*(1-x), [-1,1]);
2
> numberroots(x^2, [-1,1]);
1
```

Example 3:

```
> verbosity = 1!;
> numberroots(x-pi, [0,4]);
Warning: the 0th coefficient of the polynomial is neither a floating point constant nor can be evaluated without rounding to a floating point constant. Will faithfully evaluate it with the current precision (165 bits)
1
```
Example 4:

```plaintext
> verbosity = 1;
> numberroots(1+x-x^2, [0, @Inf@]);
Warning: the given interval must have finite bounds.
Warning: at least one of the given expressions or a subexpression is not correctly typed
or its evaluation has failed because of some error on a side-effect.
error
> numberroots(exp(x), [0, 1]);
Warning: the given function must be a polynomial in this context.
Warning: at least one of the given expressions or a subexpression is not correctly typed
or its evaluation has failed because of some error on a side-effect.
error
```

See also: dirtyfindzeros (8.42), findzeros (8.67), gcd (8.74)

### 8.119 numerator

**Name:** numerator

- gives the numerator of an expression

**Library name:**

`sollya_obj_t sollya_lib_numerator(sollya_obj_t)`

**Usage:**

`numerator(expr) : function → function`

**Parameters:**

- `expr` represents an expression

**Description:**

- If `expr` represents a fraction `expr1/expr2`, `numerator(expr)` returns the numerator of this fraction, i.e. `expr1`.
  
  If `expr` represents something else, `numerator(expr)` returns the expression itself, i.e. `expr`.

  Note that for all expressions `expr`, `numerator(expr) / denominator(expr)` is equal to `expr`.

**Example 1:**

```plaintext
> numerator(5/3);
5
```

**Example 2:**

```plaintext
> numerator(exp(x));
exp(x)
```

**Example 3:**

```plaintext
> a = 5/3;
> b = numerator(a)/denominator(a);
> print(a);
5 / 3
> print(b);
5 / 3
```
Example 4:

```plaintext
> a = exp(x/3);
> b = numerator(a)/denominator(a);
> print(a);
exp(x / 3)
> print(b);
exp(x / 3)
```

See also: denominator [8.38], rationalmode [8.150]

8.120 object

Name: object

keyword representing a Sollya object type

Library name: SULLYA_EXTERNALPROC_TYPE_OBJECT

Usage:

```
object : type type
```

Description:

- **object** represents the Sollya object type for declarations of external procedures externalproc.

  Remark that in contrast to other indicators, type indicators like object cannot be handled outside the externalproc context. In particular, they cannot be assigned to variables.

See also: externalproc [8.64], boolean [8.21], constant [8.29], function [8.73], list of [8.100], range [8.148], string [8.176], integer [8.92]

8.121 objectname

Name: objectname

returns, given a Sollya object, a string that can be reparsed to the object

Library name:

```
sollya_obj_t sollya_lib_objectname(sollya_obj_t);
```

Usage:

```
objectname(obj) : any type → string
```

Description:

- **objectname(obj)** queries the Sollya symbol table in order to recover the name of an identifier the object **obj** is assigned to. If it succeeds, it returns a string containing the recovered identifier. In contrast, if it does not succeed, it returns a string simply containing a textual representation of **obj**.

- The only condition for an identifier to be eligible to be returned by **objectname(obj)** is to be accessible in the scope **objectname** is executed in, *i.e.*, not to be shadowed by an identifier of the same name which does not hold the object **obj**.

- In any case, if the string returned by **objectname** is given to the parse command in the same scope, the original object **obj** is recovered.

- **objectname** is particularly useful in combination with getbacktrace, when the Sollya procedure stack is to be displayed in a fashion, where procedures are identified by their name and not their procedural content.
• **objectname** may also be used to get a string representation of the free mathematical variable.

• If an object is simply to be cast into a string, without trying to retrieve an identifier for it, **objectname** is not appropriate. In this case, it suffices to concatenate it to an empty string with the @ operator.

Example 1:

```plaintext
> s = "Hello";
> objectname("Hello");
```

Example 2:

```plaintext
> f = exp(x);
> g = sin(x);
> [\[ objectname(exp(x)), objectname(sin(x)), objectname(cos(x)) \]];
```

Example 3:

```plaintext
> o = \{ .f = exp(x), .I = [-1;1] \};
> s1 = o@""; s1;
{ .f = exp(x), .I = [-1;1] }
> s2 = objectname({ .I = [-1;1], .f = exp(x)}); s2;
> parse(s1) == parse(s2);
true
> write("s2 = ", s2, " \" parses to ", parse(s2), "\n");
s2 = "o" parses to \{ .f = exp(x), .I = [-1;1] \}
```

Example 4:

```plaintext
> n = 1664;
> objectname(n);
```

Example 5:

```plaintext
> f = exp(x);
> g = sin(x);
> procedure test() {
    var f;
    var h;
    f = tan(x);
    h = cos(x);
    [\[ objectname(exp(x)), objectname(sin(x)), objectname(cos(x)), objectname(tan(x)) \]];
}
> test();
```

Example 6:

```plaintext
150
```
> procedure apply_proc(p, a, b) {
    return p(a, b);
};
> procedure show_trace_and_add(n, m) {
    var i, bt;
    bt = getbacktrace();
    write("Procedure stack:\n");
    for i from 0 to length(bt) - 1 do {
        write("  Procedure ", objectname((bt[i]).called_proc), " called with ", length((bt[i]).passed_args), " arguments\n");
   );
    write("\n");
    return n + m;
};
> procedure show_and_succ(u) {
    return apply_proc(show_trace_and_add, u, 1);
};
> show_and_succ(16);
Procedure stack:
Procedure show_trace_and_add called with 2 arguments
Procedure apply_proc called with 3 arguments
Procedure show_and_succ called with 1 arguments
17

Example 7:

> f = exp(three_decker_sauerkraut_and_toadstool_sandwich_with_arsenic_sauce);
> g = sin(_x_);
> h = f(g);
> h;
exp(sin(three_decker_sauerkraut_and_toadstool_sandwich_with_arsenic_sauce))
> objectname(_x_);
three_decker_sauerkraut_and_toadstool_sandwich_with_arsenic_sauce

See also: parse [8.125], var [8.194], getbacktrace [8.76], proc [8.143], procedure [8.144], @ [8.28]

8.122 off
Name: off
   special value for certain global variables.
Library names:
   sollya_obj_t sollya_lib_off()
   int sollya_lib_is_off(sollya_obj_t)
Description:
   • off is a special value used to deactivate certain functionnalities of Sollya.
   • As any value it can be affected to a variable and stored in lists.
Example 1:
> canonical=on;
Canonical automatic printing output has been activated.
> p=1+x+x^2;
> mode=off;
> p;
1 + x + x^2
> canonical=mode;
Canonical automatic printing output has been deactivated.
> p;
1 + x * (1 + x)

See also: on [8.123], autosimplify [8.16], canonical [8.22], timing [8.190], fullparentheses [8.72], midpointmode [8.109], rationalmode [8.150], roundingwarnings [8.164], timing [8.190], dieonerrormode [8.40]

8.123 on

Name: on
   special value for certain global variables.

Library names:
   sollya_obj_t sollya_lib_on()
   int sollya_lib_is_on(sollya_obj_t)

Description:
   • on is a special value used to activate certain functionalities of Sollya.
   • As any value it can be affected to a variable and stored in lists.

Example 1:

   > p=1+x+x^2;
   > mode=on;
   > p;
   1 + x * (1 + x)
   > canonical=mode;
   Canonical automatic printing output has been activated.
   > p;
   1 + x + x^2

See also: off [8.122], autosimplify [8.16], canonical [8.22], timing [8.190], fullparentheses [8.72], midpointmode [8.109], rationalmode [8.150], roundingwarnings [8.164], timing [8.190], dieonerrormode [8.40]

8.124 ||

Name: ||
   boolean OR operator

Library name:
   sollya_obj_t sollya_lib_or(sollya_obj_t, sollya_obj_t)

Usage:

   exp1 || exp2 : (boolean, boolean) → boolean

Parameters:

   • exp1 and exp2 represent boolean expressions
• \(||\) evaluates to the boolean OR of the two boolean expressions \(\text{expr1}\) and \(\text{expr2}\). \(||\) evaluates to true iff at least one of \(\text{expr1}\) or \(\text{expr2}\) evaluates to true.

Example 1:

```plaintext
> false || false;
false
```

Example 2:

```plaintext
> (1 == exp(0)) || (0 == log(1));
true
```

See also: && (8.6), † (8.117)

8.125 parse

Name: parse

parses an expression contained in a string

Library name:

sollya_obj_t sollya_lib_parse(sollya_obj_t)

Usage:

```
parse(string) : string → function | error
```

Parameters:

• string represents a character sequence

Description:

• \(\text{parse(string)}\) parses the character sequence \(\text{string}\) containing an expression built on constants and base functions.

If the character sequence does not contain a well-defined expression, a warning is displayed indicating a syntax error and \(\text{parse}\) returns a error of type error.

• The character sequence to be parsed by \(\text{parse}\) may contain commands that return expressions, including \(\text{parse}\) itself. Those commands get executed after the string has been parsed. \(\text{parse(string)}\) will return the expression computed by the commands contained in the character sequence \(\text{string}\).

Example 1:

```plaintext
> parse("exp(x)");
exp(x)
```

Example 2:

```plaintext
> text = "remez(exp(x),5,[-1;1])";
> print("The string \"text\", text, \"gives\", parse(text));
The string "remez(exp(x),5,[-1;1])" gives 8.73819098827562036768683157316876049039e-3 * x^5 + 4.37936963795960154782331712653652729379500558381e-2 * x^4 + 0.1664246614952768185129433844012193925654066755905 * x^3 + 0.49919692629636149182657545209410156204819693772 * x^2 + 1.000038346505998154663400680582 * x + 1.00004475029559502602603712816558243384077522932213
```

Example 3:
verbosity = 1;
parse("5 + * 3");
Warning: syntax error, unexpected *. Will try to continue parsing (expecting ";");
May leak memory.
Warning: the string "5 + * 3" could not be parsed by the miniparser.
Warning: at least one of the given expressions or a subexpression is not correctly typed
or its evaluation has failed because of some error on a side-effect.
error

See also: execute (8.58), readfile (8.152), print (8.138), error (8.56), dieonerrormode (8.40)

8.126 perturb

Name: perturb
indicates random perturbation of sampling points for externalplot

Library names:
sollya_obj_t sollya_lib_perturb()
int sollya_lib_is_perturb(sollya_obj_t)

Usage:

perturb : perturb

Description:

- The use of perturb in the command externalplot enables the addition of some random noise around each sampling point in externalplot.

See externalplot for details.

Example 1:

> bashexecute("gcc -fPIC -c externalplotexample.c");
> bashexecute("gcc -shared -o externalplotexample externalplotexample.o -lgmp -lm
mpfr");
> externalplot("./externalplotexample",relative,exp(x),[-1/2;1/2],12,perturb);

See also: externalplot (8.63), absolute (8.2), relative (8.154), bashexecute (8.18)

8.127 pi

Name: pi
the constant \( \pi \).

Library names:
sollya_obj_t sollya_lib_pi()
int sollya_lib_is_pi(sollya_obj_t)
sollya_obj_t sollya_lib_build_function_pi()
#define SOLLYA_PI (sollya_lib_build_function_pi())

Description:

- \( \pi \) is the constant \( \pi \), defined as half the period of sine and cosine.

- In Sollya, \( \pi \) is considered a 0-ary function. This way, the constant is not evaluated at the time of its definition but at the time of its use. For instance, when you define a constant or a function relating to \( \pi \), the current precision at the time of the definition does not matter. What is important is the current precision when you evaluate the function or the constant value.
Remark that when you define an interval, the bounds are first evaluated and then the interval is defined. In this case, \( \pi \) will be evaluated as any other constant value at the definition time of the interval, thus using the current precision at this time.

Example 1:

```plaintext
> verbosity=1!; prec=12!;
> a = 2*pi;
> a;
Warning: rounding has happened. The value displayed is a faithful rounding to 12 bits of the true result.
6.283
> prec=20!;
> a;
Warning: rounding has happened. The value displayed is a faithful rounding to 20 bits of the true result.
6.28319
```

Example 2:

```plaintext
> display=binary;
Display mode is binary numbers.
> prec=12!;
> d = [pi; 5];
> d;
[1.1001001_2 * 2^(1);1.01_2 * 2^(2)]
> prec=20!;
> d;
[1.1001001_2 * 2^(1);1.01_2 * 2^(2)]
```

See also: \( \cos \) (8.30), \( \sin \) (8.17), \( \tan \) (8.18), \( \text{asin} \) (8.4), \( \text{acos} \) (8.13), \( \text{atan} \) (8.13), \( \text{evaluate} \) (8.57), \( \text{prec} \) (8.13), \( \text{libraryconstant} \) (8.99)

8.128 plot

Name: plot

plots one or several functions

Library names:

```plaintext
void sollya_lib_plot(sollya_obj_t, sollya_obj_t, ...)
void sollya_lib_v_plot(sollya_obj_t, sollya_obj_t, va_list)
```

Usage:

```plaintext
plot(f1, ... fn, I) : (function, ..., function, range) → void
plot(f1, ... fn, I, file, name) : (function, ... , function, range, file, string) → void
plot(f1, ... fn, I, postscript, name) : (function, ... , function, range, postscript, string) → void
plot(f1, ... fn, I, postscriptfile, name) : (function, ... , function, range, postscriptfile, string) → void
plot(L, I) : (list, range) → void
plot(L, I, file, name) : (list, range, file, string) → void
plot(L, I, postscript, name) : (list, range, postscript, string) → void
plot(L, I, postscriptfile, name) : (list, range, postscriptfile, string) → void
```

Parameters:

- \( f1, ..., fn \) are functions to be plotted.
- \( L \) is a list of functions to be plotted.
- \( I \) is the interval where the functions have to be plotted.
- *name* is a string representing the name of a file.

Description:

- This command plots one or several functions \( f_1, \ldots, f_n \) on an interval \( I \). Functions can be either given as parameters of `plot` or as a list \( L \) which elements are functions. The functions are drawn on the same plot with different colors.

- If \( L \) contains an element that is not a function (or a constant), an error occurs.

- `plot` relies on the value of global variable *points*. Let \( n \) be the value of this variable. The algorithm is the following: each function is evaluated at \( n \) evenly distributed points in \( I \). At each point, the computed value is a faithful rounding of the exact value with a sufficiently high precision. Each point is finally plotted. This should avoid numerical artefacts such as critical cancellations.

- The plot can be saved either as a data file or as a postscript file.

- If you use argument *file* with a string *name*, Sollya will save a data file called *name.dat* and a gnuplot directives file called *name.p*. Invoking gnuplot on *name.p* will plot the data stored in *name.dat*.

- If you use argument *postscript* with a string *name*, Sollya will save a postscript file called *name.eps* representing your plot.

- If you use argument *postscriptfile* with a string *name*, Sollya will produce the corresponding *name.dat*, *name.p* and *name.eps*.

- By default, this command uses gnuplot to produce the final plot. If Sollya is run while the environment variable SOLLYA_GNUPLOT is set, the content of that variable is used as the gnuplot binary. If your terminal is not graphic (typically if you use Sollya through ssh without -X) gnuplot should be able to detect that and produce an ASCII-art version on the standard output. If it is not the case, you can either store the plot in a postscript file to view it locally, or use `asciiplot` command.

- If every function is constant, `plot` will not plot them but just display their value.

- If the interval is reduced to a single point, `plot` will just display the value of the functions at this point.

Example 1:

```
> plot(sin(x),0,cos(x),[-Pi,Pi]);
```

Example 2:

```
> plot(sin(x),0,cos(x),[-Pi,Pi],postscriptfile,"plotSinCos");
```

Example 3:

```
> plot(exp(0), sin(1), [0;1]);
1
0.84147098480789650665250232163029899962256306079837
```

Example 4:

```
> plot(sin(x), cos(x), [1;1]);
0.84147098480789650665250232163029899962256306079837
0.5403023058681397140093660744297660373231042061792
```

See also: `externalplot` (8.63), `asciiplot` (8.10), `file` (8.66), `postscript` (8.131), `postscriptfile` (8.132), `points` (8.130)
8.129  +

Name: +
  addition function

Library names:
  sollya_obj_t sollya_lib_add(sollya_obj_t, sollya_obj_t)
  sollya_obj_t sollya_lib_build_function_add(sollya_obj_t, sollya_obj_t)
  #define SOLLYA_ADD(x,y) sollya_lib_build_function_add((x), (y))

Usage:

  \[ function1 + function2 : (function, function) \rightarrow function \]
  \[ interval1 + interval2 : (range, range) \rightarrow range \]
  \[ interval1 + constant : (range, constant) \rightarrow range \]
  \[ interval1 + constant : (constant, range) \rightarrow range \]

Parameters:
  
  * \textit{function1} and \textit{function2} represent functions
  * \textit{interval1} and \textit{interval2} represent intervals (ranges)
  * \textit{constant} represents a constant or constant expression

Description:

  * + represents the addition (function) on reals. The expression \( function1 + function2 \) stands for the function composed of the addition function and the two functions \( function1 \) and \( function2 \).
  
  * + can be used for interval arithmetic on intervals (ranges). + will evaluate to an interval that safely encompasses all images of the addition function with arguments varying in the given intervals. Any combination of intervals with intervals or constants (resp. constant expressions) is supported. However, it is not possible to represent families of functions using an interval as one argument and a function (varying in the free variable) as the other one.

Example 1:

  \begin{verbatim}
  > 1 + 2;
  3
  \end{verbatim}

Example 2:

  \begin{verbatim}
  > x + 2;
  2 + x
  \end{verbatim}

Example 3:

  \begin{verbatim}
  > x + x;
  x * 2
  \end{verbatim}

Example 4:

  \begin{verbatim}
  > diff(sin(x) + exp(x));
  cos(x) + exp(x)
  \end{verbatim}

Example 5:

  \begin{verbatim}
  > [1;2] + [3;4];
  [4;6]
  > [1;2] + 17;
  [18;19]
  > 13 + [-4;17];
  [9;30]
  \end{verbatim}

See also:  − (8.111), * (8.113), / (8.48), ^ (8.133)
8.130 points

Name: points
controls the number of points chosen by Sollya in certain commands.

Library names:
void sollya_lib_set_points_and_print(sollya_obj_t)
void sollya_lib_set_points(sollya_obj_t)
sollya_obj_t sollya_lib_get_points()

Usage:
points = n : integer → void
points = n ! : integer → void
points : constant

Parameters:
• n represents the number of points

Description:
• points is a global variable. Its value represents the number of points used in numerical algorithms of Sollya (namely dirtyinfnorm, dirtyintegral, dirtyfindzeros, plot).

Example 1:

```plaintext
> f=x^2*sin(1/x);
> points=10;
The number of points has been set to 10.
> dirtyfindzeros(f, [0;1]);
[|0, 0.31830988618379067153776752674502872406891929148092|
> points=100;
The number of points has been set to 100.
> dirtyfindzeros(f, [0;1]);
[|0, 2.448537586029159011828909749617594159147637806224e-2, 3.9788735777297383394222094084312859058614911435115e-2, 4.5472840883398667362538218106432674866988470211559e-2, 5.3051647679298445256294587790838120678153215246819e-2, 6.3661977236758134075553650349005744813783858296184e-2, 7.957747154594766788444188168625718101722962287023e-2, 1.06103295394596890512589175581676241356306430493638, 0.159154940391895335768837337251436203445964574046, 0.31830988618379067153776752674502872406891929148092|
```

See also: dirtyinfnorm (8.43), dirtyintegral (8.44), dirtyfindzeros (8.42), plot (8.128), diam (8.39), prec (8.135)

8.131 postscript

Name: postscript
special value for commands plot and externalplot

Library names:
sollya_obj_t sollya_lib_postscript()
int sollya_lib_is_postscript(sollya_obj_t)

Description:
• postscript is a special value used in commands plot and externalplot to save the result of the command in a postscript file.
• As any value it can be affected to a variable and stored in lists.
Example 1:

```c
> savemode=postscript;
> name="plotSinCos";
> plot(sin(x),0,cos(x),[-Pi,Pi],savemode, name);
```

See also: externalplot [8.63], plot [8.128], file [8.66], postscriptfile [8.132]

### 8.132 postscriptfile

Name: postscriptfile

special value for commands plot and externalplot

Library names:

```c
sollya_obj_t sollya_lib_postscriptfile()
int sollya_lib_is_postscriptfile(sollya_obj_t)
```

Description:

- postscriptfile is a special value used in commands plot and externalplot to save the result of the command in a data file and a postscript file.
- As any value it can be affected to a variable and stored in lists.

Example 1:

```c
> savemode=postscriptfile;
> name="plotSinCos";
> plot(sin(x),0,cos(x),[-Pi,Pi],savemode, name);
```

See also: externalplot [8.63], plot [8.128], file [8.66], postscript [8.131]

### 8.133 ^

Name: ^

power function

Library names:

```c
sollya_obj_t sollya_lib_pow(sollya_obj_t, sollya_obj_t)
sollya_obj_t sollya_lib_build_function_pow(sollya_obj_t, sollya_obj_t)
#define SOLLYA_POW(x,y) sollya_lib_build_function_pow((x), (y))
```

Usage:

```
function1 ^ function2 : (function, function) → function
interval1 ^ interval2 : (range, range) → range
interval1 ^ constant : (range, constant) → range
interval1 ^ constant : (constant, range) → range
```

Parameters:

- function1 and function2 represent functions
- interval1 and interval2 represent intervals (ranges)
- constant represents a constant or constant expression

Description:

- ^ represents the power (function) on reals. The expression function1 ^ function2 stands for the function composed of the power function and the two functions function1 and function2, where function1 is the base and function2 the exponent. If function2 is a constant integer, ^ is defined on negative values of function1. Otherwise ^ is defined as $e^{y \ln x}$. 

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Note that whenever several \(^\) are composed, the priority goes to the last \(^\). This corresponds to the natural way of thinking when a tower of powers is written on a paper. Thus, \(2^3^5\) is read as \(2^{3^5}\) and is interpreted as \(2^{(3^5)}\).

\(^\) can be used for interval arithmetic on intervals (ranges). \(^\) will evaluate to an interval that safely encompasses all images of the power function with arguments varying in the given intervals. If the intervals given contain points where the power function is not defined, infinities and NaNs will be produced in the output interval. Any combination of intervals with intervals or constants (resp. constant expressions) is supported. However, it is not possible to represent families of functions using an interval as one argument and a function (varying in the free variable) as the other one.

Example 1:

```plaintext
de> 5 ^ 2;
de25
```

Example 2:

```plaintext
de> x ^ 2;
de x^2
```

Example 3:

```plaintext
de> 3 ^ (-5);
de 4.1152263374485596707818930041152263374485596707819e-3
```

Example 4:

```plaintext
de> (-3) ^ (-2.5);
de NaN
```

Example 5:

```plaintext
de> diff(sin(x) ^ exp(x));
de sin(x)^exp(x) * ((cos(x) * exp(x)) / sin(x) + exp(x) * log(sin(x)))
```

Example 6:

```plaintext
de> 2^3^5;
de 1.413477651822707463666380005943348126619871175005e73

de> (2^3)^5;
de 32768

de> 2^(3^5);
de 1.413477651822707463666380005943348126619871175005e73
```

Example 7:

```plaintext
de> [1;2] ^ [3;4];
de [1;16.00000000000000000000000000000000000000000001]

de> [1;16.00000000000000000000000000000000000000000001] ^ 17;
de [1;131072]

de> [1;131072] ^ [-4;17];
de [3.50127796645775708133468716081369699404782745702e-5;8650415919381337933]
```

See also: + [8.129], - [8.111], * [8.113], / [8.48]
8.134 powers

Name: powers
special value for global state display

Library names:
sollya_obj_t sollya_lib_powers()
int sollya_lib_is_powers(sollya_obj_t)

Description:
• powers is a special value used for the global state display. If the global state display is equal to powers, all data will be output in dyadic notation with numbers displayed in a Maple and PARI/GP compatible format.

As any value it can be affected to a variable and stored in lists.

See also: decimal [8.35], dyadic [8.52], hexadecimal [8.82], binary [8.19], display [8.46]

8.135 prec

Name: prec
controls the precision used in numerical computations.

Library names:
void sollya_lib_set_prec_and_print(sollya_obj_t)
void sollya_lib_set_prec(sollya_obj_t)
sollya_obj_t sollya_lib_get_prec()

Description:
• prec is a global variable. Its value represents the precision of the floating-point format used in numerical computations.

• Many commands try to adapt their working precision in order to have approximately $n$ correct bits in output, where $n$ is the value of prec.

Example 1:

```
> display=binary!;
> prec=50;
The precision has been set to 50 bits.
> dirtyinfnorm(exp(x),[1;2]);
1.110110001110011001001011100011010100110111011_2 * 2^2
> prec=100;
The precision has been set to 100 bits.
> dirtyinfnorm(exp(x),[1;2]);
1.110110001110011001001011100011010100110111011_2 * 2^2
```

See also: evaluate [8.57], diam [8.39]

8.136 precision

Name: precision
returns the precision necessary to represent a number.

Library name:
sollya_obj_t sollya_lib_precision(sollya_obj_t)

Usage:

```
precision(x) : constant → integer
```

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Parameters:

- $x$ is a dyadic number.

Description:

- **precision**($x$) is by definition $|x|$ if $x$ equals 0, NaN, or Inf.
- If $x$ is not zero, it can be uniquely written as $x = m \cdot 2^e$ where $m$ is an odd integer and $e$ is an integer. **precision**($x$) returns the number of bits necessary to write $m$ in binary (i.e. $1 + \lfloor \log_2(m) \rfloor$).

Example 1:

```
> a=round(Pi,20,RN);
> precision(a);
19
> m=mantissa(a);
> 1+floor(log2(m));
19
```

Example 2:

```
> a=255;
> precision(a);
8
> m=mantissa(a);
> 1+floor(log2(m));
8
```

Example 3:

```
> a=256;
> precision(a);
1
> m=mantissa(a);
> 1+floor(log2(m));
1
```

See also: **mantissa** [8.106], **exponent** [8.62], **round** [8.161]

### 8.137 `.:

Name: `.:

add an element at the beginning of a list.

Library name:

- **sollya_obj_t sollya_lib_prepend(sollya_obj_t, sollya_obj_t)**

Usage:

```
x:L : (any type, list) → list
```

Parameters:

- $x$ is an object of any type.
- $L$ is a list (possibly empty).

Description:

- `.:` adds the element $x$ at the beginning of the list $L$. 
• Note that since \( x \) may be of any type, it can be in particular a list.

Example 1:

\[
> 1.:[1,2,4];
[1, 2, 3, 4]
\]

Example 2:

\[
> [[1,2,3]], [[4,5,6]]; 
[[1, 2, 3], 4, 5, 6]
\]

Example 3:

\[
> 1.:[[]]; 
[[]]
\]

See also: \( 8.8 \), @ \( 8.28 \)

8.138 print

Name: print

prints an expression

Usage:

\[
\text{print(} \text{expr1,\ldots,exprn} \text{)} : (\text{any type,\ldots, any type}) \rightarrow \text{void} \\
\text{print(} \text{expr1,\ldots,exprn} \text{)} > \text{filename} : (\text{any type,\ldots, any type, string}) \rightarrow \text{void} \\
\text{print(} \text{expr1,\ldots,exprn} \text{)} >> \text{filename} : (\text{any type,\ldots,any type, string}) \rightarrow \text{void}
\]

Parameters:

• \( \text{expr} \) represents an expression

• \( \text{filename} \) represents a character sequence indicating a file name

Description:

• \( \text{print(} \text{expr1,\ldots,exprn} \text{)} \) prints the expressions \( \text{expr1} \) through \( \text{exprn} \) separated by spaces and followed by a newline.

If a second argument \( \text{filename} \) is given after a single '>'', the displaying is not output on the standard output of \texttt{Sollya} but if in the file \( \text{filename} \) that get newly created or overwritten. If a double '>>' is given, the output will be appended to the file \( \text{filename} \).

The global variables \( \texttt{display} \), \( \texttt{midpointmode} \) and \( \texttt{fullparentheses} \) have some influence on the formatting of the output (see \( \texttt{display} \), \( \texttt{midpointmode} \) and \( \texttt{fullparentheses} \)).

Remark that if one of the expressions \( \text{expri} \) given in argument is of type string, the character sequence \( \text{expri} \) evaluates to is displayed. However, if \( \text{expri} \) is of type list and this list contains a variable of type string, the expression for the list is displayed, i.e. all character sequences get displayed surrounded by double quotes (''). Nevertheless, escape sequences used upon defining character sequences are interpreted immediately.

Example 1:

\[
> \text{print(x + 2 + exp(sin(x)))}; \\
x + 2 + \exp(\sin(x)) \\
> \text{print("Hello","world");} \\
\text{Hello world} \\
> \text{print("Hello","you", 4 + 3, "other persons.");} \\
\text{Hello you 7 other persons.}
\]

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Example 2:

```plaintext
> print("Hello");
Hello
> print(["Hello"|]);
["Hello"]
> s = "Hello";
> print(s,[|s|]);
Hello ["Hello"]
> t = "Hello\tyou";
> print(t,[|t|]);
Hello you ["Hello\tyou"]
```

Example 3:

```plaintext
> print(x + 2 + exp(sin(x))) > "foo.sol"
> readfile("foo.sol")
x + 2 + exp(sin(x))
```

Example 4:

```plaintext
> print(x + 2 + exp(sin(x))) >> "foo.sol"
```

Example 5:
> display = decimal;
Display mode is decimal numbers.
> a = evaluate(sin(pi * x), 0.25);
> b = evaluate(sin(pi * x), [0.25; 0.25 + 1b-50]);
> print(a);
0.7071067811865475244008443621048903928483593768847
> display = binary;
Display mode is binary numbers.
> print(a);
1.01101010000101110011000101111011110101101011111011011010111110101010001011101
010001_2 * 2^(-1)
> display = hexadecimal;
Display mode is hexadecimal numbers.
> print(a);
0x1.6a09e667f3bcc908b2fb1366ea957d3e3adec1751p-1
> display = dyadic;
Display mode is dyadic numbers.
> print(a);
3307006991101558613323983488220944360067107133265b-165
> display = powers;
Display mode is dyadic numbers in integer-power-of-2 notation.
> print(a);
3307006991101558613323983488220944360067107133265 * 2^(-165)
> display = decimal;
Display mode is decimal numbers.
> midpointmode = off;
Midpoint mode has been deactivated.
> print(b);
[0.7071067811865475244008443621048903928483593768845;0.70710678118654949743721782517557347782646274417049]
> midpointmode = on;
Midpoint mode has been activated.
> print(b);
0.7071067811865-4/5-
> display = dyadic;
Display mode is dyadic numbers.
> print(b);
[20668754369438474133327498680138090225041941995829b-161;1653500349555082544419623701938593641432675156571b-164]
> display = decimal;
Display mode is decimal numbers.
> autosimplify = off;
Automatic pure tree simplification has been deactivated.
> fullparentheses = off;
Full parentheses mode has been deactivated.
> print(x + x * ((x + 1) + 1));
   x + x * (x + 1 + 1)
> fullparentheses = on;
Full parentheses mode has been activated.
> print(x + x * ((x + 1) + 1));
   x + (x * ((x + 1) + 1))

See also: write 8.198, printexpansion 8.140, printdouble 8.139, printsingle 8.141, printxml 8.142, readfile 8.152, autosimplify 8.16, display 8.46, midpointmode 8.109, fullparentheses 8.72, evaluate 8.57, rationalmode 8.150
8.139 printdouble

Name: printdouble
prints a constant value as a hexadecimal double precision number

Library name:

void sollya_lib_printdouble(sollya_obj_t)

Usage:

printdouble(constant) : constant -> void

Parameters:

- constant represents a constant

Description:

- Prints a constant value as a hexadecimal number on 16 hexadecimal digits. The hexadecimal number represents the integer equivalent to the 64 bit memory representation of the constant considered as a double precision number.
  
  If the constant value does not hold on a double precision number, it is first rounded to the nearest double precision number before displayed. A warning is displayed in this case.

Example 1:

> printdouble(3);
0x4008000000000000

Example 2:

> prec=100!;
> verbosity = 1!;
> printdouble(exp(5));
Warning: the given expression is not a constant but an expression to evaluate. A faithful evaluation to 100 bits will be used.
Warning: rounding down occurred before printing a value as a double.
0x40628d389970338f

See also: printsingle [8.141], printexpansion [8.140], double [8.49]

8.140 printexpansion

Name: printexpansion
prints a polynomial in Horner form with its coefficients written as a expansions of double precision numbers

Library name:

void sollya_lib_printexpansion(sollya_obj_t)

Usage:

printexpansion(polynomial) : function -> void

Parameters:

- polynomial represents the polynomial to be printed

Description:
The command \texttt{printexpansion} prints the polynomial \textit{polynomial} in Horner form writing its coefficients as expansions of double precision numbers. The double precision numbers themselves are displayed in hexadecimal memory notation (see \texttt{printdouble}).

If some of the coefficients of the polynomial \textit{polynomial} are not floating-point constants but constant expressions, they are evaluated to floating-point constants using the global precision \texttt{prec}. If a rounding occurs in this evaluation, a warning is displayed.

If the exponent range of double precision is not sufficient to display all the mantissa bits of a coefficient, the coefficient is displayed rounded and a warning is displayed.

If the argument \textit{polynomial} does not a polynomial, nothing but a warning or a newline is displayed.

Constants can be displayed using \texttt{printexpansion} since they are polynomials of degree 0.

\begin{verbatim}
Example 1:
> printexpansion(roundcoefficients(taylor(exp(x),5,[0]));
0x3ff0000000000000 + x * (0x3ff0000000000000 + x * (0x3fc5555555555555 + 0x3c65555555555555) + x * ((0x3fa5555555555555 + 0x3c45555555555555) + x * (0x3f81111111111111 + 0x3c01111111111111))))
\end{verbatim}

\begin{verbatim}
Example 2:
> printexpansion(remez(exp(x),5,[1;1]));
(0x3ff0002ee9ae6a0087757 + 0xb8eb3e644ef4998) + x * ((0x3ff0002830f04d95a + 0xb91a9809b13dd54 + 0x35c0000000000000) + x * ((0x3ff0002e6a9f6e4e04ef4e2 + 0x38fcd1b64e85bb0 + 0x3590000000000000) + x * ((0x3fc54d673b4839e + 0x3c6654e4d8af544 + 0xb905c7a26b6ea92 + 0xb598000000000000) + x * (0x3fa66c2c89f7150a8 + 0x3c4b1bba87f8092 + 0xb8c75f6eb90d + 0x3560000000000000) + x * (0x3f81e654242ab128 + 0xbc23e920a76e760c + 0x38c0589c2ca065caef + 0x3564000000000000))))
\end{verbatim}

\begin{verbatim}
Example 3:
> verbosity = 1!;
> prec = 3500!;
> printexpansion(pi);
(0x400921fb54442d18 + 0x3ca1a62633145c07 + 0xb29f19767ed8fbc + 0x35c4cf99e804177d + 0x32631d89c9128a5 + 0x2ec0f31c68099bf + 0xb2f519b3cd3a431b + 0xb7e8158536f92fa + 0x246a7f90ab6669a + 0xa0aedd0dd2544cf + 0xb77f1bd1310ba + 0x1a1a637ed6b5bf6 + 0x96aa485fca4909e + 0x933e501295d98169 + 0x8fd160db83b4e0 + 0x8e5b96799ae131c + 0x08f6cf70801f2e28 + 0x05963bf0598da483 + 0x023871574e69a459 + 0x8000000005702db3 + 0x8000000000000000)
Warning: the expansion is not complete because of the limited exponent range of double precision.
Warning: rounding occurred while printing.
\end{verbatim}

See also: \texttt{printdouble}, \texttt{horner}, \texttt{print}, \texttt{prec}, \texttt{remez}, \texttt{taylor}, \texttt{roundcoefficients}, \texttt{fpminimax}, \texttt{implementpoly}.

\subsection{8.141 \texttt{printsingle}}

\textbf{Name:} \texttt{printsingle}

prints a constant value as a hexadecimal single precision number

\textbf{Library name:} 
void sollya_lib_printsingle(sollya_obj_t)

\textbf{Usage:}

\texttt{printsingle(constant) : constant \rightarrow void}
Parameters:

- *constant* represents a constant

Description:

- Prints a constant value as a hexadecimal number on 8 hexadecimal digits. The hexadecimal number represents the integer equivalent to the 32 bit memory representation of the constant considered as a single precision number.

  If the constant value does not hold on a single precision number, it is first rounded to the nearest single precision number before it is displayed. A warning is displayed in this case.

Example 1:

```
> printsingle(3);
0x40400000
```

Example 2:

```
> prec=100!;
> verbosity = 1!;
> printsingle(exp(5));
Warning: the given expression is not a constant but an expression to evaluate. A faithful evaluation to 100 bits will be used.
Warning: rounding up occurred before printing a value as a single.
0x431469c5
```

See also: `printdouble` (8.139), `single` (8.172)

8.142 printxml

Name: *printxml*

prints an expression as an MathML-Content-Tree

Library names:

- `void sollya_lib_printxml(sollya_obj_t)`
- `void sollya_lib_printxml_newfile(sollya_obj_t, sollya_obj_t)`
- `void sollya_lib_printxml_appendfile(sollya_obj_t, sollya_obj_t)`

Usage:

```
printxml(expr) : function → void
printxml(expr) > filename : (function, string) → void
printxml(expr) >> filename : (function, string) → void
```

Parameters:

- *expr* represents a functional expression

- *filename* represents a character sequence indicating a file name

Description:

- `printxml(expr)` prints the functional expression *expr* as a tree of MathML Content Definition Markups. This XML tree can be re-read in external tools or by usage of the `readxml` command. If a second argument *filename* is given after a single >, the MathML tree is not output on the standard output of Sollya but if in the file *filename* that get newly created or overwritten. If a double >> is given, the output will be appended to the file *filename*.

Example 1:
Example 2:

```plaintext
> printxml(x + 2 + exp(sin(x))); > "foo.xml";
```

Example 3:

```plaintext
> printxml(x + 2 + exp(sin(x))) >> "foo.xml";
```

See also: `readxml` [8.153], `print` [8.138], `write` [8.198]

## 8.143 proc

Name: **proc**

defines a Sollya procedure

Usage:

```
proc(formal parameter1, formal parameter2..., formal parameter n) { procedure body } : void → procedure
```
\[
\text{proc}(\text{formal parameter}_1, \text{formal parameter}_2, ..., \text{formal parameter}_n) \{ \text{ procedure body return expression; } \} : \text{void} \rightarrow \text{procedure}
\]

\[
\text{proc}(\text{formal list parameter} = ...) \{ \text{ procedure body } \} : \text{void} \rightarrow \text{procedure}
\]

\[
\text{proc}(\text{formal list parameter} = ...) \{ \text{ procedure body return expression; } \} : \text{void} \rightarrow \text{procedure}
\]

Parameters:

- \text{formal parameter}_1, \text{formal parameter}_2 \text{ through } \text{formal parameter}_n \text{ represent identifiers used as formal parameters}
- \text{formal list parameter} \text{ represents an identifier used as a formal parameter for the list of an arbitrary number of parameters}
- \text{procedure body} \text{ represents the imperative statements in the body of the procedure}
- \text{expression} \text{ represents the expression proc shall evaluate to}

Description:

- The \text{proc} keyword allows for defining procedures in the \text{Sollya} language. These procedures are common \text{Sollya} objects that can be applied to actual parameters after definition. Upon such an application, the \text{Sollya} interpreter applies the actual parameters to the formal parameters \text{formal parameter}_1 \text{ through } \text{formal parameter}_n \text{ (resp. builds up the list of arguments and applies it to the list \text{formal list parameter}) and executes the \text{procedure body}. The procedure applied to actual parameters evaluates then to the expression \text{expression} in the \text{return statement after the \text{procedure body} or to \text{void}, if no return statement is given (i.e. a \text{return void} statement is implicitly given).}

- \text{Sollya} procedures defined by \text{proc} have no name. They can be bound to an identifier by assigning the procedure object a \text{proc} expression produces to an identifier. However, it is possible to use procedures without giving them any name. For instance, \text{Sollya} procedures, i.e. procedure objects, can be elements of lists. They can even be given as an argument to other internal \text{Sollya} procedures. See also \text{procedure} on this subject.

- Upon definition of a \text{Sollya} procedure using \text{proc}, no type check is performed. More precisely, the statements in \text{procedure body} are merely parsed but not interpreted upon procedure definition with \text{proc}. Type checks are performed once the procedure is applied to actual parameters or to \text{void}. At this time, if the procedure was defined using several different formal parameters \text{formal parameter}_1 \text{ through } \text{formal parameter}_n \text{, it is checked whether the number of actual parameters corresponds to the number of formal parameters. If the procedure was defined using the syntax for a procedure with an arbitrary number of parameters by giving a \text{formal list parameter}, the number of actual arguments is not checked but only a list \text{formal list parameter} of appropriate length is built up. Type checks are further performed upon execution of each statement in \text{procedure body} and upon evaluation of the expression \text{expression} to be returned.

Procedures defined by \text{proc} containing a \text{quit} or \text{restart} command cannot be executed (i.e. applied). Upon application of a procedure, the \text{Sollya} interpreter checks beforehand for such a statement. If one is found, the application of the procedure to its arguments evaluates to \text{error}. A warning is displayed. Remark that in contrast to other type or semantic correctness checks, this check is really performed before interpreting any other statement in the body of the procedure.

- Through the \text{var} keyword it is possible to declare local variables and thus to have full support of recursive procedures. This means a procedure defined using \text{proc} may contain in its \text{procedure body} an application of itself to some actual parameters: it suffices to assign the procedure (object) to an identifier with an appropriate name.

- \text{Sollya} procedures defined using \text{proc} may return other procedures. Further \text{procedure body} may contain assignments of locally defined procedure objects to identifiers. See \text{var} for the particular behaviour of local and global variables.
The expression expression returned by a procedure is evaluated with regard to Sollya commands, procedures and external procedures. Simplification may be performed. However, an application of a procedure defined by proc to actual parameters evaluates to the expression expression that may contain the free global variable or that may be composed.

Example 1:

```plaintext
> succ = proc(n) { return n + 1; };
> succ(5);
6
> 3 + succ(0);
4
> succ;
proc(n)
{
    nop;
    return (n) + (1);
}
```

Example 2:

```plaintext
> add = proc(m,n) { var res; res := m + n; return res; };
> add(5,6);
11
> add;
proc(m, n)
{
    var res;
    res := (m) + (n);
    return res;
}
> verbosity = 1!;
> add(3);
Warning: at least one of the given expressions or a subexpression is not correctly typed
or its evaluation has failed because of some error on a side-effect.
error
> add(true,false);
Warning: at least one of the given expressions or a subexpression is not correctly typed
or its evaluation has failed because of some error on a side-effect.
Warning: the given expression or command could not be handled.
error
```

Example 3:

```plaintext
> succ = proc(n) { return n + 1; };
> succ(5);
6
> succ(x);
1 + x
```

Example 4:
> hey = proc() { print("Hello world."); }; 
> hey();
Hello world.
> print(hey());
Hello world.
void
> hey;
proc()
{
print("Hello world.");
return void;
}

Example 5:

> fac = proc(n) { var res; if (n == 0) then res := 1 else res := n * fac(n - 1); return res; }; 
> fac(5);
120
> fac(11);
39916800
> fac;
proc(n)
{
var res;
if (n) == (0) then
res := 1
else
res := (n) * (fac((n) - (1)));
return res;
}

Example 6:

> myprocs = [ [ proc(m,n) { return m + n; }, proc(m,n) { return m - n; } ] ];
> (myprocs[0])(5,6);
11
> (myprocs[1])(5,6);
-1
> succ = proc(n) { return n + 1; };
> pred = proc(n) { return n - 1; };
> applier = proc(p,n) { return p(n); };
> applier(succ,5);
6
> applier(pred,5);
4

Example 7:
Example 8:

```plaintext
> printsucc = proc(n) { var succ; succ = proc(n) { return n + 1; }; print("Successor of",n,"is",succ(n)); }; 
> printsucc(5);
Successor of 5 is 6
```

Example 9:

```plaintext
> makeadd = proc(n) { var add; print("n =",n); add = proc(m,n) { return n + m; }; return add; }; 
> makeadd(4);
n = 4
proc(m, n)
{
  nop;
  return (n) + (m);
}
> (makeadd(4))(5,6);
n = 4
11
```

Example 10:
> sumall = proc(L = ...) { var acc, i; acc = 0; for i in L do acc = acc + i; return acc; }
> sumall;
proc(L = ...)
{ var acc, i;
acc = 0;
for i in L do
acc = (acc) + (i);
return acc;
}
> sumall();
0
> sumall(2);
2
> sumall(2,5);
7
> sumall(2,5,7,9,16);
39
> sumall @ [|1,...,10|];
55

See also: return [8.158], externalproc [8.64], void [8.196], quit [8.147], restart [8.157], var [8.194], @ [8.28], bind [8.20], getbacktrace [8.76], error [8.56]

### 8.144 procedure

**Name:** procedure  
defines and assigns a Sollya procedure

**Usage:**

```
procedure identifier(formal parameter1, formal parameter2,..., formal parameter n) { procedure body }
```

```
procedure identifier(formal parameter1, formal parameter2,..., formal parameter n) { procedure body
    return expression; } : void → void
```

```
procedure identifier(formal list parameter = ...) { procedure body } : void → void
```

**Parameters:**

- **identifier** represents the name of the procedure to be defined and assigned
- **formal parameter1, formal parameter2** through **formal parameter n** represent identifiers used as formal parameters
- **formal list parameter** represents an identifier used as a formal parameter for the list of an arbitrary number of parameters
- **procedure body** represents the imperative statements in the body of the procedure
- **expression** represents the expression **procedure** shall evaluate to

**Description:**

- The **procedure** keyword allows for defining and assigning procedures in the Sollya language. It is an abbreviation to a procedure definition using **proc** with the same formal parameters, procedure body and return-expression followed by an assignment of the procedure (object) to the identifier **identifier**. In particular, all rules concerning local variables declared using the **var** keyword apply for **procedure**.

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Example 1:

```plaintext
> procedure succ(n) { return n + 1; }
> succ(5);
6
> 3 + succ(0);
4
> succ;
proc(n)
{
  nop;
  return (n) + (1);
}
```

Example 2:

```plaintext
> procedure myprint(L = ...) { var i; for i in L do i; }
> myprint("Lyon","Nancy","Beaverton","Coye-la-Foret","Amberg","Nizhny Novgorod","Cluj-Napoca");
Lyon
Nancy
Beaverton
Coye-la-Foret
Amberg
Nizhny Novgorod
Cluj-Napoca
```

See also: `proc` (8.143), `var` (8.194), `bind` (8.20), `getbacktrace` (8.76)

### 8.145 QD

Name: QD

short form for `quad`

See also: `quad` (8.146)

### 8.146 quad

Names: `quad`, QD

rounding to the nearest IEEE 754 quad (binary128).

Library names:

- `sollya_obj_t sollya_lib_quad(sollya_obj_t)`
- `sollya_obj_t sollya_lib_quad_obj()`
- `int sollya_lib_is_quad_obj(sollya_obj_t)`
- `sollya_obj_t sollya_lib_build_function_quad(sollya_obj_t)`
- `#define SOLLYA_QD(x) sollya_lib_build_function_quad(x)`

Description:

- `quad` is both a function and a constant.
- As a function, it rounds its argument to the nearest IEEE 754 quad precision (i.e. IEEE754-2008 binary128) number. Subnormal numbers are supported as well as standard numbers: it is the real rounding described in the standard.
- As a constant, it symbolizes the quad precision format. It is used in contexts when a precision format is necessary, e.g. in the commands `round` and `roundcoefficients`. It is not supported for `implementpoly`. See the corresponding help pages for examples.
Example 1:

```
> display=binary!;
> QD(0.1);
1.100110011001100110011001100110011001100110011001100110011001100110011001100110
011001100110011001100110011001100110011001100110011001100110011001101_2 * 2^(-4)
> QD(4.17);
1.000010101110000101000111101011100001010001111010111000010100011110101110000101
00011110110100000101000111101011110111_2 * 2^(2)
> QD(1.011_2 * 2^(-16493));
1.1_2 * 2^(-16493)
```

See also: halfprecision (8.80), single (8.172), double (8.49), doubleextended (8.51), doubledouble (8.50), tripledouble (8.191), roundcoefficients (8.162), implementpoly (8.88), fpminimax (8.71), round (8.161), printsingle (8.141)

8.147 quit

Name: quit

quits Sollya

Usage:

```
quit : void → void
```

Description:

- The command `quit`, when executed, stops the execution of a Sollya script and leaves the Sollya interpreter unless the `quit` command is executed in a Sollya script read into a main Sollya script by `execute` or `#include`.

Upon exiting the Sollya interpreter, all state is thrown away, all memory is deallocated, all bound libraries are unbound and the temporary files produced by `plot` and `externalplot` are deleted.

If the `quit` command does not lead to a halt of the Sollya interpreter, a warning is displayed.

Example 1:

```
> quit;
```

See also: restart (8.157), execute (8.58), plot (8.128), externalplot (8.63), return (8.158)

8.148 range

Name: range

keyword representing a range type

Library name:

SOLLYA_EXTERNALPROC_TYPE_RANGE

Usage:

```
range : type type
```

Description:

- `range` represents the range type for declarations of external procedures by means of `externalproc`.

Remark that in contrast to other indicators, type indicators like `range` cannot be handled outside the `externalproc` context. In particular, they cannot be assigned to variables.

See also: externalproc (8.64), boolean (8.21), constant (8.29), function (8.73), integer (8.92), list of (8.100), string (8.176), object (8.120)
8.149 rationalapprox

Name: rationalapprox
returns a fraction close to a given number.

Library name:
sollya_obj_t sollya_lib_rationalapprox(sollya_obj_t, sollya_obj_t)

Usage:
\texttt{rationalapprox}(x,n) : (constant, integer) \rightarrow function

Parameters:

\begin{itemize}
\item $x$ is a number to approximate.
\item $n$ is a integer (representing a format).
\end{itemize}

Description:

\begin{itemize}
\item \texttt{rationalapprox}(x,n) returns a constant function of the form $a/b$ where $a$ and $b$ are integers. The value $a/b$ is an approximation of $x$. The quality of this approximation is determined by the parameter $n$ that indicates the number of correct bits that $a/b$ should have.
\item The command is not safe in the sense that it is not ensured that the error between $a/b$ and $x$ is less than $2^{-n}$.
\item The following algorithm is used: $x$ is first rounded downwards and upwards to a format of $n$ bits, thus obtaining an interval $[x_l, x_u]$. This interval is then developed into a continued fraction as far as the representation is the same for every elements of $[x_l, x_u]$. The corresponding fraction is returned.
\item Since rational numbers are not a primitive object of Sollya, the fraction is returned as a constant function. This can be quite amazing, because Sollya immediately simplifies a constant function by evaluating it when the constant has to be displayed. To avoid this, you can use \texttt{print} (that displays the expression representing the constant and not the constant itself) or the commands \texttt{numerator} and \texttt{denominator}.
\end{itemize}

Example 1:

\begin{verbatim}
> pi10 = rationalapprox(Pi,10);
> pi50 = rationalapprox(Pi,50);
> pi100 = rationalapprox(Pi,100);
> print( pi10, ": ", dirtysimplify(floor(-log2(abs(pi10-Pi)/Pi))), "bits." );
3.140625 : 11 bits.
> print( pi50, ": ", dirtysimplify(floor(-log2(abs(pi50-Pi)/Pi))), "bits." );
85563208 / 27235615 : 51 bits.
> print( pi100, ": ", dirtysimplify(floor(-log2(abs(pi100-Pi)/Pi))), "bits." );
4422001152019829 / 1407566683404023 : 100 bits.
\end{verbatim}

Example 2:

\begin{verbatim}
> a=0.1;
> b=rationalapprox(a,4);
> numerator(b); denominator(b);
1
10
> print(dirtysimplify(floor(-log2(abs((b-a)/a)))), "bits.");
166 bits.
\end{verbatim}

See also: print (8.138), numerator (8.119), denominator (8.38), rationalmode (8.150)
8.150 rationalmode

Name: rationalmode
  global variable controlling if rational arithmetic is used or not.

Library names:
  void sollya_lib_set_rationalmode_and_print(sollya_obj_t)
  void sollya_lib_set_rationalmode(sollya_obj_t)
  sollya_obj_t sollya_lib_get_rationalmode()

Usage:
  rationalmode = activation value : on|off → void
  rationalmode = activation value ! : on|off → void
  rationalmode : on|off

Parameters:
  • activation value controls if rational arithmetic should be used or not

Description:
  • rationalmode is a global variable. When its value is off, which is the default, Sollya will not use rational arithmetic to simplify expressions. All computations, including the evaluation of constant expressions given on the Sollya prompt, will be performed using floating-point and interval arithmetic. Constant expressions will be approximated by floating-point numbers, which are in most cases faithful roundings of the expressions, when shown at the prompt.
  • When the value of the global variable rationalmode is on, Sollya will use rational arithmetic when simplifying expressions. Constant expressions, given at the Sollya prompt, will be simplified to rational numbers and displayed as such when they are in the set of the rational numbers. Otherwise, floating-point and interval arithmetic will be used to compute a floating-point approximation, which is in most cases a faithful rounding of the constant expression.

Example 1:

| rationalmode=off!;  |
| 19/17 + 3/94;       |
| 1.1495619524405506883604505632040050062578222778473 |
| rationalmode=on!;   |
| 19/17 + 3/94;       |
| 1837 / 1598         |

Example 2:

| rationalmode=off!;  |
| exp(19/17 + 3/94);  |
| 3.1568097739551413675470920894482427634032816281442 |
| rationalmode=on!;   |
| exp(19/17 + 3/94);  |
| 3.1568097739551413675470920894482427634032816281442 |

See also: on (8.123), off (8.122), numerator (8.119), denominator (8.33), simplify (8.170), rationalapprox (8.149), autosimplify (8.16)

8.151 RD

Name: RD
  constant representing rounding-downwards mode.

Library names:
sollya_obj_t sollya_lib_round_down()
int sollya_lib_is_round_down(sollya_obj_t)

Description:

- **RD** is used in command `round` to specify that the value $x$ must be rounded to the greatest floating-point number $y$ such that $y \leq x$.

Example 1:

```
> display=binary!;
> round(Pi,20,RD);
1.1001001000011111101_2 * 2^(1)
```

See also: RZ (8.166), RU (8.165), RN (8.160), round (8.161), floor (8.70)

8.152   `readfile`

Name: `readfile`

reads the content of a file into a string variable

Usage:

```
readfile(filename) : string → string
```

Parameters:

- `filename` represents a character sequence indicating a file name

Description:

- `readfile` opens the file indicated by `filename`, reads it and puts its contents in a character sequence of type `string` that is returned.

If the file indicated by `filename` cannot be opened for reading, a warning is displayed and `readfile` evaluates to an `error` variable of type `error`.

Example 1:

```
> print("Hello world") > "myfile.txt";
> t = readfile("myfile.txt");
> t;
Hello world
```

Example 2:

```
> verbosity=1!;
> readfile("afile.txt");
Warning: the file "afile.txt" could not be opened for reading.
Warning: at least one of the given expressions or a subexpression is not correctly typed
or its evaluation has failed because of some error on a side-effect.
```

See also: parse (8.125), execute (8.58), write (8.198), print (8.138), bashexecute (8.18), error (8.56)
8.153 readxml

Name: readxml
reads an expression written as a MathML-Content-Tree in a file

Library name:
sollya_obj_t sollya_lib_readxml(sollya_obj_t)

Usage:

readxml(filename) : string → function | error

Parameters:

- filename represents a character sequence indicating a file name

Description:

- readxml(filename) reads the first occurrence of a lambda application with one bounded variable on
  applications of the supported basic functions in file filename and returns it as a Sollya functional
  expression.

If the file filename does not contain a valid MathML-Content tree, readxml tries to find an 'annota-
notation encoding' markup of type 'sollya/text'. If this annotation contains a character sequence
that can be parsed by parse, readxml returns that expression. Otherwise readxml displays a
warning and returns an error variable of type error.

Example 1:

> readxml("readxmlexample.xml");
2 + x + exp(sin(x))

See also: printxml (8.142), readFile (8.152), parse (8.125), error (8.56)

8.154 relative

Name: relative
indicates a relative error for externalplot, fpminimax or supnorm

Library names:
sollya_obj_t sollya_lib_relative()
int sollya_lib_is_relative(sollya_obj_t)

Usage:

relative : absolute|relative

Description:

- The use of relative in the command externalplot indicates that during plotting in externalplot
  a relative error is to be considered.
  See externalplot for details.
- Used with fpminimax, relative indicates that fpminimax must try to minimize the relative
  error.
  See fpminimax for details.
- When given in argument to supnorm, relative indicates that a relative error is to be considered
  for supremum norm computation.
  See supnorm for details.

Example 1:
> bashexecute("gcc -fPIC -c externalplotexample.c");
> bashexecute("gcc -shared -o externalplotexample externalplotexample.o -lgmp -lmpfr");
> externalplot("./externalplotexample",absolute,exp(x),[-1/2;1/2],12,perturb);

See also: externalplot [8.63], fpminimax [8.71], absolute [8.2], bashexecute [8.18], supnorm [8.180]

8.155 remez

Name: remez

computes the minimax of a function on an interval.

Library names:

sollya_obj_t sollya_lib_remez(sollya_obj_t, sollya_obj_t, sollya_obj_t, ...)
sollya_obj_t sollya_lib_v_remez(sollya_obj_t, sollya_obj_t, sollya_obj_t, va_list)

Usage:

remez(f, n, range, w, quality, bounds) : (function, integer, range, function, constant, range) → function
remez(f, L, range, w, quality, bounds) : (function, list, range, function, constant, range) → function

Parameters:

- f is the function to be approximated
- n is the degree of the polynomial that must approximate f
- L is a list of integers or a list of functions and indicates the basis for the approximation of f
- range is the interval where the function must be approximated
- w (optional) is a weight function. Default is 1.
- quality (optional) is a parameter that controls the quality of the returned polynomial p, with respect to the exact minimax p*. Default is 1e-5.
- bounds (optional) is a parameter that allows the user to make the algorithm stop earlier, whenever a given accuracy is reached or a given accuracy is proved unreachable. Default is [0, +∞].

Description:

- remez computes an approximation of the function f with respect to the weight function w on the interval range. More precisely, it searches p such that \|pw - f\|_\infty is (almost) minimal among all p of a certain form. The norm is the infinity norm, e.g. \|g\|_\infty = \max\{|g(x)|, x \in range\}.
- If w = 1 (the default case), it consists in searching the best polynomial approximation of f with respect to the absolute error. If f = 1 and w is of the form 1/g, it consists in searching the best polynomial approximation of g with respect to the relative error.
- If n is given, p is searched among the polynomials with degree not greater than n. If L is given and is a list of integers, p is searched as a linear combination of monomials X^k where k belongs to L. In the case when L is a list of integers, it may contain ellipses but cannot be end-elliptic. If L is given and is a list of functions g_k, p is searched as a linear combination of the g_k. In that case L cannot contain ellipses. It is the user responsibility to check that the g_k are linearly independent over the interval range. Moreover, the functions w · g_k must be at least twice differentiable over range. If these conditions are not fulfilled, the algorithm might fail or even silently return a result as if it successfully found the minimax, though the returned p is not optimal.
The polynomial is obtained by a convergent iteration called Remez’ algorithm (and an extension of this algorithm, due to Stiefel). The algorithm computes a sequence \( p_1, \ldots, p_k, \ldots \) such that 
\[
e_k = \|p_k w - f\|_{\infty}
\]
converges towards the optimal value \( e \). The algorithm is stopped when the relative error between \( e_k \) and \( e \) is less than \( \text{quality} \).

The optional argument \( \text{bounds} \) is an interval \([\varepsilon_l, \varepsilon_u]\) with the following behavior:

- if, during the algorithm, we manage to prove that \( \varepsilon_u \) is unreachable, we stop the algorithm returning the last computed polynomial.
- if, during the algorithm, we obtain a polynomial with an error smaller than \( \varepsilon_l \), we stop the algorithm returning that polynomial.
- otherwise we loop until we find an optimal polynomial with the required quality, as usual.

Examples of use:

- \([0, +\infty]\) (compute the optimal polynomial with the required quality)
- \([\varepsilon_u]\) (stops as soon as a polynomial achieving \( \varepsilon_u \) is obtained or as soon as such a polynomial is proved not to exist).
- \([0, \varepsilon_u]\) (finds the optimal polynomial, but provided that its error is smaller than \( \varepsilon_u \)).
- \([\varepsilon_l, +\infty]\) (stops as soon as a polynomial achieving \( \varepsilon_l \) is obtained. If such a polynomial does not exist, returns the optimal polynomial).

Example 1:

```matlab
> p = remez(exp(x),5,[0;1]);
> degree(p);
5
> dirtyinfnorm(p-exp(x),[0;1]);
1.129569815109614870717193829266077607222634589363e-6
```

Example 2:

```matlab
> p = remez(1,[0,2,4,6,8],[0,Pi/4],1/cos(x));
> canonical=on!;
> p;
0.9999999994339732180959690352543887130348096061124 + -0.499999997155685776877
20530637215446709467222259 * x^-2 + 4.1666613234736330099410594805702758701132
20089059e-2 * x^-4 + -1.3886529147145693651355523880319714051047635695061e-3 * x^-6 + 2.4372679177224179934800328511009205218114284220126e-5 * x^-8
```

Example 3:

```matlab
> p1 = remez(exp(x),5,[0;1],default,1e-5);
> p2 = remez(exp(x),5,[0;1],default,1e-10);
> p3 = remez(exp(x),5,[0;1],default,1e-15);
> dirtyinfnorm(p1-exp(x),[0;1]);
1.129569815109614870717193829266077607222634589363e-6
> dirtyinfnorm(p2-exp(x),[0;1]);
1.12956980227478675612619255125474525171079325793124e-6
> dirtyinfnorm(p3-exp(x),[0;1]);
1.12956980227478675612619255125474525171079325793124e-6
```

Example 4:
Example 5:

\[
\begin{align*}
&> f = \sin(x); \\
&> I = [-3b-5;-1b-1074]; \\
&> \text{time}(popt = \text{remez}(1, [1, 3, 4, 5, 7, 8, 9], I, 1/f)); \\
&> 0.165646661999999999999999995895879399697 \\
&> \text{time}(p1 = \text{remez}(1, [1, 3, 4, 5, 7, 8, 9], I, 1/f, \text{default}, [0, 1b-73])); \\
&> 0.1247007759999999999999999999999795672675522 \\
&> \text{time}(p2 = \text{remez}(1, [1, 3, 4, 5, 7, 8, 9], I, 1/f, \text{default}, [3b-72, +@Inf@])); \\
&> 0.1370361279999999999999999999999962799427707 \\
&> \text{dirtyinfnorm}(\text{popt/f-1, I}); \\
&> 2.067503145411283509803930810531156576504665659064e-22 \\
&> \text{dirtyinfnorm}(\text{p1/f-1, I}); \\
&> 2.4971126837493110470637913808914046704452778960875e-22 \\
&> \text{dirtyinfnorm}(\text{p2/f-1, I}); \\
&> 5.456724553631543524637697723125383426524875696947e-22 \\
&> > 1b-73; \\
&> 1.05879118406787542383540312584955245256423950195312e-22 \\
&> > 3b-72; \\
&> 6.35274710440725254301248187550973147153854370117187e-22 \\
\end{align*}
\]

See also: \texttt{dirtyinfnorm} \cite{8.43}, \texttt{infnorm} \cite{8.91}, \texttt{fpminimax} \cite{8.71}, \texttt{guessdegree} \cite{8.79}, \texttt{taylorform} \cite{8.186}, \texttt{taylor} \cite{8.185}

8.156 rename

Name: \texttt{rename}

rename the free variable.

Library name:

\texttt{void sollya\_lib\_name\_free\_variable(const char *)}

Usage:

\texttt{rename(ident1,ident2) : void}

Parameters:

- \textit{ident1} is the current name of the free variable.
- \textit{ident2} is a fresh name.

Description:

- \texttt{rename} permits a change of the name of the free variable. Sollya can handle only one free variable at a time. The first time in a session that an unbound name is used in a context where it can be interpreted as a free variable, the name is used to represent the free variable of Sollya. In the following, this name can be changed using \texttt{rename}.
- Be careful: if \textit{ident2} has been set before, its value will be lost. Use the command \texttt{isbound} to know if \textit{ident2} is already used or not.
If \textit{ident1} is not the current name of the free variable, an error occurs.

If \textbf{rename} is used at a time when the name of the free variable has not been defined, \textit{ident1} is just ignored and the name of the free variable is set to \textit{ident2}.

It is always possible to use the special keyword \_x\_ to denote the free variable. Hence \textit{ident1} can be \_x\_.

**Example 1:**

\begin{verbatim}
> f=sin(x);
> f;
sin(x)
> rename(x,y);
> f;
  sin(y)
\end{verbatim}

**Example 2:**

\begin{verbatim}
> a=1;
> f=sin(x);
> rename(x,a);
> a;
  a
> f;
  sin(a)
\end{verbatim}

**Example 3:**

\begin{verbatim}
> verbosity=1!;
> f=sin(x);
> rename(y, z);
Warning: the current free variable is named "x" and not "y". Can only rename the free variable.
The last command will have no effect.
> rename(_x_, z);
Information: the free variable has been renamed from "x" to "z".
\end{verbatim}

**Example 4:**

\begin{verbatim}
> verbosity=1!;
> rename(x,y);
Information: the free variable has been named "y".
> isbound(x);
false
> isbound(y);
true
\end{verbatim}

See also: \textbf{isbound} (8.94)

**8.157 restart**

Name: \textbf{restart}

- brings \texttt{Sollya} back to its initial state

**Usage:**

\begin{verbatim}
restart : void → void
\end{verbatim}

**Description:**
• The command `restart` brings Sollya back to its initial state. All current state is abandoned, all libraries unbound and all memory freed.

    The `restart` command has no effect when executed inside a Sollya script read into a main Sollya script using `execute`. It is executed in a Sollya script included by a `#include` macro.

    Using the `restart` command in nested elements of imperative programming like for or while loops is possible. Since in most cases abandoning the current state of Sollya means altering a loop invariant, warnings for the impossibility of continuing a loop may follow unless the state is rebuilt.

**Example 1:**

```plaintext
> print(exp(x));
exp(x)
> a = 3;
> restart;
The tool has been restarted.
> print(x);
x
> a;
Warning: the identifier "a" is neither assigned to, nor bound to a library function nor external procedure, nor equal to the current free variable. Will interpret "a" as "x".
x
```

**Example 2:**

```plaintext
> print(exp(x));
exp(x)
> for i from 1 to 10 do {
    print(i);
    if (i == 5) then restart;
};
1
2
3
4
5
The tool has been restarted.
Warning: the tool has been restarted inside a for loop.
The for loop will no longer be executed.
```

**Example 3:**

...
> print(exp(x));
> exp(x)
> a = 3;
> for i from 1 to 10 do {
>    print(i);
>    if (i == 5) then {
>       restart;
>       i = 7;
>    }
> }
> 1 2 3 4 5
The tool has been restarted.
8 9 10
> print(x);
x
> a;
Warning: the identifier "a" is neither assigned to, nor bound to a library function nor external procedure, nor equal to the current free variable.
Will interpret "a" as "x".
x
See also: quit [8.147], execute [8.58]

8.158 return

Name: return

indicates an expression to be returned in a procedure

Usage:

\[ \text{return expression : void} \]

Parameters:

- \text{expression} represents the expression to be returned

Description:

- The keyword \text{return} allows for returning the (evaluated) expression \text{expression} at the end of a begin-end-block (-block) used as a \text{Sollya} procedure body. See \text{proc} for further details concerning \text{Sollya} procedure definitions.

Statements for returning expressions using \text{return} are only possible at the end of a begin-end-block used as a \text{Sollya} procedure body. Only one \text{return} statement can be given per begin-end-block.

- If at the end of a procedure definition using \text{proc} no \text{return} statement is given, a \text{return void} statement is implicitly added. Procedures, i.e. procedure objects, when printed out in \text{Sollya} defined with an implicit \text{return void} statement are displayed with this statement explicitly given.

Example 1:
Example 2:

```sollya
> hey = proc(s) { print("Hello",s); }; 
> hey("world"); 
Hello world
> hey; 
proc(s) 
{ 
print("Hello", s); 
return void; 
}
```

See also: `proc` [8.143], `void` [8.196]

### 8.159 revert

**Name:** revert

revert a list.

**Library name:**

- `sollya_obj_t sollya_lib_revert(sollya_obj_t)`

**Usage:**

```
revert(L) : list → list
```

**Parameters:**

- `L` is a list.

**Description:**

- `revert(L)` returns the same list, but with its elements in reverse order.
- If `L` is an end-elliptic list, `revert` will fail with an error.

**Example 1:**

```
> revert([| 1 |]); 
[| 1 |]
```

**Example 2:**

```
> revert([|2,3,5,2,1,4|]); 
[|4, 1, 2, 5, 3, 2|]
```

See also: `sort` [8.174], `head` [8.81], `tail` [8.182]
8.160 RN

Name: RN
constant representing rounding-to-nearest mode.

Library names:
sollya_obj_t sollya_lib_round_to_nearest()
int sollya_lib_is_round_to_nearest(sollya_obj_t)

Description:
• RN is used in command round to specify that the value must be rounded to the nearest representable floating-point number.

Example 1:

> display=binary!;
> round(Pi,20,RN);
1.100100100001111111_2 * 2^1

See also: RD [8.151], RU [8.155], RZ [8.166], round [8.161], nearestint [8.114]

8.161 round

Name: round
rounds a number to a floating-point format.

Library name:
sollya_obj_t sollya_lib_round(sollya_obj_t, sollya_obj_t, sollya_obj_t)

Usage:
round(x,n,mode) : (constant, integer, RN|RZ|RU|RD) → constant
round(x,format,mode) : (constant, HP|halfprecision|SG|single|D|double|DE|doubleextended|DD|doubledouble|QD|quad|TD|tripledouble, RN|RZ|RU|RD) → constant

Parameters:
• x is a constant to be rounded.
• n is the precision of the target format.
• format is the name of a supported floating-point format.
• mode is the desired rounding mode.

Description:
• If used with an integer parameter n, round(x,n,mode) rounds x to a floating-point number with precision n, according to rounding-mode mode.
• If used with a format parameter format, round(x,format,mode) rounds x to a floating-point number in the floating-point format format, according to rounding-mode mode.
• Subnormal numbers are handled for the case when format is one of halfprecision, single, double, doubleextended, doubledouble, quad or triplicatedouble. Otherwise, when format is an integer, round does not take any exponent range into consideration, i.e. typically uses the full exponent range of the underlying MPFR library.
• It is worth mentioning that the result of round does not depend on the current global precision of Sollya, unless a warning is displayed. As a matter of fact, round rounds the given constant or constant expression x applying all rules of IEEE 754 correct rounding, unless a warning is displayed. The result of round is hence the floating-point value of the given precision n or format format that is nearest to x (resp. just below or just above, depending on mode), computed as if infinite precision were used for evaluating the constant x, unless a warning is displayed.
Example 1:
> display=binary!;
> round(Pi,20,RN);
1.100100100001111111_2 * 2^(1)

Example 2:
> printdouble(round(exp(17),53,RU));
0x417709348c0ea4f9
> printdouble(D(exp(17)));
0x417709348c0ea4f9

Example 3:
> display=binary!;
> a=2^(-1100);
> round(a,53,RN);
1_2 * 2^(-1100)
> round(a,D,RN);
0
> double(a);
0

See also: RN [8.160], RD [8.151], RU [8.165], RZ [8.166], halfprecision [8.80], single [8.172],
double [8.49], doubleextended [8.51], doubledouble [8.50], quad [8.146], tripledouble [8.191],
roundcoefficients [8.162], roundcorrectly [8.163], printdouble [8.139], printsingle [8.141], ceil [8.23], floor [8.70], nearestint [8.114]

8.162 roundcoefficients

Name: roundcoefficients
rounds the coefficients of a polynomial to classical formats.

Library name:
sollya_obj_t sollya_lib_roundcoefficients(sollya_obj_t, sollya_obj_t)

Usage:
roundcoefficients(p, L) : (function, list) \rightarrow function

Parameters:
- p is a function. Usually a polynomial.
- L is a list of formats.

Description:
- If p is a polynomial and L a list of floating-point formats, roundcoefficients(p, L) rounds each coefficient of p to the corresponding format in L.
- If p is not a polynomial, roundcoefficients does not do anything.
- If L contains other elements than HP, halfprecision, SG, single, D, double, DE, doubleextended, DD, doubledouble, QD, quad, TD and tripledouble, an error occurs.
- The coefficients in p corresponding to $X^i$ is rounded to the format L[i]. If L does not contain enough elements (e.g. if length(L) < degree(p)+1), a warning is displayed. However, the coefficients corresponding to an element of L are rounded. The trailing coefficients (that do not have a corresponding element in L) are kept with their own precision. If L contains too much elements, the trailing useless elements are ignored. In particular L may be end-elliptic in which case roundcoefficients has the natural behavior.
Example 1:

```
> p = exp(1) + x*(exp(2) + x*exp(3));
> display = binary!
> roundcoefficients(p, ['|DD,D,D|']);
1.0101101111110000101010000011101001010110011011000010101001010101111111101001
001010100000000100011110101000010100101010001001010010100101001001001001001001001001001001
00000011102 * 2^(-4)))
> roundcoefficients(p, ['|DD,D...|']);
1.0101101111110000101010000011101001010110011011000010101001010101111111101001
0010101000000001000111101010000101001010100010010100101001001001001001001001001001001001
00000011102 * 2^(-4)))
```

Example 2:

```
> f = sin(exp(1)*x);
> display = binary!
> f;
sin(x * (1.0101101111110000101010000011101001010110011011000010101001010101111111101001
0010101000000001000111101010000101001010100010010100101001001001001001001001001001001001
000000111102 * 2^(-1)))
> roundcoefficients(f, ['|D...|']);
sin(x * (1.0101101111110000101010000011101001010110011011000010101001010101111111101001
0010101000000001000111101010000101001010100010010100101001001001001001001001001001001001
000000111102 * 2^(-1)))
```

Example 3:

```
> p = exp(1) + x*(exp(2) + x*exp(3));
> verbosity = 1!
> display = binary!
> roundcoefficients(p, ['|DD,D|']);
Warning: the number of the given formats does not correspond to the degree of the given polynomial.
Warning: the 0th coefficient of the given polynomial does not evaluate to a floating-point constant without any rounding.
Will evaluate the coefficient in the current precision in floating-point before rounding to the target format.
Warning: the 1th coefficient of the given polynomial does not evaluate to a floating-point constant without any rounding.
Will evaluate the coefficient in the current precision in floating-point before rounding to the target format.
Warning: rounding may have happened.
1.0101101111110000101010000011101001010110011011000010101001010101111111101001
0010101000000001000111101010000101001010100010010100101001001001001001001001001001001
00000011102 * 2^(-4)))
```

See also: halfprecision (8.80), single (8.172), double (8.49), doubleextended (8.51), doubledouble (8.50), quad (8.146), tripledouble (8.191), fpminimax (8.71), remez (8.155), implementpoly (8.88), subpoly (8.177)
8.163 roundcorrectly

Name: roundcorrectly

rounds an approximation range correctly to some precision

Library name:

sollya_obj_t sollya_lib_roundcorrectly(sollya_obj_t)

Usage:

\texttt{roundcorrectly}(range) : range \rightarrow \text{constant}

Parameters:

- \texttt{range} represents a range in which an exact value lies

Description:

- Let \texttt{range} be a range of values, determined by some approximation process, safely bounding an unknown value \( v \). The command \texttt{roundcorrectly}(range) determines a precision such that for this precision, rounding to the nearest any value in \texttt{range} yields to the same result, i.e. to the correct rounding of \( v \).

If no such precision exists, a warning is displayed and \texttt{roundcorrectly} evaluates to NaN.

Example 1:

\begin{verbatim}
> printbinary(roundcorrectly([1.010001_2; 1.0101_2]));
1.01_2
> printbinary(roundcorrectly([1.00001_2; 1.001_2]));
1_2
\end{verbatim}

Example 2:

\begin{verbatim}
> roundcorrectly([-1; 1]);
NaN
\end{verbatim}

See also: \texttt{round [8.161]}, \texttt{mantissa [8.106]}, \texttt{exponent [8.62]}, \texttt{precision [8.136]}

8.164 roundingwarnings

Name: roundingwarnings

global variable controlling whether or not a warning is displayed when roundings occur.

Library names:

void sollya_lib_set_roundingwarnings_and_print(sollya_obj_t)
void sollya_lib_set_roundingwarnings(sollya_obj_t)
sollya_obj_t sollya_lib_get_roundingwarnings()

Usage:

\texttt{roundingwarnings} = activation value : on|off \rightarrow \text{void}
\texttt{roundingwarnings} = activation value ! : on|off \rightarrow \text{void}
\texttt{roundingwarnings} : on|off

Parameters:

- \texttt{activation value} controls if warnings should be shown or not

Description:

- \texttt{roundingwarnings} is a global variable. When its value is \texttt{on}, warnings are emitted in appropriate verbosity modes (see \texttt{verbosity}) when roundings occur. When its value is \texttt{off}, these warnings are suppressed.
• This mode depends on a verbosity of at least 1. See verbosity for more details.
• Default is on when the standard input is a terminal and off when Sollya input is read from a file.

Example 1:

```plaintext
> verbosity=1!
> roundingwarnings = on;
Rounding warning mode has been activated.
> exp(0.1);
Warning: Rounding occurred when converting the constant "0.1" to floating-point with 165 bits.
If safe computation is needed, try to increase the precision.
Warning: rounding has happened. The value displayed is a faithful rounding to 16 5 bits of the true result.
1.1051709180756476248117078264902466682245471947375
> roundingwarnings = off;
Rounding warning mode has been deactivated.
> exp(0.1);
1.1051709180756476248117078264902466682245471947375
```

See also: on [8.123], off [8.122], verbosity [8.195], midpointmode [8.109], rationalmode [8.150], suppressmessage [8.181], unsuppressmessage [8.193], showmessagenumbers [8.169], getsuppressedmessages [8.77]

8.165 RU

Name: RU
constant representing rounding-upwards mode.

Library names:
sollya_obj_t sollya_lib_round_up()
int sollya_lib_is_round_up(sollya_obj_t)

Description:
• RU is used in command round to specify that the value \(x\) must be rounded to the smallest floating-point number \(y\) such that \(x \leq y\).

Example 1:

```plaintext
> display=binary!;
> round(Pi,20,RU);
1.100100100001111111_2 * 2^(1)
```

See also: RZ [8.166], RD [8.151], RN [8.160], round [8.161], ceil [8.23]

8.166 RZ

Name: RZ
constant representing rounding-to-zero mode.

Library names:
sollya_obj_t sollya_lib_round_towards_zero()
int sollya_lib_is_round_towards_zero(sollya_obj_t)

Description:
• RZ is used in command round to specify that the value must be rounded to the closest floating-point number towards zero. It just consists in truncating the value to the desired format.
Example 1:

```plaintext
> display=binary!;
> round(Pi,20,RZ);
1.100100100001111101_2 * 2^(1)
```

See also: RD (8.151), RU (8.165), RN (8.160), round (8.161), floor (8.70), ceil (8.23)

### 8.167 `searchgal`

**Name:** `searchgal`

Searches for a preimage of a function such that the rounding the image yields an error smaller than a constant.

**Library name:**

```plaintext
sollya_obj_t sollya_lib_searchgal(sollya_obj_t, sollya_obj_t, sollya_obj_t,
sollya_obj_t, sollya_obj_t, sollya_obj_t)
```

**Usage:**

`searchgal(function, start, preimage precision, steps, format, error bound) : (function, constant, integer, HP|halfprecision|SG|single|D|double|DE|doubleextemed|DD|doubledouble|QD|quad|TD|tripledouble, constant) → list`

`searchgal(list of functions, start, preimage precision, steps, list of format, list of error bounds) : (list, constant, integer, integer, list, list) → list`

**Parameters:**

- `function` represents the function to be considered
- `start` represents a value around which the search is to be performed
- `preimage precision` represents the precision (discretization) for the eligible preimage values
- `steps` represents the binary logarithm ($\log_2$) of the number of search steps to be performed
- `format` represents the format the image of the function is to be rounded to
- `error bound` represents an upper bound on the relative rounding error when rounding the image
- `list of functions` represents the functions to be considered
- `list of formats` represents the respective formats the images of the functions are to be rounded to
- `list of error bounds` represents an upper bound on the relative rounding error when rounding the image

**Description:**

The command `searchgal` searches for a preimage $z$ of function `function` or a list of functions `list of functions` such that $z$ is a floating-point number with `preimage precision` significant mantissa bits and the image $y$ of the function, respectively each image $y_i$ of the functions, rounds to format `format` respectively to the corresponding format in `list of format` with a relative rounding error less than `error bound` respectively the corresponding value in `list of error bounds`. During this search, at most $2^{\text{steps}}$ attempts are made. The search starts with a preimage value equal to `start`. This value is then increased and decreased by 1 ulp in precision `preimage precision` until a value is found or the step limit is reached.

If the search finds an appropriate preimage $z$, `searchgal` evaluates to a list containing this value. Otherwise, `searchgal` evaluates to an empty list.

**Example 1:**
Example 2:

```latex
\begin{verbatim}
> f = exp(x);
> s = searchgal(f,2,53,18,DD,1b-112);
> if (s != []]) then {
    v = s[0];
    print("The rounding error is 2^("+\text{evaluate}(log2(abs(DD(f)/f - 1)),v),")");
} else print("No value found");
\end{verbatim}
```

The rounding error is $2^{(-112.1068784388093801482069898258358542322113874177832)}$

Example 3:

```latex
\begin{verbatim}
> searchgal([[sin(x),cos(x)],[1,53,15,[[D,D]],[[1b-62,1b-60]]]);
\end{verbatim}
```

See also: `round` [8.161], `double` [8.49], `doubledouble` [8.50], `tripledouble` [8.191], `evaluate` [8.57], `worstcase` [8.197]

### 8.168 SG

Name: **SG**
short form for **single**

See also: `single` [8.172]

#### 8.169 showmessagenumbers

Name: **showmessagenumbers**
activates, deactivates or inspects the state variable controlling the displaying of numbers for messages

Library names:
- `void sollya_lib_set_showmessagenumbers_and_print(sollya_obj_t)`
- `void sollya_lib_set_showmessagenumbers(sollya_obj_t)`
- `sollya_obj_t sollya_lib_get_showmessagenumbers()`

Usage:

- `showmessagenumbers = activation value : on|off → void`
- `showmessagenumbers = activation value ! : on|off → void`
- `showmessagenumbers : on|off`

Parameters:
- `activation value` represents `on` or `off`, i.e. activation or deactivation

Description:
- An assignment `showmessagenumbers = activation value`, where `activation value` is one of `on` or `off`, activates respectively deactivates the displaying of numbers for warning and information messages. Every Sollya warning or information message (that is not fatal to the tool’s execution) has a message number. By default, these numbers are not displayed when a message is output. When message number displaying is activated, the message numbers are displayed together with the message. This allows the user to recover the number of a particular message in order to suppress resp. unsuppress the displaying of this particular message (see `suppressmessage` and `unsuppressmessage`).

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- The user should be aware of the fact that message number display activation resp. deactivation through `showmessagenumbers` does not affect message displaying in general. For instance, even with message number displaying activated, messages with only displayed when general verbosity and rounding warning mode are set accordingly.

- If the assignment `showmessagenumbers = activation value` is followed by an exclamation mark, no message indicating the new state is displayed. Otherwise the user is informed of the new state of the global mode by an indication.

Example 1:

```plaintext
> verbosity = 1;
The verbosity level has been set to 1.
> 0.1;
Warning: Rounding occurred when converting the constant "0.1" to floating-point with 165 bits.
If safe computation is needed, try to increase the precision.
0.1
> showmessagenumbers = on;
Displaying of message numbers has been activated.
> 0.1;
Warning (174): Rounding occurred when converting the constant "0.1" to floating-point with 165 bits.
If safe computation is needed, try to increase the precision.
0.1
> showmessagenumbers;
on
> showmessagenumbers = off!;
> 0.1;
Warning: Rounding occurred when converting the constant "0.1" to floating-point with 165 bits.
If safe computation is needed, try to increase the precision.
0.1
```

Example 2:
> showmessagenumbers = on;
Displaying of message numbers has been activated.
> verbosity = 1;
The verbosity level has been set to 1.
> diff(0.1 * x + 1.5 * x^2);
Warning (174): Rounding occurred when converting the constant "0.1" to floating-
point with 165 bits.
If safe computation is needed, try to increase the precision.
0.1 + x * 3
> verbosity = 0;
The verbosity level has been set to 0.
> diff(0.1 * x + 1.5 * x^2);
0.1 + x * 3
> verbosity = 12;
The verbosity level has been set to 12.
> diff(0.1 * x + 1.5 * x^2);
Warning (174): Rounding occurred when converting the constant "0.1" to floating-
point with 165 bits.
If safe computation is needed, try to increase the precision.
Information (196): formally differentiating a function.
Information (197): differentiating the expression '0.1 * x + 1.5 * x^2'
Information (195): expression '0.1 + 2 * 1.5 * x' has been simplified to express-
ion '0.1 + 3 * x'.
0.1 + x * 3

See also: getsuppressedmessages [8.77], suppressmessage [8.181], unsuppressmessage [8.193],
verbosity [8.195], roundingwarnings [8.164]

8.170 simplify

Name: simplify
simplifies an expression representing a function

Library name:
  sollya_obj_t sollya_lib_simplify(sollya_obj_t)

Usage:

    simplify(function) : function → function

Parameters:

  • function represents the expression to be simplified

Description:

  • The command simplify simplifies the expression given in argument representing the function
    function. The command simplify does not endanger the safety of computations even in Sollya’s
    floating-point environment: the function returned is mathematically equal to the function function.

    Remark that the simplification provided by simplify is not perfect: they may exist simpler equiva-
    lent expressions for expressions returned by simplify.

Example 1:

    > print(simplify((6 + 2) + (5 + exp(0)) * x));
    8 + 6 * x

Example 2:
Example 3:

```plaintext
> print(simplify((log(x - x + 1) + asin(1))) - (atan(1) * 2));
(\pi) / 2 - (\pi) / 4 * 2
```

See also: `dirtysimplify` (8.45), `autosimplify` (8.16), `rationalmode` (8.150), `horner` (8.85)

### 8.171 `sin`

**Name:** `sin`  
the sine function.

**Library names:**
- `sollya_obj_t sollya_lib_sin(sollya_obj_t)`  
- `sollya_obj_t sollya_lib_build_function_sin(sollya_obj_t)`  
- `#define SOLLYA_SIN(x) sollya_lib_build_function_sin(x)`

**Description:**
- `sin` is the usual sine function.
- It is defined for every real number $x$.

See also: `asin` (8.11), `cos` (8.30), `tan` (8.183)

### 8.172 `single`

**Names:** `single`, `SG`  
rounding to the nearest IEEE 754 single (binary32).

**Library names:**
- `sollya_obj_t sollya_lib_single(sollya_obj_t)`  
- `sollya_obj_t sollya_lib_single_obj()`  
- `int sollya_lib_is_single_obj(sollya_obj_t)`  
- `sollya_obj_t sollya_lib_build_function_single(sollya_obj_t)`  
- `#define SOLLYA_SG(x) sollya_lib_build_function_single(x)`

**Description:**
- `single` is both a function and a constant.
- As a function, it rounds its argument to the nearest IEEE 754 single precision (i.e. IEEE754-2008 binary32) number. Subnormal numbers are supported as well as standard numbers: it is the real rounding described in the standard.
- As a constant, it symbolizes the single precision format. It is used in contexts when a precision format is necessary, e.g. in the commands `round` and `roundcoefficients`. In is not supported for `implementpoly`. See the corresponding help pages for examples.

**Example 1:**

```plaintext
> display=binary!;
> SG(0.1);
1.1001100110011001101_2 * 2^(-4)
> SG(4.17);
1.000010101110000101001_2 * 2^(2)
> SG(1.011_2 * 2^(-1073));
0
```
8.173 sinh

Name: sinh
the hyperbolic sine function.

Library names:

sollya_obj_t sollya_lib_sinh(sollya_obj_t)
sollya_obj_t sollya_lib_build_function_sinh(sollya_obj_t)
#define SOLLYA_SINH(x) sollya_lib_build_function_sinh(x)

Description:

- sinh is the usual hyperbolic sine function: \( \sinh(x) = \frac{e^x - e^{-x}}{2} \).
- It is defined for every real number \( x \).

See also: asinh (8.12), cosh (8.31), tanh (8.184)

8.174 sort

Name: sort
sorts a list of real numbers.

Library name:

sollya_obj_t sollya_lib_sort(sollya_obj_t)

Usage:

sort(L) : list \rightarrow list

Parameters:

- \( L \) is a list.

Description:

- If \( L \) contains only constant values, sort\( (L) \) returns the same list, but sorted in increasing order.
- If \( L \) contains at least one element that is not a constant, the command fails with a type error.
- If \( L \) is an end-elliptic list, sort will fail with an error.

Example 1:

```plaintext
> sort([1 |]);
[1]
> sort([[1,2,3,5,2,1,4]]);
[1, 2, 3, 4, 5]
```

See also: revert (8.159)

8.175 sqrt

Name: sqrt
square root.

Library names:

sollya_obj_t sollya_lib_sqrt(sollya_obj_t)
sollya_obj_t sollya_lib_build_function_sqrt(sollya_obj_t)
#define SOLLYA_SQRT(x) sollya_lib_build_function_sqrt(x)

Description:
• **sqrt** is the square root, e.g. the inverse of the function square: $\sqrt{y}$ is the unique positive $x$ such that $x^2 = y$.

• It is defined only for $x$ in $[0; +\infty]$.

### 8.176 string

Name: **string**

- keyword representing a string type

Library name:

SOLLYA_EXTERNALPROC_TYPE_STRING

Usage:

```plaintext
string : type type
```

Description:

- **string** represents the string type for declarations of external procedures by means of `externalproc`. Remark that in contrast to other indicators, type indicators like `string` cannot be handled outside the `externalproc` context. In particular, they cannot be assigned to variables.

See also: `externalproc` (8.64), `boolean` (8.21), `constant` (8.29), `function` (8.73), `integer` (8.92), `list of` (8.100), `range` (8.148), `object` (8.120)

### 8.177 subpoly

Name: **subpoly**

- restricts the monomial basis of a polynomial to a list of monomials

Library name:

```plaintext
sollya_obj_t sollya_lib_subpoly(sollya_obj_t, sollya_obj_t)
```

Usage:

```plaintext
subpoly(polynomial, list) : (function, list) → function
```

Parameters:

- **polynomial** represents the polynomial the coefficients are taken from
- **list** represents the list of monomials to be taken

Description:

- **subpoly** extracts the coefficients of a polynomial **polynomial** and builds up a new polynomial out of those coefficients associated to monomial degrees figuring in the list **list**.

If **polynomial** represents a function that is not a polynomial, subpoly returns 0.

If **list** is a list that is end-elliptic, let be $j$ the last value explicitly specified in the list. All coefficients of the polynomial associated to monomials greater or equal to $j$ are taken.

Example 1:

```
> p = taylor(exp(x),5,0);
> s = subpoly(p,[1,3,5]);
> print(p);
1 + x * (1 + x * (0.5 + x * (1 / 6 + x * (1 / 24 + x * 1 / 120))))
> print(s);
  x * (1 + x^2 * (1 / 6 + x^2 / 120))
```

Example 2:
Example 3:

```plaintext
> p = remez(atan(x), 10, [-1, 1]);
> subpoly(p, [[1, 3, 5 ...]]);
```

```
x * (0.99986632941452949026018468446163586361700915018232 + x^2 * (-0.3303047850245536779405988443130926433421739 + x^2 * (0.1801592931781875664229885693072e-9 + x * (2.284558411542478285112501565358576642429885693072e-9 + x^2 * (0.1801592931781875664229885693072e-9 + x * (2.284558411542478285112501565358576642429885693072e-9 + x * (-8.515634906411113778955005529960618449777507560037485e-2 + x * (-2.717563490641113778955005529960618449777507560037485e-2 + x * (2.084511343071147293732e-9 + x * 0.99986632941452949026018468446163586361700915018232))))))))))
```

See also: `roundcoefficients` [8.162], `taylor` [8.185], `remez` [8.155], `fpminimax` [8.71], `implementpoly` [8.88]

### 8.178 substitute

**Name:** substitute

replaces the occurrences of the free variable in an expression.

**Library name:**

sollya_obj_t sollya_lib_substitute(sollya_obj_t, sollya_obj_t)

**Usage:**

```
substitute(f, g) : (function, function) → function
substitute(f, t) : (function, constant) → constant
```

**Parameters:**

- `f` is a function.
- `g` is a function.
- `t` is a real number.

**Description:**

- `substitute(f, g)` produces the function $(f \circ g) : x \mapsto f(g(x))$.
- `substitute(f, t)` is the constant $f(t)$. Note that the constant is represented by its expression until it has been evaluated (exactly the same way as if you type the expression $f$ replacing instances of the free variable by $t$).
- If $f$ is stored in a variable $F$, the effect of the commands `substitute(F, g)` or `substitute(F, t)` is absolutely equivalent to writing $F(g)$ resp. $F(t)$.

**Example 1:**

```plaintext
> f = sin(x);
> g = cos(x);
> substitute(f, g);
```

```
sin(cos(x))
```

**Example 2:**

```plaintext
> f = sin(x);
> g = cos(x);
> substitute(f, g);
```

```
sin(cos(x))
```
See also: evaluate \(8.57\), composepolynomials \(8.27\)

### 8.179 sup

**Name:** sup  

gives the upper bound of an interval.

**Library name:**  
\[
\text{sollya\_obj\_t sollya\_lib\_sup(sollya\_obj\_t)}
\]

**Usage:**  
\[
\text{sup}(I) : \text{range} \rightarrow \text{constant} \\
\text{sup}(x) : \text{constant} \rightarrow \text{constant}
\]

**Parameters:**  
- \(I\) is an interval.  
- \(x\) is a real number.

**Description:**  
- Returns the upper bound of the interval \(I\). Each bound of an interval has its own precision, so this command is exact, even if the current precision is too small to represent the bound.  
- When called on a real number \(x\), \text{sup} behaves like the identity.

**Example 1:**

\[
\begin{align*}
> \text{sup}([1;3]); \\
3 \\
> \text{sup}(5); \\
5
\end{align*}
\]

**Example 2:**

\[
\begin{align*}
> \text{display=binary!}; \\
> \text{I}=[0; 0.111110000111111_2]; \\
> \text{sup}(I); \\
1.1110000011111_2 \times 2^{-1} \\
> \text{prec=12!}; \\
> \text{sup}(I); \\
1.1111000011111_2 \times 2^{-1}
\end{align*}
\]

See also: inf \(8.90\), mid \(8.108\), max \(8.107\), min \(8.110\)

### 8.180 supnorm

**Name:** supnorm  

computes an interval bounding the supremum norm of an approximation error (absolute or relative) between a given polynomial and a function.

**Library name:**
sollya_obj_t sollya_lib_supnorm(sollya_obj_t, sollya_obj_t, sollya_obj_t, sollya_obj_t, sollya_obj_t)

Usage:
supnorm(p, f, I, errorType, accuracy) : (function, function, range, absolute|relative, constant) → range

Parameters:
- p is a polynomial.
- f is a function.
- I is an interval.
- errorType is the type of error to be considered: absolute or relative (see details below).
- accuracy is a constant that controls the relative tightness of the interval returned.

Description:
- supnorm(p, f, I, errorType, accuracy) tries to compute an interval bound \( r = [\ell, u] \) for the supremum norm of the error function \( \varepsilon_{\text{absolute}} = p - f \) (when errorType evaluates to absolute) or \( \varepsilon_{\text{relative}} = \frac{p}{f} - 1 \) (when errorType evaluates to relative), over the interval I, such that \( \sup_{x \in I} \{|\varepsilon(x)|\} \subseteq r \) and \( 0 \leq |\frac{u}{\ell} - 1| \leq \text{accuracy} \). If supnorm succeeds in computing a suitable interval \( r \), which it returns, that interval is guaranteed to contain the supremum norm value and to satisfy the required quality. Otherwise, supnorm evaluates to error, displaying a corresponding error message. These failure cases are rare and basically happen only for functions which are too complicated.

- Roughly speaking, supnorm is based on taylorform to obtain a higher degree polynomial approximation for \( f \). This process is coupled with an a posteriori validation of a potential supremum norm upper bound. The validation is based on showing a certain polynomial the problem gets reduced to does not vanish. In cases when this process alone does not succeed, for instance because taylorform is unable to compute a sufficiently good approximation to \( f \), supnorm falls back to bisecting the working interval until safe supremum norm bounds can be computed with the required accuracy or until the width of the subintervals becomes less than \( \text{diam} \) times the original interval \( I \), in which case supnorm fails.

- In practical cases, supnorm should be able to automatically handle removable discontinuities that relative errors might have. This means that usually, if \( f \) vanishes at a point \( x_0 \) in the interval considered, the approximation polynomial \( p \) is designed such that it also vanishes at the same point with a multiplicity large enough. Hence, although \( f \) vanishes, \( \varepsilon_{\text{relative}} = \frac{p}{f} - 1 \) may be defined by continuous extension at such points \( x_0 \), called removable discontinuities (see Example 3).

Example 1:

```plaintext
> p = remez(exp(x), 5, [-1;1]);
> midpointmode=on!;
> supnorm(p, exp(x), [-1;1], absolute, 2^-40));
0.45205613967-0/2-e-4
```
Example 2:

```plaintext
> prec=200!
> midpointmode=on!
> d = [1;2]
> f = exp(cos(x)^2 + 1)
> p = remez(1,15,d,1/f,1e-40)
> theta=1b-60;
> prec=default!
> mode=relative;
> supnorm(p,f,d,mode,theta);
0.30893006200251428~5/6~e-13
```

Example 3:

```plaintext
> midpointmode=on!
> mode=relative;
> theta=1b-135;
> d = [-1b-2;1b-2]
> f = expm1(x)
> p = x * (1 + x * ( 2097145 * 2^(-22) + x * ( 349527 * 2^(-21) + x * (87609 * 2^(-21) + x * 4369 * 2^(-19)))))
> theta=1b-40;
> supnorm(p,f,d,mode,theta);
0.98349131972~2/3~e-7
```

See also: dirtyinfnorm (8.43), infnorm (8.91), checkinfnorm (8.25), absolute (8.2), relative (8.154), taylorform (8.186), autodiff (8.15), numberroots (8.118), diam (8.39)

8.181 suppressmessage

Name: suppressmessage

suppresses the displaying of messages with a certain number

Library names:
void sollya_lib_suppressmessage(sollya_obj_t, ...);
void sollya_lib_v_suppressmessage(sollya_obj_t, va_list);

Usage:
```
suppressmessage(msg num 1, ..., msg num n) : (integer, ..., integer) → void
suppressmessage(msg list) : list → void
```

Parameters:
- `msg num 1` thru `msg num n` represent the numbers of `n` messages to be suppressed
- `msg list` represents a list with numbers of messages to be suppressed

Description:
- The `suppressmessage` command allows particular warning and information messages to be suppressed from message output, while maintaining global verbosity levels (see `verbosity`) high. Every Sollya warning or information message (that is not fatal to the tool’s execution) has a message number. When these message numbers `msg num 1` thru `msg num n` are given to `suppressmessage`, the corresponding message are no longer displayed. The `unsuppressmessage` command reverts this suppression from output for a particular message.
- Instead of giving `suppressmessage` several message numbers `msg num 1` thru `msg num n` or calling `suppressmessage` several times, it is possible to give a whole list `msg list` of message numbers to `suppressmessage`.

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• The user should be aware that `suppressmessage` presents sticky behavior for the warning and information messages suppressed from output. This means that even if subsequent calls to `suppressmessage` occur, a message suppressed by a call to `suppressmessage` stays suppressed until it is unsuppressed using `unsuppressmessage` or the tool is restarted. This behavior distinguishes message suppression from other global states of the Sollya tool. The user may use `getsuppressedmessages` to obtain a list of currently suppressed messages.

• When `suppressmessage` is used on message numbers that do not exist in the current version of the tool, a warning is displayed. The call has no other effect though.

Example 1:

```
> verbosity = 1;
The verbosity level has been set to 1.
> 0.1;
Warning: Rounding occurred when converting the constant "0.1" to floating-point with 165 bits.
If safe computation is needed, try to increase the precision.
0.1
> suppressmessage(174);
> 0.1;
0.1
> suppressmessage(407);
> 0.1;
0.1
> verbosity = 12;
The verbosity level has been set to 12.
> showmessagenumbers = on;
Displaying of message numbers has been activated.
> diff(exp(x * 0.1));
Information (196): formally differentiating a function.
Information (197): differentiating the expression 'exp(x * 0.1)'
Information (207): no Horner simplification will be performed because the given tree is already in Horner form.
exp(x * 0.1) * 0.1
> suppressmessage(207, 196);
> diff(exp(x * 0.1));
Information (197): differentiating the expression 'exp(x * 0.1)'
exp(x * 0.1) * 0.1
> unsuppressmessage(174);
> 0.1;
Warning (174): Rounding occurred when converting the constant "0.1" to floating-point with 165 bits.
If safe computation is needed, try to increase the precision.
0.1
```

Example 2:
> verbosity = 12;
The verbosity level has been set to 12.
> showmessagenumbers = on;
Displaying of message numbers has been activated.
> diff(exp(x * 0.1));
Warning (174): Rounding occurred when converting the constant "0.1" to floating-point with 165 bits.
If safe computation is needed, try to increase the precision.
Information (196): formally differentiating a function.
Information (197): differentiating the expression 'exp(x * 0.1)'
Information (207): no Horner simplification will be performed because the given tree is already in Horner form.
exp(x * 0.1) * 0.1
> suppressmessage([| 174, 207, 196 |]);
> diff(exp(x * 0.1));
Information (197): differentiating the expression 'exp(x * 0.1)'
exp(x * 0.1) * 0.1
See also: getsuppressedmessages [8.77], suppressmessage [8.181], unsuppressmessage [8.193], verbosity [8.195], roundingwarnings [8.164]

8.182 tail

Name: tail
gives the tail of a list.

Library name:
sollya_obj_t sollya_lib_tail(sollya_obj_t)

Usage:

\[
\text{tail}(L) : \text{list} \rightarrow \text{list}
\]

Parameters:

- \( L \) is a list.

Description:

- \( \text{tail}(L) \) returns the list \( L \) without its first element.
- If \( L \) is empty, the command will fail with an error.
- \( \text{tail} \) can also be used with end-elliptic lists. In this case, the result of \( \text{tail} \) is also an end-elliptic list.

Example 1:

\[
> \text{tail}([|1,2,3|]);
[|2, 3|]
> \text{tail}([|1,2...|]);
[|2...|]
\]

See also: head [8.81], revert [8.159]

8.183 tan

Name: tan
the tangent function.

Library names:
sollya_obj_t sollya_lib_tan(sollya_obj_t)
sollya_obj_t sollya_lib_build_function_tan(sollya_obj_t)
#define SOLLYA_TAN(x) sollya_lib_build_function_tan(x)

Description:

- \( \tan \) is the tangent function, defined by \( \tan(x) = \sin(x)/\cos(x) \).
- It is defined for every real number \( x \) that is not of the form \( n\pi + \pi/2 \) where \( n \) is an integer.

See also: \atan \([8.13]\), \cos \([8.30]\), \sin \([8.171]\)

8.184 \( \tanh \)

Name: \( \tanh \)

the hyperbolic tangent function.

Library names:

sollya_obj_t sollya_lib_tanh(sollya_obj_t)
sollya_obj_t sollya_lib_build_function_tanh(sollya_obj_t)
#define SOLLYA_TANH(x) sollya_lib_build_function_tanh(x)

Description:

- \( \tanh \) is the hyperbolic tangent function, defined by \( \tanh(x) = \sinh(x)/\cosh(x) \).
- It is defined for every real number \( x \).

See also: \atanh \([8.14]\), \cosh \([8.31]\), \sinh \([8.173]\)

8.185 \( \text{taylor} \)

Name: \text{taylor}

computes a Taylor expansion of a function in a point

Library name:

sollya_obj_t sollya_lib_taylor(sollya_obj_t, sollya_obj_t, sollya_obj_t)

Usage:

\text{taylor}(\text{function}, \text{degree}, \text{point}) : (\text{function}, \text{integer}, \text{constant}) \rightarrow \text{function}

Parameters:

- \text{function} represents the function to be expanded
- \text{degree} represents the degree of the expansion to be delivered
- \text{point} represents the point in which the function is to be developed

Description:

- The command \text{taylor} returns an expression that is a Taylor expansion of function \text{function} in point \text{point} having the degree \text{degree}.

Let \( f \) be the function \text{function}, \( t \) be the point \text{point} and \( n \) be the degree \text{degree}. Then, \text{taylor}(\text{function}, \text{degree}, \text{point}) evaluates to an expression mathematically equal to

\[
\sum_{i=0}^{n} \frac{f^{(i)}(t)}{i!} x^i.
\]

In other words, if \( p(x) \) denotes the polynomial returned by \text{taylor}, \( p(x - t) \) is the Taylor polynomial of degree \( n \) of \( f \) developed at point \( t \).

Remark that \text{taylor} evaluates to 0 if the degree \text{degree} is negative.
Example 1:

```plaintext
> print(taylor(exp(x),3,1));
exp(1) + x * (exp(1) + x * (0.5 * exp(1) + x * exp(1) / 6))
```

Example 2:

```plaintext
> print(taylor(asin(x),7,0));
x * (1 + x^2 * (1 / 6 + x^2 * (3 / 40 + x^2 * 5 / 112)))
```

Example 3:

```plaintext
> print(taylor(erf(x),6,0));
x * (2 / sqrt(pi) + x^2 * ((2 / sqrt(pi) * (-2)) / 6 + x^2 * (2 / sqrt(pi) * 12) / 120))
```

See also: remez \[8.155\], fpminimax \[8.71\], taylorform \[8.186\]

8.186 taylorform

Name: taylorform

computes a rigorous polynomial approximation (polynomial, interval error bound) for a function, based on Taylor expansions.

Library names:

```
sollya_obj_t sollya_lib_taylorform(sollya_obj_t, sollya_obj_t, sollya_obj_t, ...)
sollya_obj_t sollya_lib_v_taylorform(sollya_obj_t, sollya_obj_t, sollya_obj_t, va_list)
```

Usage:

```
taylorform(f, n, x0, I, errorType) : (function, integer, constant, range, absolute\|relative) → list
taylorform(f, n, x0, I, errorType) : (function, integer, range, range, absolute\|relative) → list
taylorform(f, n, x0, errorType) : (function, integer, constant, absolute\|relative) → list
taylorform(f, n, x0, errorType) : (function, integer, range, absolute\|relative) → list
```

Parameters:

- \( f \) is the function to be approximated.
- \( n \) is the degree of the polynomial that must approximate \( f \).
- \( x_0 \) is the point (it can be a real number or an interval) where the Taylor expansion of the function is to be considered.
- \( I \) is the interval over which the function is to be approximated. If this parameter is omitted, the behavior is changed (see detailed description below).
- \( errorType \) (optional) is the type of error to be considered. See the detailed description below. Default is absolute.

Description:

- **WARNING:** taylorform is a certified command, not difficult to use but not completely straightforward to use either. In order to be sure to use it correctly, the reader is invited to carefully read this documentation entirely.
- taylorform computes an approximation polynomial and an interval error bound for function \( f \). More precisely, it returns a list \( L = [p, coeffErrors, \Delta] \) where:
– $p$ is an approximation polynomial of degree $n$ such that $p(x - x_0)$ is roughly speaking a numerical Taylor expansion of $f$ at the point $x_0$.

– coeffsErrors is a list of $n + 1$ intervals. Each interval coeffsErrors[i] contains an enclosure of all the errors accumulated when computing the $i$-th coefficient of $p$.

– $\Delta$ is an interval that provides a bound for the approximation error between $p$ and $f$. Its significance depends on the errorType considered.

• The polynomial $p$ and the bound $\Delta$ are obtained using Taylor Models principles.

• Please note that $x_0$ can be an interval. In general, it is meant to be a small interval approximating a non representable value. If $x_0$ is given as a constant expression, it is first numerically evaluated (leading to a faithful rounding $\tilde{x}_0$ at precision prec), and it is then replaced by the (exactly representable) point-interval $[\tilde{x}_0, \tilde{x}_0]$. In particular, it is not the same to call taylorform with $x_0 = \pi$ and with $x_0 = [\pi]$, for instance. In general, if the point around which one desires to compute the polynomial is not exactly representable, one should preferably use a small interval for $x_0$.

• More formally, the mathematical property ensured by the algorithm may be stated as follows. For all $\xi_0$ in $x_0$, there exist (small) values $\varepsilon_i \in \text{coeffsErrors}[i]$ such that:

If errorType is absolute, $\forall x \in I, \exists \delta \in \Delta, f(x) - p(x - \xi_0) = \sum_{i=0}^{n} \varepsilon_i (x - \xi_0)^i + \delta$.

If errorType is relative, $\forall x \in I, \exists \delta \in \Delta, f(x) - p(x - \xi_0) = \sum_{i=0}^{n} \varepsilon_i (x - \xi_0)^i + \delta (x - \xi_0)^{n+1}$.

• It is also possible to use a large interval for $x_0$, though it is not obvious to give an intuitive sense to the result of taylorform in that case. A particular case that might be interesting is when $x_0 = I$ in relative mode. In that case, denoting by $p_i$ the coefficient of $p$ of order $i$, the interval $p_i + \text{coeffsError}[i]$ gives an enclosure of $f^{(i)}(I)/i!$. However, the command autodiff is more convenient for computing such enclosures.

• When the interval $I$ is not given, the approximated Taylor polynomial is computed but no remainder is produced. In that case the returned list is $L = [p, \text{coeffErrors}]$.

• The relative case is especially useful when functions with removable singularities are considered. In such a case, this routine is able to compute a finite remainder bound, provided that the expansion point given is the problematic removable singularity point.

• The algorithm does not guarantee that by increasing the degree of the approximation, the remainder bound will become smaller. Moreover, it may even become larger due to the dependency phenomenon present with interval arithmetic. In order to reduce this phenomenon, a possible solution is to split the definition domain $I$ into several smaller intervals.

• The command taylor also computes a Taylor polynomial of a function. However it does not provide a bound on the remainder. Besides, taylor is a somehow symbolic command: each coefficient of the Taylor polynomial is computed exactly and returned as an expression tree exactly equal to the theoretical value. It is henceforth much more inefficient than taylorform and taylorform should be preferred if only numerical (yet safe) computations are required. The same difference exists between commands diff and autodiff.

Example 1:
Example 2:

\[
> \text{TL}=\text{taylorform}(\text{exp}(x), 10, 0, [-1,1], \text{absolute});
> \text{p} = \text{TL}[0];
> \Delta = \text{TL}[2];
> \text{p; } \Delta;
1 + x * (1 + x * (0.5 + x * (0.1666666666666666666666666666666666666666666666 + x * (0.1666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666
Example 5:

```plaintext
> f = exp(cos(x)); x0 = 0;
> TL = taylorform(f, 3, x0);
> T1 = TL[0];
> T2 = taylor(f, 3, x0);
> print(coeff(T1, 2));
-1.35914091422952261768014373567633124887862354685
> print(coeff(T2, 2));
-(0.5 * exp(1))
```

See also: `diff` [8.41], `autodiff` [8.15], `taylor` [8.185], `remez` [8.155], `chebyshevform` [8.24]

### 8.187 taylorrecursions

**Name**: `taylorrecursions`  
controls the number of recursion steps when applying Taylor’s rule.

**Library names**:  
void sollya_lib_set_taylorrecursions_and_print(sollya_obj_t)  
void sollya_lib_set_taylorrecursions(sollya_obj_t)  
sollya_obj_t sollya_lib_get_taylorrecursions()

**Usage**:  
```
taylorrecursions = n : integer → void
```
```
taylorrecursions = n ! : integer → void
```
```
taylorrecursions : integer
```

**Parameters**:  
- `n` represents the number of recursions

**Description**:  
- `taylorrecursions` is a global variable. Its value represents the number of steps of recursion that are used when applying Taylor’s rule. This rule is applied by the interval evaluator present in the core of Sollya (and particularly visible in commands like `infnorm`).
- To improve the quality of an interval evaluation of a function `f`, in particular when there are problems of decorrelation, the evaluator of Sollya uses Taylor’s rule:  
  
  \[
  f([a, b]) \subseteq f(m) + [a - m, b - m] \cdot f'([a, b]) \quad \text{where} \quad m = \frac{a + b}{2}.
  \]

  This rule can be applied recursively. The number of step in this recursion process is controlled by `taylorrecursions`.
- Setting `taylorrecursions` to 0 makes Sollya use this rule only once; setting it to 1 makes Sollya use the rule twice, and so on. In particular: the rule is always applied at least once.

**Example 1**:  

```plaintext
> TL1 = taylorform(exp(x), 3, 0, [0,1], relative);
> TL2 = taylorform(exp(x), 3, 0, relative);
> TL1[0]==TL2[0];
true
> TL1[1]==TL2[1];
true
> length(TL1);
3
> length(TL2);
2
```
> f = exp(x);
> p = remez(f, 3, [0; 1]);
> taylorrecursions = 0;
The number of recursions for Taylor evaluation has been set to 0.
> evaluate(f - p, [0; 1]);
[-0.46839364816268368775174657814112460243249079671039; 0.46947781754664820647293019728402934746974652584671]
> taylorrecursions = 1;
The number of recursions for Taylor evaluation has been set to 1.
> evaluate(f - p, [0; 1]);
[-0.138131114954063839905475752120786856031651747712954; 0.139215824337843586266593712636916010690746849727]

See also: hopitalrecursions [8.84], evaluate [8.57], infnorm [8.91]

8.188 TD

Name: TD
short form for tripledouble
See also: tripledouble [8.191]

8.189 time

Name: time
procedure for timing Sollya code.

Usage:

```
time(code) : code → constant
```

Parameters:

- code is the code to be timed.

Description:

- time permits timing a Sollya instruction, resp. a begin-end block of Sollya instructions. The timing value, measured in seconds, is returned as a Sollya constant (and not merely displayed as for timing). This permits performing computations of the timing measurement value inside Sollya.

- The extended nop command permits executing a defined number of useless instructions. Taking the ratio of the time needed to execute a certain Sollya instruction and the time for executing a nop therefore gives a way to abstract from the speed of a particular machine when evaluating an algorithm’s performance.

Example 1:

```
> t = time(p = remez(sin(x), 10, [-1; 1]));
> write(t, "s were spent computing p = ", p, "\n");
4.8366210999999999999999999999999902343311586e-2 s were spent computing p =
9.0486898749977990986908851357759191711354777014602e-17 * x^10 + 2.6876259511512359629995932095914640012683406736586e-6 * x^9 + -2.424797849252131334907322328924620572785628698001e-16 * x^8 + -1.9834486302096592970124560650358641226130937598776e-4 * x^7 + 2.274821475775354434916242628185791016257549216267e-16 * x^6 + 8.3333037186560980567967821420813799547276481409702e-3 * x^5 + -8.57471519897206697417069613035495331211051121887e-17 * x^4 + -0.16666666138601323707621656649395847771564552744173 * x^3 + 1.05699585896983875841493332282097022580493449058156e-17 * x^2 + 0.99999999736283656765998251817764717246038944720795 * x + (-3.120653096601883024316320853642604562810646600878e-19)
```
Example 2:

```plaintext
> write(time({ p=remez(sin(x),10,[-1;1]); write("The error is 2^(" , log2(dirtyin fnorm(p-sin(x),[-1;1])), ")\n")); } , " s were spent\n"));
The error is 2^((log2((2.39601979446524486646952828933482070294808074097e-11))
7.9472044000000000000000000000000000004018615329303e-2 s were spent
```

Example 3:

```plaintext
> t = time(bashexecute("sleep 10"));
> write(~(t-10),"s of execution overhead.\n");
3.9814599999999999999999999999999994616717656646574e-3s of execution overhead.
```

Example 4:

```plaintext
> ratio := time(p=remez(sin(x),10,[-1;1]))/time(nop(10));
> write("This ratio = ", ratio, " should somehow be independent of the type of m
achine.\n");
This ratio = 1.415680330315803952345374661654986884071966148744 should somehow
be independent of the type of machine.
```

See also: `timing` [8.190], `nop` [8.116]

### 8.190 timing

**Name:** timing  
Global variable controlling timing measures in Sollya.

**Library names:**
- `void sollya_lib_set_timing_and_print(sollya_obj_t)`
- `void sollya_lib_set_timing(sollya_obj_t)`
- `sollya_obj_t sollya_lib_get_timing()`

**Usage:**

```plaintext
timing = activation value : on|off → void
timing = activation value ! : on|off → void
timing : on|off
```

**Parameters:**

- `activation value` controls if timing should be performed or not

**Description:**

- `timing` is a global variable. When its value is `on`, the time spent in each command is measured and displayed (for `verbosity` levels higher than 1).

**Example 1:**

```plaintext
> verbosity=1!;
> timing=on;
Timing has been activated.
> p=remez(sin(x),10,[-1;1]);
Information: Remez: computing the quality of approximation spent 4 ms
Information: Remez: computing the quality of approximation spent 4 ms
Information: Remez: computing the quality of approximation spent 4 ms
Information: computing a minimax approximation spent 30 ms
Information: assignment spent 36 ms
Information: full execution of the last parse chunk spent 41 ms
```

See also: `on` [8.123], `off` [8.122], `time` [8.189]
8.191 tripledouble

Names: tripledouble, TD

represents a number as the sum of three IEEE doubles.

Library names:

```c
sollya_obj_t sollya_lib_triple_double(sollya_obj_t)
sollya_obj_t sollya_lib_triple_double_obj()
int sollya_lib_is_triple_double_obj(sollya_obj_t)
sollya_obj_t sollya_lib_build_function_triple_double(sollya_obj_t)
#define SOLLYA_TD(x) sollya_lib_build_function_triple_double(x)
```

Description:

- **tripledouble** is both a function and a constant.
- As a function, it rounds its argument to the nearest number that can be written as the sum of three double precision numbers.
- The algorithm used to compute tripledouble(x) is the following: let \( x_h = \text{double}(x) \), let \( x_m = \text{double}(x - x_h) \) and let \( x_l = \text{double}(x - x_h - x_m) \). Return the number \( x_h + x_m + x_l \). Note that if the current precision is not sufficient to represent exactly \( x_h + x_m + x_l \), a rounding will occur and the result of tripledouble(x) will be useless.
- As a constant, it symbolizes the triple-double precision format. It is used in contexts when a precision format is necessary, e.g. in the commands roundcoefficients and implementpoly. See the corresponding help pages for examples.

Example 1:

```plaintext
> verbosity=1!
> a = 1+ 2^(-55)+2^(-115);
> TD(a);
1.00000000000000002775557561562891353466491600711096
> prec=110!;
> TD(a);
1.00000000000000002775557561562891353466491600711095597569724
```

See also: halfprecision [8.80], single [8.172], double [8.49], doubleextended [8.51], doubledouble [8.50], quad [8.146], roundcoefficients [8.162], implementpoly [8.88], fpminimax [8.71], printexpansion [8.140]

8.192 true

Name: true

the boolean value representing the truth.

Library names:

```c
sollya_obj_t sollya_lib_true()
int sollya_lib_is_true(sollya_obj_t)
```

Description:

- **true** is the usual boolean value.

Example 1:

```plaintext
> true && false;
false
> 2>1;
true
```

See also: false [8.65], && [8.6], || [8.124]
8.193 unsuppressmessage

Name: unsuppressmessage
unsuppresses the displaying of messages with a certain number

Library names:
void sollya_lib_unsuppressmessage(sollya_obj_t, ...);
void sollya_lib_v_unsuppressmessage(sollya_obj_t, va_list);

Usage:
unsuppressmessage(msg num 1, ..., msg num n) : (integer, ..., integer) → void
unsuppressmessage(msg list) : list → void

Parameters:
- msg num 1 thru msg num n represent the numbers of n messages to be suppressed
- msg list represents a list with numbers of messages to be suppressed

Description:
- The unsuppressmessage command allows particular warning and information messages that have been suppressed from message output to be unsuppressed, i.e. activated for display again. Every Sollya warning or information message (that is not fatal to the tool’s execution) has a message number. When these message numbers msg num 1 thru msg num n are given to unsuppressmessage, the corresponding message are displayed again, as they are by default at according verbosity levels. Actually, the unsuppressmessage command just reverts the effects of the suppressmessage command.
- Instead of giving unsuppressmessage several message numbers msg num 1 thru msg num n or calling unsuppressmessage several times, it is possible to give a whole list msg list of message numbers to unsuppressmessage.
- The user should be aware that unsuppressmessage presents sticky behavior for the warning and information messages suppressed from output. In fact, unsuppressmessage just unsuppresses the warning or information messages given in argument. All other suppressed messages stay suppressed until they get unsuppressed by subsequent calls to unsuppressmessage or the Sollya tool is restarted. This behavior distinguishes message suppression from other global states of the Sollya tool. The user may use getsuppressedmessages to obtain a list of currently suppressed messages. In particular, in order to unsuppressed all currently suppressed warning or information messages, the user may feed the output of getsuppressedmessages (a list) into unsuppressmessage.
- The user should also note that unsuppressing warning or information messages with unsuppressmessage just reverts the effects of the suppressmessage command but that other conditions exist that affect the actual displaying of a message, such as global verbosity (see verbosity) and modes like rounding warnings (see roundingwarnings). A message will not just get displayed because it was unsuppressed with unsuppressmessage.
- When unsuppressmessage is used on message numbers that do not exist in the current version of the tool, a warning is displayed. The call has no other effect though.

Example 1:
Example 2:

```
> verbosity = 12;
The verbosity level has been set to 12.
> showmessagenumbers = on;
Displaying of message numbers has been activated.
> diff(exp(x * 0.1));
Warning (174): Rounding occurred when converting the constant "0.1" to floating-point
with 165 bits.
If safe computation is needed, try to increase the precision.
ex(x * 0.1) * 0.1
> suppressmessage(174);
> 0.1;
0.1
> suppressmessage(174);
> 0.1;
0.1
> suppressmessage(174);
```

Example 3:

```
> verbosity = 12;
The verbosity level has been set to 12.
> showmessagenumbers = on;
Displaying of message numbers has been activated.
> suppressmessage(207, 387, 390, 388, 391, 196, 195, 197, 205);
> unsuppressmessage(getsuppressedmessages());
```

See also: `getsuppressedmessages`, `suppressmessage`, `unsuppressmessage`, `verbosity`, `roundingwarnings`.

8.194 `var`

**Name:** `var`

`declaration of a local variable in a scope`
Usage:

```plaintext
var identifier1, identifier2,... , identifiern : void
```

Parameters:

- `identifier1, identifier2,... , identifiern` represent variable identifiers

Description:

- The keyword `var` allows for the declaration of local variables `identifier1` through `identifiern` in a begin-end-block (`{}`-block). Once declared as a local variable, an identifier will shadow identifiers declared in higher scopes and undeclared identifiers available at top-level.

Variable declarations using `var` are only possible in the beginning of a begin-end-block. Several `var` statements can be given. Once another statement is given in a begin-end-block, no more `var` statements can be given.

Variables declared by `var` statements are dereferenced as `error` until they are assigned a value.

Example 1:

```plaintext
> exp(x);
exp(x)
> a = 3;
> {var a, b; a=5; b=3; {var a; var b; b = true; a = 1; a; b;}; a; b;);
1
true
5
3
> a;
3
```

See also: `error` (8.56), `proc` (8.143)

### 8.195 `verbosity`

**Name:** `verbosity`  
Global variable controlling the amount of information displayed by commands.

**Library names:**

- `void sollya_lib_set_verbosity_and_print(sollya_obj_t)`
- `void sollya_lib_set_verbosity(sollya_obj_t)`
- `sollya_obj_t sollya_lib_get_verbosity()`

**Usage:**

```plaintext
 verbosity = n : integer → void
 verbosity = n ! : integer → void
    verbosity : integer
```

**Parameters:**

- `n` controls the amount of information to be displayed

**Description:**

- `verbosity` accepts any integer value. At level 0, commands do not display anything on standard output. Note that very critical information may however be displayed on standard error.

- Default level is 1. It displays important information such as warnings when roundings happen.

- For higher levels more information is displayed depending on the command.
Example 1:

```plaintext
> verbosity=0!
> 1.2"toto"
 error
> verbosity=1!
> 1.2"toto"
 Warning: Rounding occurred when converting the constant "1.2" to floating-point with 165 bits. If safe computation is needed, try to increase the precision.
 Warning: at least one of the given expressions or a subexpression is not correctly typed or its evaluation has failed because of some error on a side-effect.
 error
> verbosity=2!
> 1.2"toto"
 Warning: Rounding occurred when converting the constant "1.2" to floating-point with 165 bits. If safe computation is needed, try to increase the precision.
 Warning: at least one of the given expressions or a subexpression is not correctly typed or its evaluation has failed because of some error on a side-effect.
 Information: the expression or a partial evaluation of it has been the following:
 (1.2) + ("toto")
 error
```

See also: roundingwarnings(8.164), suppressmessage(8.181), unsuppressmessage(8.193), showmessages(8.169), getsuppressedmessages(8.178)

8.196 void

Name: void

the functional result of a side-effect or empty argument resp. the corresponding type

Library names:

```plaintext
sollya_obj_t sollya_lib_void()
int sollya_lib_is_void(sollya_obj_t)
SOLLYA_EXTERNALPROC_TYPE_VOID
```

Usage:

```plaintext
void : void | type
```

Description:

- The variable **void** represents the functional result of a side-effect or an empty argument. It is used only in combination with the applications of procedures or identifiers bound through **externalproc** to external procedures.

The **void** result produced by a procedure or an external procedure is not printed at the prompt. However, it is possible to print it out in a print statement or in complex data types such as lists.

The **void** argument is implicit when giving no argument to a procedure or an external procedure when applied. It can nevertheless be given explicitly. For example, suppose that foo is a procedure or an external procedure with a void argument. Then foo() and foo(void) are correct calls to foo. Here, a distinction must be made for procedures having an arbitrary number of arguments. In this case, an implicit **void** as the only parameter to a call of such a procedure gets converted into an empty list of arguments, an explicit **void** gets passed as-is in the formal list of parameters the procedure receives.
• **void** is used also as a type identifier for **externalproc**. Typically, an external procedure taking **void** as an argument or returning **void** is bound with a signature **void** → some type or some type → **void**. See **externalproc** for more details.

Example 1:

```plaintext
> print(void);
void
> void;
```

Example 2:

```plaintext
> hey = proc() { print("Hello world."); }; 
> hey;
proc()
{
print("Hello world.");
return void;
}
> hey();
Hello world.
> hey(void);
Hello world.
> print(hey());
Hello world.
void
```

Example 3:

```plaintext
> bashexecute("gcc -fPIC -Wall -c externalprocvoidexample.c"); 
> bashexecute("gcc -fPIC -shared -o externalprocvoidexample externalprocvoidexample.o"); 
> externalproc(foo, "./externalprocvoidexample", void -> void);
> foo;
foo
> foo();
Hello from the external world.
> foo(void);
Hello from the external world.
> print(foo());
Hello from the external world.
void
```

Example 4:

```plaintext
> procedure blub(L = ...) { print("Argument list:", L); };  
> blub(1);
Argument list: [1]
> blub();
Argument list: []
> blub(void);
Argument list: [void]
```

See also: **error** (8.56), **proc** (8.143), **externalproc** (8.64)
8.197 worstcase

Name: worstcase
searches for hard-to-round cases of a function

Library names:
void sollya_lib_worstcase(sollya_obj_t, sollya_obj_t, sollya_obj_t, 
sollya_obj_t, sollya_obj_t, ...)
void sollya_lib_v_worstcase(sollya_obj_t, sollya_obj_t, sollya_obj_t, 
sollya_obj_t, sollya_obj_t, va_list)

Usage:

worstcase(function, preimage precision, preimage exponent range, image precision, error bound) :
    (function, integer, range, integer, constant) → void
worstcase(function, preimage precision, preimage exponent range, image precision, error bound, 
filename) : (function, integer, range, integer, constant, string) → void

Parameters:

- function represents the function to be considered
- preimage precision represents the precision of the preimages
- preimage exponent range represents the exponents in the preimage format
- image precision represents the precision of the format the images are to be rounded to
- error bound represents the upper bound for the search w.r.t. the relative rounding error
- filename represents a character sequence containing a filename

Description:

- The worstcase command is deprecated. It searches for hard-to-round cases of a function. The command searchgal has a comparable functionality.

Example 1:

```
> worstcase(exp(x),24,[1,2],24,1b-26);
prec = 165
x = 1.99999988079071044921875 f(x) = 7.3890552520751953125 eps = 4
.599860142344695596184695493764120138001954979037e-9 = 2^(-27.695763)
x = 2 f(x) = 7.38905620574951171846954979037e-9 = 2^(-26.043720)
```

See also: round [8.161], searchgal [8.167], evaluate [8.57]

8.198 write

Name: write
prints an expression without separators

Usage:

```
write(expr1,...,exprn) : (any type,..., any type) → void
write(expr1,...,exprn) > filename : (any type,..., any type, string) → void
write(expr1,...,exprn) >> filename : (any type,...,any type, string) → void
```

Parameters:

- expr represents an expression
**filename** represents a character sequence indicating a file name

**Description:**

- **write**(expr1,...,exprn) prints the expressions expr1 through exprn. The character sequences corresponding to the expressions are concatenated without any separator. No newline is displayed at the end. In contrast to **print**, **write** expects the user to give all separators and newlines explicitly.

  If a second argument filename is given after a single '>' and a double '>>' is given, the output will be appended to the file filename.

  The global variables **display**, midpointmode and **fullparentheses** have some influence on the formatting of the output (see **display**, midpointmode and **fullparentheses**).

  Remark that if one of the expressions expri given in argument is of type string, the character sequence expri evaluates to is displayed. However, if expri is of type list and this list contains a variable of type string, the expression for the list is displayed, i.e. all character sequences get displayed surrounded by quotes (''). Nevertheless, escape sequences used upon defining character sequences are interpreted immediately.

**Example 1:**

```plaintext
> write(x + 2 + exp(sin(x)));
> write("Hello\n");
x + 2 + exp(sin(x))Hello
> write("Hello","world\n");
Hello world
> write("Hello","you", 4 + 3, "other persons.\n");
Hello you7other persons.
```

**Example 2:**

```plaintext
> write("Hello","\n");
Hello
> write(["Hello"],["\n"]);
["Hello"]
> s = "Hello";
> write(s,[s],"\n");
Hello["Hello"]
> t = "Hello\tyou";
> write(t,[t],"\n");
Hello you["Hello\tyou"]
```

**Example 3:**

```plaintext
> write(x + 2 + exp(sin(x))) > "foo.sol";
> readfile("foo.sol");
x + 2 + exp(sin(x))
```

**Example 4:**

```plaintext
> write(x + 2 + exp(sin(x))) >> "foo.sol";
```

See also: **print** (8.138), **printexpansion** (8.140), **printdouble** (8.139), **printsingle** (8.141), **printxml** (8.142), **readfile** (8.152), **autosimplify** (8.16), **display** (8.46), midpointmode (8.109), **fullparentheses** (8.72), **evaluate** (8.57), **roundingwarnings** (8.164), **autosimplify** (8.16)
**8.199  \_x\_**

Name: \_x\_  
universal name for the mathematical free variable.

Library names:
- `sollya_obj_t sollya_lib_free_variable()`  
- `sollya_obj_t sollya_lib_build_function_free_variable()`  
  
  #define SOLLYA_X_ (sollya_lib_build_function_free_variable())

Description:
- \_x\_ is an identifier that always denotes the mathematical free variable. It cannot be assigned.
- Sollya manipulates mathematical functions of a single variable. The first time that a variable name is used without having been assigned before, this variable name is automatically considered by Sollya as the name of the free variable. Subsequently, any other unassigned variable name will be considered as the free variable with a warning making this conversion explicit. This is convenient for an every-day use of the interactive tool, but it has the drawback that the free variable name can change from a session to another. There are contexts (e.g., within a procedure, or for doing pattern matching) when one might want to refer to the free variable regardless of its name in the current session. For this purpose \_x\_ is a universal identifier, always available and always denoting the free variable, whatever its name is in the current context.

Example 1:
```
> verbosity=1!;
> sin(a);
sin(a)
> b;
Warning: the identifier "b" is neither assigned to, nor bound to a library function nor external procedure, nor equal to the current free variable.
Will interpret "b" as "a".
a
> _x_

a
```

Example 2:
```
> verbosity=1!;
> sin(y);
sin(y)
> f = proc(a) {
    return sin(a + _x_);
}
> rename(y,z);
Information: the free variable has been renamed from "y" to "z".
> f(1);
sin(1 + z)
```

Example 3:
> f = sin(y);
> match f with
  sin(a) : { print("sin of a with a =", a);
          match a with
            _x_ : { print("a turns out to be the free variable"); }
          default : { print("a is some expression"); }
        };
  _x_ : { print("Free variable"); }
  default: { print("Something else"); };

sin of a with a = y
a turns out to be the free variable

See also: rename [8.156], isbound [8.94], proc [8.143]
9 Appendix: interval arithmetic philosophy in Sollya

Although it is currently based on the MPFI library, Sollya has its own way of interpreting interval arithmetic when infinities or NaN occur, or when a function is evaluated on an interval containing points out of its domain, etc. This philosophy may differ from the one applied in MPFI. It is also possible that the behavior of Sollya does not correspond to the behavior that one would expect, e.g., as a natural consequence of the IEEE-754 standard.

The topology that we consider is always the usual topology of \( \mathbb{R} = \mathbb{R} \cup \{ -\infty, +\infty \} \). For any function, if one of its arguments is empty (respectively NaN), we return empty (respectively NaN).

9.1 Univariate functions

Let \( f \) be a univariate basic function and \( I \) an interval. We denote by \( J \) the result of the interval evaluation of \( f \) over \( I \) in Sollya. If \( I \) is completely included in the domain of \( f \), \( J \) will usually be the smallest interval (at the current precision) containing the exact image \( f(I) \). However, in some cases, it may happen that \( J \) is not as small as possible. It is guaranteed however that \( J \) tends to \( f(I) \) when the precision of the tool tends to infinity.

When \( f \) is not defined at some point \( x \) but is defined on a neighborhood of \( x \), we consider that the “value” of \( f \) at \( x \) is the convex hull of the limit points of \( f \) around \( x \). For instance, consider the evaluation of \( f = \tan \) on \( [0, \pi] \). It is not defined at \( \pi/2 \) (and only at this point). The limit points of \( f \) around \( \pi/2 \) are \(-\infty\) and \(+\infty\), so, we return \([-\infty, +\infty]\). Another example: \( f = \sin \) on \([+\infty]\). The function has no limit at this point, but all points of \([-1, 1]\) are limit points. So, we return \([-1, 1]\).

Finally, if \( I \) contains a subinterval on which \( f \) is not defined, we return \([\text{NaN}, \text{NaN}]\) (example: \( \sqrt{-1, 2} \)).

9.2 Bivariate functions

Let \( f \) be a bivariate function and \( I_1 \) and \( I_2 \) be intervals. If \( I_1 = [x] \) and \( I_2 = [y] \) are both point-intervals, we return the convex hull of the limit points of \( f \) around \((x, y)\) if it exists. In particular, if \( f \) is defined at \((x, y)\) we return its value (or a small interval around it, if it is not exactly representable). As an example \([1]/[+\infty]\) returns \([0]\). Also, \([1]/[0]\) returns \([-\infty, +\infty]\) (note that Sollya does not consider signed zeros). If it is not possible to give a meaning to the expression \( f(I_1, I_2) \), we return NaN: for instance \([0]/[0]\) or \([0]*[+\infty]\).

If one and only one of the intervals is a point-interval (say \( I_1 = [x] \)), we consider the partial function \( g : y \mapsto f(x, y) \) and return the value that would be obtained when evaluating \( g \) on \( I_2 \). For instance, in order to evaluate \([0]/I_2\), we consider the function \( g \) defined for every \( y \neq 0 \) by \( g(y) = 0/y = 0 \). Hence, \( g(I_2) = [0] \) (even if \( I_2 \) contains 0, by the argument of limit-points). In particular, please note that \([0]/[-1, 1]\) returns \([0]\) even though \([0]/[0]\) returns NaN. This rule even holds when \( g \) can only be defined as limit points: for instance, in the case \( I_1/[0] \) we consider \( g : x \mapsto x/0 \). This function cannot be defined \emph{stricto sensu}, but we can give it a meaning by considering 0 as a limit. Hence \( g \) is multivalued and its value is \([-\infty, +\infty]\) for every \( x \). Hence, \( I_1/[0] \) returns \([-\infty, +\infty]\) when \( I_1 \) is not a point-interval.

Finally, if neither \( I_1 \) nor \( I_2 \) are point-intervals, we try to give a meaning to \( f(I_1, I_2) \) by an argument of limit-points when possible. For instance \([1, 2]/[0, 1]\) returns \([1, +\infty]\).

As a special exception to these rules, \([0]/[0]\) returns \([1]\).
10 Appendix: the Sollya library

10.1 Introduction

The header file of the Sollya library is sollya.h. Its inclusion may provoke the inclusion of other header files, such as gmp.h, mpfr.h or mpfi.h.

The library provides a virtual Sollya session that is perfectly similar to an interactive session: global variables such as verbosity, prec, display, midpointmode, etc. are maintained and affect the behavior of the library, warning messages are displayed when something is not exact, etc. Please notice that the Sollya library currently is not re-entrant and can only be opened once. A process using the library must hence not be multi-threaded and is limited to one single virtual Sollya session.

In order to get started with the Sollya library, the first thing to do is hence to initialize this virtual session. This is performed with the sollya_lib_init function. Accordingly, one should close the session at the end of the program (which has the effect of releasing all the memory used by Sollya). Please notice that Sollya uses its own allocation functions and registers them to GMP using the custom allocation functions provided by GMP. Particular precautions should hence be taken when using the Sollya library in a program that also registers its own functions to GMP: in that case sollya_lib_init_with_custom_memory_functions should be used instead of sollya_lib_init for initializing the library. This is discussed in Section 10.19.

In the usual case when Sollya is used in a program that does not register allocation functions to GMP, a minimal file using the library is hence the following.

```c
#include <sollya.h>

int main(void) {
    sollya_lib_init();

    /* Functions of the library can be called here */

    sollya_lib_close();
    return 0;
}
```

Suppose that this code is saved in a file called foo.c. The compilation is performed as usual without forgetting to link against librarysollya (since the libraries libgmp, libmpfr and libmpfi are dependencies of Sollya, it might also be necessary to explicitly link against them):

```bash
~/% cc foo.c -c
~/% cc foo.o -o foo -lsollya -lmpfi -lmpfr -lgmp
```

10.2 Sollya object data-type

The library provides a single data type called sollya_obj_t that can contain any Sollya object (a Sollya object is anything that can be stored in a variable within the interactive tool. See Section 5 of the present documentation for details). Please notice that sollya_obj_t is in fact a pointer type; this has two consequences:

- NULL is a placeholder that can be used as a sollya_obj_t in some contexts. This placeholder is particularly useful as an end marker for functions with a variable number of arguments (see Sections 10.5.4 and 10.17).
- An assignment with the “=” sign does not copy an object but only copies the reference to it. In order to perform a (deep) copy, the sollya_lib_copy_obj() function is available.

Except for a few functions for which the contrary is explicitly specified, the following conventions are used:
A function does not touch its arguments. Hence if `sollya_lib_foo` is a function of the library, a call to `sollya_lib_foo(a)` leaves the object referenced by `a` unchanged (the notable exceptions to that rule are the functions containing `build` in their name, e.g., `sollya_lib_build_foo`).

A function that returns a `sollya_obj_t` creates a new object (this means that memory is dynamically allocated for that object). The memory allocated for that object should manually be cleared when the object is no longer used and all references to it (on the stack) get out of reach, e.g., on a function return: this is performed by the `sollya_lib_clear_obj()` function. By convenience `sollya_lib_clear_obj(NULL)` is a valid call, which just does nothing.

In general, except if the user perfectly knows what they are doing, the following rules should be applied (here `a` and `b` are C variables of type `sollya_obj_t`, and `sollya_lib_foo` and `sollya_lib_bar` are functions of the library):

- One should never write `a = b`. Instead, use `a = sollya_lib_copy_obj(b)`.
- One should never write `a = sollya_lib_foo(a)` because one loses the reference to the object initially referenced by the variable `a` (which is hence not cleared).
- One should never chain function calls such as, e.g., `a = sollya_lib_foo(sollya_lib_bar(b))` (the reference to the object created by `sollya_lib_bar(b)` would be lost and hence not cleared).
- A variable `a` should never be used twice at the left-hand side of the “=” sign (or as an lvalue in general) without performing `sollya_lib_clear_obj(a)` in-between.
- In an assignment of the form “`a = ...`”, the right-hand side should always be a function call (i.e., something like `a = sollya_lib_foo(...);`).

Please notice that `sollya_lib_close()` clears the memory allocated by the virtual Sollya session but not the objects that have been created and stored in C variables. All the `sollya_obj_t` created by function calls should be cleared manually.

We can now write a simple Hello World program using the Sollya library:

```c
#include <sollya.h>

int main(void) {
  sollya_obj_t s1, s2, s;
  sollya_lib_init();

  s1 = sollya_lib_string("Hello ");
  s2 = sollya_lib_string("World!");
  s = sollya_lib_concat(s1, s2);
  sollya_lib_clear_obj(s1);
  sollya_lib_clear_obj(s2);

  sollya_lib_printf("%b\n", s);
  sollya_lib_clear_obj(s);
  sollya_lib_close();
  return 0;
}
```

A universal function allows the user to execute any expression, as if it were given at the prompt of the Sollya tool, and to get a `sollya_obj_t` containing the result of the evaluation: this function is `sollya_lib_parse_string("some expression here")`. This is very convenient, and indeed, any script written in the Sollya language, could easily be converted into a C program by intensively using `sollya_lib_parse_string`. However, this should not be the preferred way if efficiency is targeted because (as its name suggests) this function uses a parser to decompose its argument, then constructs intermediate data structures to store the abstract interpretation of the expression, etc. Low-level functions are provided for efficiently creating Sollya objects; they are detailed in the next Section.
10.3 Conventions in use in the library

The library follows some conventions that are useful to remember:

- When a function is a direct transposition of a command or function available in the interactive tool, it returns a `sollya_obj_t`. This is true, even when it would sound natural to return, e.g., an `int`. For instance, `sollya_lib_get_verbosity()` returns a `sollya_obj_t`, whose integer value must then be recovered with `sollya_lib_get_constant_as_int`. This forces the user to declare (and clear afterwards) a temporary `sollya_obj_t` to store the value, but this is the price of homogeneity in the library.

- When a function returns an integer, this integer generally is a boolean in the usual C meaning, i.e., 0 represents false and any non-zero value represents true. In many cases, the integer returned by the function indicates a status of success or failure: the convention is “false means failure” and “true means success”. In case of failure, the convention is that the function did not touch any of its arguments.

- When a function would need to return several things, or when a function would need to return something together with a status of failure or success, the convention is that pointers are given as the first arguments of the function. These pointers shall point to valid addresses where the function will store the results. This can sometimes give obscure signatures, when the function would in principle returns a pointer and actually takes as argument a pointer to a pointer (this typically happens when the function allocates a segment of memory and should return a pointer to that segment of memory).

10.4 Displaying Sollya objects and numerical values

Within the interactive tool, the most simple way of displaying the content of a variable or the value of an expression is to write the name of the variable or the expression, followed by the character “;”. As a result, Sollya evaluates the expression or the variable and displays the result. Alternatively, a set of objects can be displayed the same way, separating the objects with commas. In library mode, the same behavior can be reproduced using the function `void sollya_lib_autoprint(sollya_obj_t, ...)`. Please notice that this function has a variable number of arguments: they are all displayed, until an argument equal to `NULL` is found. The `NULL` argument is mandatory, even if only one object shall be displayed (the function has no other way to know if other arguments follow or not). So, if only one argument should be displayed, the correct function call is `sollya_lib_autoprint(arg, NULL)`. Accordingly, if two arguments should be displayed, the function call is `sollya_lib_autoprint(arg1, arg2, NULL)`, etc. The function `void sollya_lib_v_autoprint(sollya_obj_t, va_list)` is the same, but it takes a `va_list` argument instead of a variable number of arguments.

Further, there is another way of printing formatted strings containing Sollya objects, using a `printf`-like syntax. Eight functions are provided, namely:

- `sollya_lib_printf`, `sollya_lib_v_printf`,
- `sollya_lib_fprintf`, `sollya_lib_v_fprintf`,
- `sollya_lib_sprintf`, `sollya_lib_v_sprintf`,
- `sollya_lib_snprintf` and `sollya_lib_v_snprintf`.

Each one of these functions overloads the usual function (respectively, `printf`, `vprintf`, `fprintf`, `vfprintf`, `sprintf`, `vsprintf`, `snprintf` and `vsnprintf`). The full syntax of conversions specifiers supported with the usual functions is handled (please note that the style using `$` – as in `%3$s` or `%*3$s` – is not handled though. It is not included in the C99 standard anyway). Additionally, the following conversion specifiers are provided:

- `%b`: corresponds to a `sollya_obj_t` argument. There is no precision modifier support.
- `%v`: corresponds to a `mpfr_t` argument. An optional precision modifier can be applied (e.g., `%5.5v`).
- `%w`: corresponds to a `mpfi_t` argument. An optional precision modifier can be applied (e.g., `%5.5w`).
• \%r: corresponds to a \texttt{mpq\_t} argument. There is no precision modifier support.
• \%k: corresponds to a \texttt{mpz\_t} argument. There is no precision modifier support.

When one of the above conversion specifiers is used, the corresponding argument is displayed as it would be within the interactive tool: \textit{i.e.}, the way the argument is displayed depends on \texttt{Sollya} environment variables, such as \texttt{prec}, \texttt{display}, \texttt{midpointmode}, etc. When a precision modifier \texttt{n} is used, the argument is first rounded to a binary precision of roughly $\log_2(10) \times n$ bits (\textit{i.e.}, roughly equivalent to \texttt{n} decimal digits) before being displayed. As with traditional \texttt{printf}, the precision modifier can be replaced with \texttt{*} which causes the precision to be determined by an additional \texttt{int} argument.

Flag characters (\textit{e.g.}, \#", '0', etc.) are allowed but have no effect, except flag character ‘-’ that is supported with its usual meaning of left-aligning the converted value. The full syntax for minimum field width is supported: it can be given directly as an integer in the format string (\textit{e.g.}, \%22b) or it can be replaced with \texttt{*}, which causes the field width to be determined by an additional \texttt{int} argument. As usual, a negative field width is taken as a ‘-’ flag followed by a positive width.

As a special (and sometimes convenient) case, \%b accepts that its corresponding \texttt{sollya\_obj\_t} argument be \texttt{NULL}; in this particular case, the string “\texttt{NULL}” is used in the displayed string. Please notice that, except for the particular case of \texttt{NULL}, the behavior of \texttt{sollya\_lib\_printf} is completely undefined if the argument of \%b is not a valid \texttt{Sollya} object.

The \texttt{sollya\_lib\_printf} functions return an integer with the same meaning as the traditional \texttt{printf} functions. It indicates the number of characters that have been output (excluding the final \texttt{\0} character). Similarly, the conversion specifier \%n can be used, even together with the \texttt{Sollya} conversion specifiers \%b, \%v, \%w, \%r and \%k. The functions \texttt{sollya\_lib\_snprintf} and \texttt{sollya\_lib\_v\_snprintf} will never write more characters than indicated by their size argument (including the final \texttt{\0} character). If the output gets truncated due to this limit, they will return the number of characters (excluding the final \texttt{\0} character) that would have been output if there had not been any truncation. In case of error, all \texttt{sollya\_lib\_printf} functions return a negative value.

\section{Creating Sollya objects}

\texttt{Sollya} objects conceptually fall into one of five categories: numerical constants (\textit{e.g.}, 1 or 1.5), functional expressions (they might contain numerical constants, \textit{e.g.}, $\sin(\cos(x + 1.5))$), other simple objects (intervals, strings, built-in constants such as \texttt{dyadic}, etc.), lists of objects (\textit{e.g.}, \[
[1, "Hello"]
\]) and structures (\textit{e.g.}, \{.a = 1; .b = "Hello"\}).

\subsection{Numerical constants}

Table \ref{table:constants} lists the different functions available to construct numerical constants. A \texttt{Sollya} constant is always created without rounding (whatever the value of global variable \texttt{prec} is at the moment of the function call): a sufficient precision is always allocated so that the constant is stored exactly. All these functions return a constant floating-point number except \texttt{sollya\_lib\_constant\_from\_mpq} that may return a constant \textit{expression} if the value of the rational number given as argument is not exactly representable as a floating-point number at some precision. The returned expression is of the form $p/q$ in this case.

The objects returned by these functions are newly allocated and copies of the argument. For instance, after the instruction \texttt{a = sollya\_lib\_constant(b)}, the user will eventually have to clear \texttt{a} (with \texttt{sollya\_lib\_clear(a)}) and \texttt{b} (with \texttt{mpfr\_clear(b)}).

The function \texttt{sollya\_lib\_constant\_from\_double} (or more conveniently its shortcut \texttt{SOLLYA\_CONST}) is probably the preferred way for constructing numerical constants. As the name indicates it, its argument is a \texttt{double}; however, due to implicit casting in C, it is perfectly possible to give an \texttt{int} as argument: it will be converted into a \texttt{double} (without rounding if the integer fits on 53 bits) before being passed to \texttt{SOLLYA\_CONST}. On the contrary, the user should be aware of the fact that if decimal non-integer constants are given, C rules of rounding (to double) are applied, regardless of the setting of the \texttt{Sollya} precision variable \texttt{prec}.

\begin{table}
\centering
\begin{tabular}{|c|c|}
\hline
\textbf{Argument} & \textbf{Returns} \\
\hline
\texttt{SOLLYA\_CONST} & \texttt{double} \\
\texttt{SOLLYA\_FINT\_TO\_REAL} & \texttt{real} \\
\texttt{SOLLYA\_FINT\_TO\_REAL\_CAST} & \texttt{real} \\
\texttt{SOLLYA\_FINT\_TO\_REAL\_CAST\_NO\_ROUND} & \texttt{double} \\
\texttt{SOLLYA\_FINT\_TO\_REAL\_CAST\_NO\_ROUND\_NO\_PREC} & \texttt{double} \\
\texttt{SOLLYA\_INT\_TO\_REAL} & \texttt{real} \\
\texttt{SOLLYA\_FINT\_TO\_REAL\_CAST\_NO\_RED} & \texttt{real} \\
\texttt{SOLLYA\_FINT\_TO\_REAL\_CAST\_NO\_RED\_NO\_PREC} & \texttt{double} \\
\texttt{SOLLYA\_INT\_TO\_REAL\_CAST\_NO\_RED\_NO\_PREC} & \texttt{double} \\
\hline
\end{tabular}
\caption{\texttt{Sollya} functions to create numerical constants.}
\label{table:constants}
\end{table}
Table 1: Creating numerical constants (Creates a fresh sollya_obj_t. Conversion is always exact)

<table>
<thead>
<tr>
<th>Type of the argument</th>
<th>Name of the function</th>
<th>Shortcut macro</th>
</tr>
</thead>
<tbody>
<tr>
<td>double</td>
<td>sollya_lib_constant_from_double(x)</td>
<td>SOLLYA_CONST(x)</td>
</tr>
<tr>
<td>uint64_t</td>
<td>sollya_lib_constant_from_uint64(x)</td>
<td>SOLLYA_CONST_UI64(x)</td>
</tr>
<tr>
<td>int64_t</td>
<td>sollya_lib_constant_from_int64(x)</td>
<td>SOLLYA_CONST_SI64(x)</td>
</tr>
<tr>
<td>int</td>
<td>sollya_lib_constant_from_int(x)</td>
<td>N/A</td>
</tr>
<tr>
<td>mpq_t</td>
<td>sollya_lib_constant_from_mpq(x)</td>
<td>N/A</td>
</tr>
<tr>
<td>mpz_t</td>
<td>sollya_lib_constant_from_mpz(x)</td>
<td>N/A</td>
</tr>
<tr>
<td>mpfr_t</td>
<td>sollya_lib_constant_from_mpfr(x)</td>
<td>N/A</td>
</tr>
</tbody>
</table>

10.5.2 Functional expressions

Functional expressions are built by composition of basic functions with constants and the free mathematical variable. Since it is convenient to build such expressions by chaining function calls, the library provides functions that “eat up” their arguments (actually embedding them in a bigger expression). The convention is that functions that eat up their arguments are prefixed by sollya_lib_build_. For the purpose of building expressions, shortcut macros for the corresponding functions exist. They are all listed in Table 2.

It is worth mentioning that, although SOLLYA_X_ and SOLLYA_PI are used without parentheses (as if they denoted constants), they are in fact function calls that create a new object each time they are used. The absence of parentheses is just more convenient for constructing expressions, such as, e.g., SOLLYA_COS(SOLLYA_X_).

For each function of the form sollya_lib_build_function_foo, there exists a function called sollya_lib_foo. There are two differences between them:

- First, sollya_lib_foo does not “eat up” its argument. This can sometimes be useful, e.g., if one has an expression stored in a variable a and one wants to build the expression exp(a) without losing the reference to the expression represented by a.

- Second, while sollya_lib_build_function_foo mechanically constructs an expression, function sollya_lib_foo also evaluates it, as far as this is possible without rounding.

For instance, after the instructions a = SOLLYA_CONST(0); b = sollya_lib_exp(a); the variable b contains the number 1, whereas it would have contained the expression “exp(0)” if it had been created by b = sollya_lib_build_function_exp(a).

Actually, sollya_lib_foo has exactly the same behavior as writing an expression at the prompt within the interactive tool. In particular, it is possible to give a range as an argument to sollya_lib_foo: the returned object will be the result of the evaluation of function foo on that range by interval arithmetic. In contrast, trying to use sollya_lib_build_function_foo on a range would result in a typing error.

Alternatively, one may create functional expressions with the functions

```c
int sollya_lib_construct_function(sollya_obj_t *res, sollya_base_function_t type, ...)  
int sollya_lib_v_construct_function(sollya_obj_t *, sollya_base_function_t, va_list)
```

The advantage of these functions with respect to the others presented above lies in the fact that they offer a way to create any functional expression, the basic function that one wants to construct being provided with the argument type. Since these functions are indeed doing the exact contrary of sollya_lib_decompose_function, they are described in details in the corresponding Section 10.12.

10.5.3 Other simple objects

Other simple objects are created with functions listed in Table 3. The functions with a name of the form sollya_lib_something follow the same convention as sollya_lib_constant: they build a new object from a copy of their argument, and the conversion is always exact, whatever the value of prec is.

Please note that in the interactive tool, D either denotes the discrete mathematical function that maps a real number to its closest double number, or is used as a symbolic constant to indicate that the
Table 2: Building functional expressions (Eats up arguments, embedding them in the returned object.)

<table>
<thead>
<tr>
<th>Name in the interactive tool</th>
<th>Function to build it</th>
<th>Shortcut macro</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>x</em></td>
<td>sollya_lib_build_function_free_variable()</td>
<td>SOLLYA_X_</td>
</tr>
<tr>
<td>π</td>
<td>sollya_lib_build_function_pi()</td>
<td>SOLLYA_PI</td>
</tr>
<tr>
<td>e1 + e2</td>
<td>sollya_lib_build_function_add(e1, e2)</td>
<td>SOLLYA_ADD(e1, e2)</td>
</tr>
<tr>
<td>e1 - e2</td>
<td>sollya_lib_build_function_sub(e1, e2)</td>
<td>SOLLYA_SUB(e1, e2)</td>
</tr>
<tr>
<td>e1 * e2</td>
<td>sollya_lib_build_function_mul(e1, e2)</td>
<td>SOLLYA_MUL(e1, e2)</td>
</tr>
<tr>
<td>e1 / e2</td>
<td>sollya_lib_build_function_div(e1, e2)</td>
<td>SOLLYA_DIV(e1, e2)</td>
</tr>
<tr>
<td>pow(e1, e2)</td>
<td>sollya_lib_build_function_pow(e1, e2)</td>
<td>SOLLYA_POW(e1, e2)</td>
</tr>
<tr>
<td>-e</td>
<td>sollya_lib_build_function_neg(e)</td>
<td>SOLLYA_NEG(e)</td>
</tr>
<tr>
<td>sqrt(e)</td>
<td>sollya_lib_build_function_sqrt(e)</td>
<td>SOLLYA_SQRT(e)</td>
</tr>
<tr>
<td>abs(e)</td>
<td>sollya_lib_build_function_abs(e)</td>
<td>SOLLYA_ABS(e)</td>
</tr>
<tr>
<td>erf(e)</td>
<td>sollya_lib_build_function_erf(e)</td>
<td>SOLLYA_ERF(e)</td>
</tr>
<tr>
<td>erfc(e)</td>
<td>sollya_lib_build_function_erfc(e)</td>
<td>SOLLYA_ERFC(e)</td>
</tr>
<tr>
<td>exp(e)</td>
<td>sollya_lib_build_function_exp(e)</td>
<td>SOLLYA_EXP(e)</td>
</tr>
<tr>
<td>expm1(e)</td>
<td>sollya_lib_build_function_expm1(e)</td>
<td>SOLLYA_EXPM1(e)</td>
</tr>
<tr>
<td>log(e)</td>
<td>sollya_lib_build_function_log(e)</td>
<td>SOLLYA_LOG(e)</td>
</tr>
<tr>
<td>log2(e)</td>
<td>sollya_lib_build_function_log2(e)</td>
<td>SOLLYA_LOG2(e)</td>
</tr>
<tr>
<td>log10(e)</td>
<td>sollya_lib_build_function_log10(e)</td>
<td>SOLLYA_LOG10(e)</td>
</tr>
<tr>
<td>log1p(e)</td>
<td>sollya_lib_build_function_log1p(e)</td>
<td>SOLLYA_LOG1P(e)</td>
</tr>
<tr>
<td>sin(e)</td>
<td>sollya_lib_build_function_sin(e)</td>
<td>SOLLYA_SIN(e)</td>
</tr>
<tr>
<td>cos(e)</td>
<td>sollya_lib_build_function_cos(e)</td>
<td>SOLLYA_COS(e)</td>
</tr>
<tr>
<td>tan(e)</td>
<td>sollya_lib_build_function_tan(e)</td>
<td>SOLLYA_TAN(e)</td>
</tr>
<tr>
<td>asin(e)</td>
<td>sollya_lib_build_function_asin(e)</td>
<td>SOLLYA_ASIN(e)</td>
</tr>
<tr>
<td>acos(e)</td>
<td>sollya_lib_build_function_acos(e)</td>
<td>SOLLYA_ACS(e)</td>
</tr>
<tr>
<td>atan(e)</td>
<td>sollya_lib_build_function_atan(e)</td>
<td>SOLLYA_ATAN(e)</td>
</tr>
<tr>
<td>sinh(e)</td>
<td>sollya_lib_build_function_sinh(e)</td>
<td>SOLLYA_SINH(e)</td>
</tr>
<tr>
<td>cosh(e)</td>
<td>sollya_lib_build_function_cosh(e)</td>
<td>SOLLYA_COSH(e)</td>
</tr>
<tr>
<td>tanh(e)</td>
<td>sollya_lib_build_function_tanh(e)</td>
<td>SOLLYA_TANH(e)</td>
</tr>
<tr>
<td>asinh(e)</td>
<td>sollya_lib_build_function_asinh(e)</td>
<td>SOLLYA_ASINH(e)</td>
</tr>
<tr>
<td>acosh(e)</td>
<td>sollya_lib_build_function_acosh(e)</td>
<td>SOLLYA_ACSH(e)</td>
</tr>
<tr>
<td>atanh(e)</td>
<td>sollya_lib_build_function_atanh(e)</td>
<td>SOLLYA_ATANH(e)</td>
</tr>
<tr>
<td>D(e), double(e)</td>
<td>sollya_lib_build_function_double(e)</td>
<td>SOLLYA_D(e)</td>
</tr>
<tr>
<td>SG(e), single(e)</td>
<td>sollya_lib_build_function_single(e)</td>
<td>SOLLYA_SG(e)</td>
</tr>
<tr>
<td>QD(e), quad(e)</td>
<td>sollya_lib_build_function_quad(e)</td>
<td>SOLLYA_QD(e)</td>
</tr>
<tr>
<td>HP(e), halfprecision(e)</td>
<td>sollya_lib_build_function_halfprecision(e)</td>
<td>SOLLYA_HP(e)</td>
</tr>
<tr>
<td>DD(e), doubledouble(e)</td>
<td>sollya_lib_build_function_double_double(e)</td>
<td>SOLLYA_DD(e)</td>
</tr>
<tr>
<td>TD(e), tripledouble(e)</td>
<td>sollya_lib_build_function_triple_double(e)</td>
<td>SOLLYA_TD(e)</td>
</tr>
<tr>
<td>DE(e), doubleextended(e)</td>
<td>sollya_lib_build_function_doubleextended(e)</td>
<td>SOLLYA_DE(e)</td>
</tr>
<tr>
<td>ceil(e)</td>
<td>sollya_lib_build_function ceil(e)</td>
<td>SOLLYA_CEIL(e)</td>
</tr>
<tr>
<td>floor(e)</td>
<td>sollya_lib_build_function floor(e)</td>
<td>SOLLYA_FLOOR(e)</td>
</tr>
<tr>
<td>nearestint(e)</td>
<td>sollya_lib_build_function_nearestint(e)</td>
<td>SOLLYA_NEARESTINT(e)</td>
</tr>
</tbody>
</table>
double format must be used (as an argument of round for instance). In the library, they are completely distinct objects, the mathematical function being obtained with sollya_lib_build_function_double and the symbolic constant with sollya_lib_double_obj. The same holds for other formats (DD, SG, etc.)

<table>
<thead>
<tr>
<th>Name in the interactive tool</th>
<th>Function to create it</th>
</tr>
</thead>
<tbody>
<tr>
<td>on</td>
<td>sollya_lib_on();</td>
</tr>
<tr>
<td>off</td>
<td>sollya_lib_off();</td>
</tr>
<tr>
<td>dyadic</td>
<td>sollya_lib_dyadic();</td>
</tr>
<tr>
<td>powers</td>
<td>sollya_lib_powers();</td>
</tr>
<tr>
<td>binary</td>
<td>sollya_lib_binary();</td>
</tr>
<tr>
<td>hexadecimal</td>
<td>sollya_lib_hexadecimal();</td>
</tr>
<tr>
<td>file</td>
<td>sollya_lib_file();</td>
</tr>
<tr>
<td>postscript</td>
<td>sollya_lib_postscript();</td>
</tr>
<tr>
<td>postscriptfile</td>
<td>sollya_lib_postscriptfile();</td>
</tr>
<tr>
<td>perturb</td>
<td>sollya_lib_perturb();</td>
</tr>
<tr>
<td>RD</td>
<td>sollya_lib_round_down();</td>
</tr>
<tr>
<td>RU</td>
<td>sollya_lib_round_up();</td>
</tr>
<tr>
<td>RZ</td>
<td>sollya_lib_round_towards_zero();</td>
</tr>
<tr>
<td>RN</td>
<td>sollya_lib_round_to_nearest();</td>
</tr>
<tr>
<td>honorcoeffprec</td>
<td>sollya_lib_honorcoeffprec();</td>
</tr>
<tr>
<td>true</td>
<td>sollya_lib_true();</td>
</tr>
<tr>
<td>false</td>
<td>sollya_lib_false();</td>
</tr>
<tr>
<td>void</td>
<td>sollya_lib_void();</td>
</tr>
<tr>
<td>default</td>
<td>sollya_lib_default();</td>
</tr>
<tr>
<td>decimal</td>
<td>sollya_lib_decimal();</td>
</tr>
<tr>
<td>absolute</td>
<td>sollya_lib_absolute();</td>
</tr>
<tr>
<td>relative</td>
<td>sollya_lib_relative();</td>
</tr>
<tr>
<td>fixed</td>
<td>sollya_lib_fixed();</td>
</tr>
<tr>
<td>floating</td>
<td>sollya_lib_floating();</td>
</tr>
<tr>
<td>error</td>
<td>sollya_lib_error();</td>
</tr>
<tr>
<td>D, double</td>
<td>sollya_lib_double_obj();</td>
</tr>
<tr>
<td>SG, single</td>
<td>sollya_lib_single_obj();</td>
</tr>
<tr>
<td>QD, quad</td>
<td>sollya_lib_quad_obj();</td>
</tr>
<tr>
<td>HP, halfprecision</td>
<td>sollya_lib_halfprecision_obj();</td>
</tr>
<tr>
<td>DE, doubleextended</td>
<td>sollya_lib_doubleextended_obj();</td>
</tr>
<tr>
<td>DD, doubledouble</td>
<td>sollya_lib_double_double_obj();</td>
</tr>
<tr>
<td>TD, tripledouble</td>
<td>sollya_lib_triple_double_obj();</td>
</tr>
<tr>
<td>&quot;Hello&quot;</td>
<td>sollya_lib_string(&quot;Hello&quot;);</td>
</tr>
<tr>
<td>[1, 3.5]</td>
<td>sollya_lib_range_from_interval(a);</td>
</tr>
<tr>
<td>[1, 3.5]</td>
<td>sollya_lib_range_from_bounds(b, c);</td>
</tr>
<tr>
<td>[1, 3.5]</td>
<td>sollya_lib_range(d, e);</td>
</tr>
</tbody>
</table>

\(^a\) a is a mpfi_t containing the interval \([1, 3.5]\). Conversion is always exact.
\(^b\) b and c are mpfr_t respectively containing the numbers 1 and 3.5. Conversion is always exact.
\(^c\) d and e are sollya_obj_t respectively containing the numbers 1 and 3.5. Conversion is always exact.

10.5.4 Lists

There are actually two kinds of lists: regular lists (such as, e.g., \([1, 2, 3]\)) and semi-infinite lists (such as, e.g., \([1, 2\ldots]\)). Withing the interactive tool, the ellipsis “...” can sometimes be used as a shortcut to define regular lists, e.g., \([1, 2, \ldots, 10]\).

In the library, there is no symbol for the ellipsis, and there are two distinct types: one for regular lists...
and one for semi-infinite lists (called end-elliptic). Defining a regular list with an ellipsis is not possible in the library (except of course with `sollya_lib_parse_string`).

Constructing regular lists is achieved through three functions:

- `sollya_obj_t sollya_lib_list(sollya_obj_t[] L, int n)`: this function returns a new object that is a list the elements of which are copies of $L[0], ..., L[n-1]$.
- `sollya_obj_t sollya_lib_build_list(sollya_obj_t obj1, ...)`: this function accepts a variable number of arguments. The last one must be NULL. It “eats up” its arguments and returns a list containing the objects given as arguments. Since arguments are eaten up, they may be directly produced by function calls, without being stored in variables. A typical use could be
  
  ```c
  sollya_lib_build_list(SOLLYA_CONST(1), SOLLYA_CONST(2), SOLLYA_CONST(3), NULL);
  ```
- `sollya_obj_t sollya_lib_v_build_list(va_list)`: the same as the previous functions, but with a `va_list`.

Following the same conventions, end-elliptic lists can be constructed with the following functions:

- `sollya_obj_t sollya_lib_end_elliptic_list(sollya_obj_t[] L, int n)`.
- `sollya_obj_t sollya_lib_build_end_elliptic_list(sollya_obj_t obj1, ...)`.
- `sollya_obj_t sollya_lib_v_build_end_elliptic_list(va_list)`.

### 10.5.5 Structures

Sollya structures are also available in library mode as any other Sollya object. The support for Sollya structures is however minimal and creating them might seem cumbersome. The only function available to create structures is

```c
int sollya_lib_create_structure(sollya_obj_t *res, sollya_obj_t s, char *name, sollya_obj_t val).
```

This function returns a boolean integer: false means failure, and true means success. Three cases of success are possible. In all cases, the function creates a new object and stores it at the address referred to by `res`.

- If `s` is NULL: `*res` is filled with a structure with only one field. This field is named after the string `name` and contains a copy of the object `val`.
- If `s` is an already existing structure that has a field named after the string `name`: `*res` is filled with a newly created structure. This structure is the same as `s` except that the field corresponding to `name` contains a copy of `val`.
- If `s` is an already existing structure that does not have a field named after the string `name`: `*res` is filled with a newly created structure. This structure is the same as `s` except that it has been augmented with a field corresponding to `name` and that contains a copy of `val`.

Please notice that `s` is not changed by this function: the structure stored in `*res` is a new one that does not refer to any of the components of `s`. As a consequence, one should not forget to explicitly clear `s` as well as `*res` when they become useless.

---

2Users are encouraged to make well-founded feature requests if they feel the need for better support of structures.
10.5.6 Library functions, library constants and procedure functions

In addition to the mathematical base functions and constants provided by Sollya and listed in the
Section above, the user may bind other mathematical functions and constants to Sollya objects under
the condition that they can provide code to evaluate these functions or constants. The mechanism
behind is similar to the one available in interactive Sollya through the library, libraryconstant and
function commands (see Sections 8.98, 8.99 and 8.73).

With the Sollya library, this binding is done through one of the following functions:

- Binding of a (non-constant) mathematical function for which evaluation code is available through
  a C pointer to a function:

```c
sollya_obj_t sollya_lib_libraryfunction(sollya_obj_t e,
    char *name,
    int (*f)(mpfi_t, mpfi_t, int));
sollya_obj_t sollya_lib_build_function_libraryfunction(sollya_obj_t e,
    char *name,
    int (*f)(mpfi_t, mpfi_t, int));
sollya_obj_t sollya_lib_libraryfunction_with_data(
    sollya_obj_t e,
    char *name,
    int (*f)(mpfi_t, mpfi_t, int, void *),
    void *data,
    void (*dealloc_func)(void *));
sollya_obj_t sollya_lib_build_function_libraryfunction_with_data(
    sollya_obj_t e,
    char *name,
    int (*f)(mpfi_t, mpfi_t, int, void *),
    void *data,
    void (*dealloc_func)(void *));
```

These four functions construct a Sollya object representing \( f(e) \) where \( e \) is given as the Sollya
object \( e \) and \( f \) is given as the pointer to a function \( f(mpfi_t y, mpfi_t x, int n) \) (resp.
\( f(mpfi_t y, mpfi_t x, int n, void *data) \)). This code must evaluate the \( n \)-th derivative of
\( f \) over the interval \( x \), yielding \( y \).

As usual, the functions whose name contains _build_function_ “eat up” the object \( e \), while the
corresponding functions (without _build_function_ in their name) do not.

The name argument of the function is taken as a suggestion to the name the Sollya object represent-
ing the function should be printed as when displayed. The user may choose to provide NULL
instead. In any case, upon the binding, the Sollya library will determine a unique displaying
name for the function. If it is not yet taken as a name (for some other Sollya object or Sollya
keyword), the suggested name will be used. If no suggested name is provided, the name of the
dynamic object behind the pointer to the function will be used if it can be determined. Otherwise,
a more-or-less random name is used. If the (suggested) base name is already taken, the name is
unified appending an underscore and a unique number to it. The name argument is never “eaten
up”, i.e., it is up to the user to free any memory allocated to that pointer.

The functions whose name contains _with_data allow for the same binding of an external function
to a Sollya object as the corresponding functions (without _with_data in their name), but addi-
tionally permit an opaque data pointer \( data \) to be registered together with the function pointer \( f \).

The data pointer \( data \) will be represented to the function \( f \) on each call, in an additional (last)
argument of type void * that the function \( f \) is supposed to take.

Such opaque data pointers may be used, e.g., to distinguish between several different external
procedure objects when only unique function pointer is available and the actual procedural code is
contained in a closure represented thru the data pointer.

As the data field the data pointer points to may require deallocation once the Sollya object
built thru invocation of the functions described inhere and all of its copies eventually get deallo-
cated, a data-field-deallocation function dealloc_func may be registered together with the data
field. That function will be called with the data pointer in argument when the Sollya object is deallocated. When the user does not need such a deallocation function, they may provide NULL as the dealloc_func argument to the sollya_lib_libraryfunction_with_data function or sollya_lib_build_function_libraryfunction_with_data function, in which case the argument is ignored and no deallocation function gets called for the Sollya object built.

- Binding of a mathematical constant for which evaluation code is available through a C pointer to a function:

  ```c
  sollya_obj_t sollya_lib_libraryconstant(char *name,
                                void (*c)(mpfr_t, mp_prec_t));
  sollya_obj_t sollya_lib_build_function_libraryconstant(char *name,
                                void (*c)(mpfr_t, mp_prec_t));
  sollya_obj_t sollya_lib_libraryconstant_with_data(
                                char *name,
                                void (*c)(mpfr_t, mp_prec_t, void *),
                                void *data,
                                void (*dealloc_func)(void *));
  sollya_obj_t sollya_lib_build_function_libraryconstant_with_data(
                                char *name,
                                void (*c)(mpfr_t, mp_prec_t, void *),
                                void *data,
                                void (*dealloc_func)(void *));
  ```

  These four functions construct a Sollya object representing the mathematical constant \( c \) for which a pointer to a function \( c(mpfr_t \ rop, \ mp_prec_t \ prec) \) (resp. \( c(mpfr_t \ rop, \ mp_prec_t \ prec, \ void *data) \) ) is provided. This code must evaluate the constant to precision \( prec \) and affect the result to \( rop \). See Section 8.99 for details with respect to \( prec \).

  The same remark as above concerning the suggested displaying name of the Sollya object applies for the name argument.

  In the same manner, the same remarks as above concerning the functions taking a data field pointer apply.

- Binding of a mathematical function for which evaluation code is available through a Sollya object representing a Sollya procedure:

  ```c
  sollya_obj_t sollya_lib_procedurefunction(sollya_obj_t e, sollya_obj_t f);
  sollya_obj_t sollya_lib_build_function_procedurefunction(sollya_obj_t e,
                    sollya_obj_t f);
  ```

  These two functions construct a Sollya library object representing \( f(e) \) where \( e \) corresponds to the mathematical function (or constant) given with argument \( e \) and where \( f \) is given as a Sollya procedure \( f(x, n, p) \) evaluating the \( n \)-th derivative of \( f \) over the interval \( x \) with precision \( p \). See Section 8.73 concerning details of the arguments of that Sollya procedure.

  As usual, sollya_lib_build_function_procedurefunction “eats up” its arguments \( e \) and \( f \) while sollya_obj_t sollya_lib_procedurefunction does not.

  Currently, the only way of constructing a Sollya library object representing a Sollya procedure is to use sollya_lib_parse_string.

10.5.7 External procedures

Similarly to library functions or library constants, the binding of which is discussed in Section 10.5.6, Sollya allows external procedural code to be bound and then used inside Sollya in a procedure-like manner. This is provided in the interactive tool with the externalproc command, described in Section 8.64.

The same mechanism is available in the Sollya library thanks to the following functions:

- To bind a function pointer \( p \) as a procedure named name, having arity arity, returning a result of type res_type and accepting arguments of types arg_types[0] thru arg_types[arity - 1],
the function

```c
sollya_obj_t
    sollya_lib_externalprocedure(sollya_externalprocedure_type_t res_type,
    sollya_externalprocedure_type_t *arg_types,
    int arity,
    char *name,
    void *p);
```

may be used.

The `name` argument of the function is only taken as a suggestion to the name the Sollya object representing the function should be printed as when displayed. The user may choose to provide `NULL` instead. In any case, upon the binding, the Sollya library will determine a unique displaying name for the procedure. If it is not yet taken as a name (for some other Sollya object or Sollya keyword), the suggested name will be used. If no suggested name is provided, the name of the dynamic object behind the pointer to the function will be used if it can be determined. Otherwise, a more-or-less random name is used. If the (suggested) base name is already taken, the name is unified appending an underscore and a unique number to it. The `name` argument is never “eaten up”, i.e., it is up to the user to free any memory allocated for that pointer.

The result type `res_type` as well as the argument types `arg_types` take one of the values defined by the enumeration type `sollya_externalprocedure_type_t`, detailed in Table 4. The array (resp. pointer) to the argument types `arg_types` provided to the `sollya_lib_externalprocedure` function is not “eaten up” by the function, i.e., it is up to the user to free any memory allocated for that pointer (where applicable). When the external procedure does not take any argument, its arity is to be set to zero. In this case, the argument type pointer `arg_types` is ignored by the `sollya_lib_externalprocedure` function; it hence may be invalid or `NULL` in this case.

The actual C function to be bound is supposed to have a function type corresponding to the result and argument types indicated. It is supposed to be provided to the `sollya_lib_externalprocedure` function as a `void *` function pointer, though, for the sake of unification of the Sollya library interface. A detailed description of the actual type of the C function is given in Section 8.64.

- In addition to the basic binding function described above, the

```c
sollya_obj_t
    sollya_lib_externalprocedure_with_data(
    sollya_externalprocedure_type_t res_type,
    sollya_externalprocedure_type_t *arg_types,
    int arity,
    char *name,
    void *p,
    void *data,
    void (*dealloc_func)(void *));
```

function allows for the same binding of an external procedure to a Sollya object but additionally permits an opaque data pointer `data` to be registered together with the function pointer `p`. The data pointer `data` will be represented to the function `p` on each call, in an additional (last) argument of type `void *` that the function `p` is supposed to take.

Such opaque data pointers may be used, e.g., to distinguish between several different external procedure objects when only unique function pointer is available and the actual procedural code is contained in a closure represented thru the data pointer.

As the data field the data pointer points to may require deallocation once the Sollya object built thru invocation of the `sollya_lib_externalprocedure_with_data` and all of its copies eventually get deallocated, a data-field-deallocation function `dealloc_func` may be registered together with the data field. That function will be called with the data pointer in argument when the Sollya object is deallocated. When the user does not need such a deallocation function, they may provide `NULL` as the `dealloc_func` argument to the `sollya_lib_externalprocedure_with_data` function, in which case the argument is ignored and no deallocation function gets called for the Sollya object built.
10.6 Getting the type of an object

Functions are provided that allow the user to test the type of a Sollya object. They are listed in Table 5. They all return an int interpreted as the boolean result of the test. Please note that from a typing point of view, a mathematical constant and a non-constant functional expression are both functions.

10.7 Recovering the value of a range

If a sollya_obj_t is a range, it is possible to recover the values corresponding to the bounds of the range. The range can be recovered either as a mpfi_t or as two mpfr_t (one per bound). This is achieved with the following conversion functions:

- int sollya_lib_get_interval_from_range(mpfi_t res, sollya_obj_t arg);
- int sollya_lib_get_bounds_from_range(mpfr_t res_left, mpfr_t res_right, sollya_obj_t arg).

They return a boolean integer: false means failure (i.e., if the sollya_obj_t is not a range) and true means success. These functions follow the same conventions as those of the MPFR and MPFI libraries: the variables res, res_left and res_right must be initialized beforehand, and are used to store the result of the conversion. Also, the functions sollya_lib_get_something_from_range do not change the internal precision of res, res_left and res_right. If the internal precision is sufficient to perform the conversion without rounding, then it is guaranteed to be exact. If, on the contrary, the internal precision is not sufficient, the actual bounds of the range stored in arg will be rounded at the target precision using a rounding mode that ensures that the inclusion property remains valid, i.e., arg ⊆ \[res\] (resp. arg ⊆ [res_left, res_right]).

Function int sollya_lib_get_prec_of_range(mp_prec_t *prec, sollya_obj_t arg) stores at *prec a precision that is guaranteed to be sufficient to represent the range stored in arg without rounding. The returned value of this function is a boolean that follows the same convention as above. In conclusion, this is an example of a completely safe conversion:
Table 5: Testing the type of a Sollya object (Returns non-zero if true, 0 otherwise)

<table>
<thead>
<tr>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>sollya_lib_obj_is_function(obj)</td>
</tr>
<tr>
<td>sollya_lib_obj_is_range(obj)</td>
</tr>
<tr>
<td>sollya_lib_obj_is_string(obj)</td>
</tr>
<tr>
<td>sollya_lib_obj_is_list(obj)</td>
</tr>
<tr>
<td>sollya_lib_obj_is_end_elliptic_list(obj)</td>
</tr>
<tr>
<td>sollya_lib_obj_is_structure(obj)</td>
</tr>
<tr>
<td>sollya_lib_obj_is_procedure(obj)</td>
</tr>
<tr>
<td>sollya_lib_obj_is_externalprocedure(obj)</td>
</tr>
<tr>
<td>sollya_lib_obj_is_error(obj)</td>
</tr>
<tr>
<td>sollya_lib_is_on(obj)</td>
</tr>
<tr>
<td>sollya_lib_is_off(obj)</td>
</tr>
<tr>
<td>sollya_lib_is_dyadic(obj)</td>
</tr>
<tr>
<td>sollya_lib_is_powers(obj)</td>
</tr>
<tr>
<td>sollya_lib_is_binary(obj)</td>
</tr>
<tr>
<td>sollya_lib_is_hexadecimal(obj)</td>
</tr>
<tr>
<td>sollya_lib_is_file(obj)</td>
</tr>
<tr>
<td>sollya_lib_is_postscript(obj)</td>
</tr>
<tr>
<td>sollya_lib_is_postscriptfile(obj)</td>
</tr>
<tr>
<td>sollya_lib_is_perturb(obj)</td>
</tr>
<tr>
<td>sollya_lib_is_round_down(obj)</td>
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<td>sollya_lib_is_round_up(obj)</td>
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<td>sollya_lib_is_round_towards_zero(obj)</td>
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<td>sollya_lib_is_round_to_nearest(obj)</td>
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<td>sollya_lib_is_honorcoeffprec(obj)</td>
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<td>sollya_lib_is_true(obj)</td>
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<td>sollya_lib_is_doubleextended_obj(obj)</td>
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<td>sollya_lib_is_double_double_obj(obj)</td>
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<td>sollya_lib_is_triple_double_obj(obj)</td>
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<tr>
<td>sollya_lib_is_pi(obj)</td>
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</table>
... mp_prec_t prec; mpfr_t a, b;

if (!sollya_lib_get_prec_of_range(&prec, arg)) {
    sollya_lib_printf("Unexpected error: \%b is not a range\n", arg);
} else {
    mpfr_init2(a, prec);
    mpfr_init2(b, prec);
    sollya_lib_get_bounds_from_range(a, b, arg);

    /* Now [a, b] = arg exactly */
}
...

10.8 Recovering the value of a numerical constant or a constant expression

From a conceptual point of view, a numerical constant is nothing but a very simple constant functional expression. Hence there is no difference in Sollya between the way constants and constant expressions are handled. The functions presented in this section allow one to recover the value of such constants or constant expressions into usual C data types.

A constant expression being given, three cases are possible:

- When naively evaluated at the current global precision, the expression always leads to provably exact computations (i.e., at each step of the evaluation, no rounding happens). For instance numerical constants or simple expressions such as (exp(0) + 5)/16 fall in this category.

- The constant expressions would be exactly representable at some precision but this is not straightforward from a naive evaluation at the current global precision. An example would be sin(\pi/3)/\sqrt{3} or even $1 + 2^{-\text{Prec}-10}$.

- Finally, a third possibility is that the value of the expression is not exactly representable at any precision on a binary floating-point number. Possible examples are $3.14$ or $0.1$.

From now on, we suppose that arg is a sollya_obj_t that contains a constant expression (or, as a particular case, a numerical constant). The general scheme followed by the conversion functions is the following: Sollya chooses an initial working precision greater than the target precision. If the value of arg is easily proved to be exactly representable at that precision, Sollya first computes this exact value and then rounds it to the nearest number of the target format (ties-to-even). Otherwise, Sollya tries to adapt the working precision automatically in order to ensure that the result of the conversion is one of both numbers in the target format that are closest to the exact value (a faithful rounding). A warning message indicates that the conversion is not exact and that a faithful rounding has been performed. In some cases really hard to evaluate, the algorithm can even fail to find a faithful rounding. In that case, too, a warning message is emitted indicating that the result of the conversion should not be trusted. Let us remark that these messages can be caught instead of being displayed and adapted handling can be provided by the user of the library at each emission of a warning (see Section 10.18).

The conversion functions are the following. They return a boolean integer: false means failure (i.e., arg is not a constant expression) and true means success.

- int sollya_lib_get_constant_as_double(double *res, sollya_obj_t arg)
- int sollya_lib_get_constant_as_int(int *res, sollya_obj_t arg): any value too big to be represented (this includes ±Inf) is converted to INT_MIN or INT_MAX and a warning is emitted. NaN is converted to 0 with a specific warning.
- int sollya_lib_get_constant_as_int64(int64_t *res, sollya_obj_t arg): any value too big to be represented (this includes ±Inf) is converted to INT64_MIN or INT64_MAX and a warning is emitted. NaN is converted to 0 with a specific warning.
• int sollya_lib_get_constant_as_uint64(uint64_t *res, sollya_obj_t arg): negative values are converted to 0 with a warning. Any value too big to be represented (this includes Inf) is converted to UINT64_MAX and a warning is emitted. NaN is converted to 0 with a specific warning.

• int sollya_lib_get_constant_as_mpz(mpz_t res, sollya_obj_t arg): the result of the conversion is stored in res. Please note that res must be initialized beforehand. Infinities and NaN are converted to 0 with specific warnings.

• int sollya_lib_get_constant_as_uint64_array(int *sign, uint64_t **value, size_t *length, sollya_obj_t arg): the result of the conversion is equivalent to the one obtained with sollya_lib_get_constant_as_mpz but it is stored differently. The sign \( \sigma \) of the result (one of \(-1, 0\) or \(1\)) is put into the variable pointed to by sign. A uint64_t-array of a certain size \( s \) is allocated; the variable pointed to by value is set to that pointer. The variable pointed to by length is set to the size \( s \) of the array. The elements \( v_i = (*value)[i] \) are set to a value such that \( \sigma \cdot \sum_{i=0}^{s-1} v_i \cdot 2^{64i} \) is equal to the value that would have been the result of the conversion with sollya_lib_get_constant_as_mpz. In case of failure, the variables pointed to by sign, length and *value are left unchanged and no allocation is performed. The user is in charge of deallocating the array *value allocated by this function when it succeeds, using sollya_lib_free. The size \( s \) of the array is at least 1 in all cases, even if the result of the conversion is zero. The element of the array \( v_{s-1} \) is guaranteed to be non-zero, unless the result of the whole conversion is zero. Infinities and NaN are converted to 0 with specific warnings. This function is provided as a convenience to wrapper libraries that cannot afford binding to the GMP library but need support for arbitrary length integers, though.

• int sollya_lib_get_constant_as_mpq(mpq_t res, sollya_obj_t arg): the result of the conversion is stored in res. Please note that res must be initialized beforehand. If arg cannot be proved to be exactly a floating-point number or the ratio of two floating-point numbers at some precision, the function returns false and res is left unchanged.

• int sollya_lib_get_constant(mpfr_t res, sollya_obj_t arg): the result of the conversion is stored in res. Please note that res must be initialized beforehand and that its internal precision is not modified by the algorithm.

Function int sollya_lib_get_prec_of_constant(mp_prec_t *prec, sollya_obj_t arg) tries to find a precision that would be sufficient to exactly represent the value of arg without rounding. If it manages to find such a precision, it stores it at *prec and returns true. If it does not manage to find such a precision, or if arg is not a constant expression, it returns false and *prec is left unchanged.

In conclusion, here is an example of use for converting a constant expression to a mpfr_t:

```c
... mp_prec_t prec;
mpfr_t a;
int test = 0;

test = sollya_lib_get_prec_of_constant(&prec, arg);
if (test) {
    mpfr_init2(a, prec);
    sollya_lib_get_constant(a, arg); /* Exact conversion */
}
else {
    mpfr_init2(a, 165); /* Initialization at some default precision */
    test = sollya_lib_get_constant(a, arg);
    if (!test) {
        sollya_lib_printf("Error: %b is not a constant expression\n", arg);
    }
}
...```
10.9 Converting a string from Sollya to C

If \( \text{arg} \) is a \texttt{sollya_obj_t} that contains a string, that string can be recovered using

\[
\text{int sollya_lib_get_string(char **res, sollya_obj_t arg).}
\]

If \( \text{arg} \) really is a string, this function allocates enough memory on the heap to store the corresponding string, it copies the string at that newly allocated place, and sets \( \ast \text{res} \) so that it points to it. The function returns a boolean integer: false means failure \( \text{(i.e., arg is not a string)} \) and true means success.

Since this function allocates memory on the heap, this memory should manually be cleared by the user with \texttt{sollya_lib_free} once it becomes useless.

10.10 Recovering the contents of a Sollya list

It is possible to recover the \( i \)-th element of a list \( \text{arg} \) (as one would do using \( \text{arg}[i] \) withing Sollya) with the following function:

\[
\text{int sollya_lib_get_element_in_list(sollya_obj_t *res, sollya_obj_t arg, int i).}
\]

It returns a boolean integer: false means failure \( \text{(i.e., arg is not a list or the index is out of range)} \) and true means success. In case of success, a copy of the \( i \)-th element of \( \text{arg} \) is stored at the address referred to by \( \text{res} \). Since it is a copy, it should be cleared with \texttt{sollya_lib_clear_obj} when it becomes useless.

Another function allows user to recover all elements of a list in a single call. This function returns a C array of \texttt{sollya_obj_t} objects and has the following signature:

\[
\text{int sollya_lib_get_list_elements(sollya_obj_t **L, int *n, int *end_ell, sollya_obj_t arg).}
\]

Three cases are possible:

- If \( \text{arg} \) is a regular list of length \( N \), the function allocates memory on the heap for \( N \) \texttt{sollya_obj_t}, sets \( \ast \text{L} \) so that it points to that memory segment, and copies each of the elements \( N \) of \( \text{arg} \) to \( (\ast \text{L})[0], \ldots, (\ast \text{L})[N-1] \). Finally, it sets \( \ast \text{n} \) to \( N \), \( \ast \text{end_ell} \) to zero and returns true. A particular case is when \( \text{arg} \) is the empty list: everything is the same except that no memory is allocated and \( \ast \text{L} \) is left unchanged.

- If \( \text{arg} \) is an end-elliptic list containing \( N \) elements plus the ellipsis. The function allocates memory on the heap for \( N \) \texttt{sollya_obj_t}, sets \( \ast \text{L} \) so that it points to that memory segment, and copies each of the elements \( N \) of \( \text{arg} \) at \( (\ast \text{L})[0], \ldots, (\ast \text{L})[N-1] \). Finally, it sets \( \ast \text{n} \) to \( N \), \( \ast \text{end_ell} \) to a non-zero value and returns true. The only difference between a regular list and an end-elliptic list containing the same elements is hence that \( \ast \text{end_ell} \) is set to a non-zero value in the latter.

- If \( \text{arg} \) is neither a regular nor an end-elliptic list, \( \ast \text{L} \), \( \ast \text{n} \) and \( \ast \text{end_ell} \) are left unchanged and the function returns false.

In case of success, please notice that \( (\ast \text{L})[0], \ldots, (\ast \text{L})[N-1] \) should manually be cleared with \texttt{sollya_lib_clear_obj} when they become useless. Also, the pointer \( \ast \text{L} \) itself should be cleared with \texttt{sollya_lib_free} since it points to a segment of memory allocated on the heap by Sollya.

10.11 Recovering the contents of a Sollya structure

If \( \text{arg} \) is a \texttt{sollya_obj_t} that contains a structure, the contents of a given field can be recovered using

\[
\text{int sollya_lib_get_element_in_structure(sollya_obj_t *res, char *name, sollya_obj_t arg).}
\]
If \texttt{arg} really is a structure and if that structure has a field named after the string \texttt{name}, this function copies the contents of that field into the Sollya object \texttt{res}. The function returns a boolean integer: false means failure (i.e., if \texttt{arg} is not a structure or if it does not have a field named after \texttt{name}) and true means success.

It is also possible to get all the field names and their contents. This is achieved through the function

\[
\text{int sollya\_lib\_get\_structure\_elements(char ***names, sollya\_obj\_t **objs, int *n, sollya\_obj\_t arg).}
\]

If \texttt{arg} really is a structure, say with \(N\) fields called “fieldA”, “fieldB”, ..., “fieldZ”, this functions sets \(*n\) to \(N\), allocates and fills an array of \(N\) strings and sets \(*names\) so that it points to that segment of memory (hence \((*names)[0]\) is the string “fieldA”, ..., \((*names)[N-1]\) is the string “fieldZ”). Moreover, it allocates memory for \(N\) \texttt{sollya\_obj\_t}, sets \(*objs\) so that it points on that memory segment, and copies the contents of each of the \(N\) fields at \((*objs)[0]\), ..., \((*objs)[N-1]\). Finally it returns true. If \texttt{arg} is not a structure, the function simply returns false without doing anything. Please note that since \(*names\) and \(*objs\) point to memory segments that have been dynamically allocated, they should manually be cleared by the user with \texttt{sollya\_lib\_free} once they become useless.

### 10.12 Decomposing a functional expression

If a \texttt{sollya\_obj\_t} contains a functional expression, one can decompose the expression tree using the following functions. These functions all return a boolean integer: true in case of success (i.e., if the \texttt{sollya\_obj\_t} argument really contains a functional expression) and false otherwise.

**Table 6: List of values defined in type \texttt{sollya\_base\_function\_t}**

| \texttt{SOLLYA\_BASE\_FUNC\_COS} | \texttt{SOLLYA\_BASE\_FUNC\_DOUBLE} | \texttt{SOLLYA\_BASE\_FUNC\_LOG} |
| \texttt{SOLLYA\_BASE\_FUNC\_ACOS} | \texttt{SOLLYA\_BASE\_FUNC\_DOUBLE\_DOUBLE} | \texttt{SOLLYA\_BASE\_FUNC\_LOG\_2} |
| \texttt{SOLLYA\_BASE\_FUNC\_ACOSH} | \texttt{SOLLYA\_BASE\_FUNC\_DOUBLE\_EXTENDED} | \texttt{SOLLYA\_BASE\_FUNC\_LOG\_10} |
| \texttt{SOLLYA\_BASE\_FUNC\_COSH} | \texttt{SOLLYA\_BASE\_FUNC\_TRIPELDOUBLE} | \texttt{SOLLYA\_BASE\_FUNC\_LOG\_1P} |
| \texttt{SOLLYA\_BASE\_FUNC\_ASIN} | \texttt{SOLLYA\_BASE\_FUNC\_HALFPRECISION} | \texttt{SOLLYA\_BASE\_FUNC\_EXP} |
| \texttt{SOLLYA\_BASE\_FUNC\_ASINH} | \texttt{SOLLYA\_BASE\_FUNC\_SINGLE} | \texttt{SOLLYA\_BASE\_FUNC\_EXP\_M1} |
| \texttt{SOLLYA\_BASE\_FUNC\_SIN} | \texttt{SOLLYA\_BASE\_FUNC\_QUAD} | \texttt{SOLLYA\_BASE\_FUNC\_NEG} |
| \texttt{SOLLYA\_BASE\_FUNC\_TAN} | \texttt{SOLLYA\_BASE\_FUNC\_FLOOR} | \texttt{SOLLYA\_BASE\_FUNC\_SUB} |
| \texttt{SOLLYA\_BASE\_FUNC\_ATAN} | \texttt{SOLLYA\_BASE\_FUNC\_CEIL} | \texttt{SOLLYA\_BASE\_FUNC\_ADD} |
| \texttt{SOLLYA\_BASE\_FUNC\_ATANH} | \texttt{SOLLYA\_BASE\_FUNC\_NEARESTINT} | \texttt{SOLLYA\_BASE\_FUNC\_MUL} |
| \texttt{SOLLYA\_BASE\_FUNC\_TANH} | \texttt{SOLLYA\_BASE\_FUNC\_LIBRARY\_CONSTANT} | \texttt{SOLLYA\_BASE\_FUNC\_DIV} |
| \texttt{SOLLYA\_BASE\_FUNC\_EXP} | \texttt{SOLLYA\_BASE\_FUNC\_LIBRARY\_FUNCTION} | \texttt{SOLLYA\_BASE\_FUNC\_POW} |
| \texttt{SOLLYA\_BASE\_FUNC\_ERF} | \texttt{SOLLYA\_BASE\_FUNC\_PROCEDURE\_FUNCTION} | \texttt{SOLLYA\_BASE\_FUNC\_SORT} |
| \texttt{SOLLYA\_BASE\_FUNC\_ABS} | \texttt{SOLLYA\_BASE\_FUNC\_FREE\_VARIABLE} | \texttt{SOLLYA\_BASE\_FUNC\_PI} |
| \texttt{SOLLYA\_BASE\_FUNC\_NEG} | \texttt{SOLLYA\_BASE\_FUNC\_CONSTANT} | |

- \texttt{int sollya\_lib\_get\_function\_arity(int *n, sollya\_obj\_t f)}: it stores the arity of the head function in \(f\) at the address referred to by \(n\). Currently, the mathematical functions handled in Sollya are at most dyadic. Mathematical constants are considered as 0-adic functions. The free variable is regarded as the identity function applied to the free variable: its arity is hence 1.

- \texttt{int sollya\_lib\_get\_head\_function(sollya\_base\_function\_t *type, sollya\_obj\_t f)}: it stores the type of \(f\) at the address referred to by \(type\). The \texttt{sollya\_base\_function\_t} is an enum type listing all possible cases (see Table 6).

- \texttt{int sollya\_lib\_get\_subfunctions(sollya\_obj\_t f, int *n, ...)}: let us denote by \(g_1, \ldots, g_k\) the arguments following the argument \(n\). They must be of type \texttt{sollya\_obj\_t} *. The function stores the arity of \(f\) at the address referred to by \(n\) (except if \(n\) is \texttt{NULL}, in which case,
sollya_lib_get_subfunctions simply ignores it and goes on). Suppose that f contains an
expression of the form $f_0(f_1, \ldots , f_s)$ (as a particular case, if f is just the free variable, it is regarded
in this context as the identity function applied to the free variable, so both $f_0$ and $f_1$ are the
free variable). For each $i$ from 1 to $s$, the expression corresponding to $f_i$ is stored at the address
referred to by $g_i$, unless one of the $g_i$ is NULL in which case the function returns when encoun-
tering it. In practice, it means that the user should always put NULL as last argument, in order to
prevent the case when they would not provide enough variables $g_i$. They can check afterwards
that they provided enough variables by checking the value contained at the address referred to
by $n$. If the user does not put NULL as last argument and do not provide enough variables $g_i$, the
algorithm will continue storing arguments at random places in the memory (on the contrary,
providing more arguments than necessary does not harm: useless arguments are simply ignored
and left unchanged). In the case when $f_0$ is a library function, a constant (i.e., represented by the
sollya_base_function_t SOLLYA_BASE_FUNC_CONSTANT), a library constant, the constant $\pi$ (i.e.,
represented by the sollya_base_function_t SOLLYA_BASE_FUNC_PI) or a procedure function, and
if the user provides a non-NULL argument $g_t$ after $g_s$, additional information is returned in the
remaining argument:

- If $f_0$ is a library function, a Sollya object corresponding to the expression $f_0(x)$ is stored at
  the address referred to by $g_t$. This allows the user to get a Sollya object corresponding
to function $f_0$. This object can further be used to evaluate $f_0$ at points or to build new
  expressions involving $f_0$. Please notice that a library function object is not necessarily the
  result of a call to the library command: it can also be, e.g., the derivative of a function
  created by a call to library.

- If $f_0$ is a procedure function, a Sollya object corresponding to the expression $f_0(x)$ is stored
  at the address referred to by $g_t$. The same remarks as above apply.

- If $f_0$ is a constant, the constant $\pi$, or a library constant, $f_0$ itself is stored at the address
  referred to by $g_t$. In this particular case, $t = 1$ and the object referred to by $g_t$ simply gets
  a copy of $f$. This (somehow useless) mechanism is made only to handle the cases of library
  functions, procedure functions, constants and library constants in a unified way.

Please note that the objects that have been stored in variables $g_i$ must manually be cleared once
they become useless.

- $\text{int sollya_lib_v_get_subfunctions(sollya_obj_t f, int } *n, \text{ va_list va)}$: the same as
  the previous function, but with a va_list argument.

- $\text{int sollya_lib_get_nth_subfunction(sollya_obj_t } *\text{res, sollya_obj_t f, int m)}$: while
  sollya_lib_get_subfunctions allows the user to retrieve all the subtrees of a functional expres-
  sion (including an extra subtree in the case of a constant, the constant $\pi$, a library constant, a library
  function or a procedure function), this function allows the user to retrieve only one of them. More
  precisely (using the same notations as in the documentation of sollya_lib_get_subfunctions
  above) if sollya_lib_get_subfunctions would put something at the address referred to by vari-
  able $g_m$, then sollya_lib_get_nth_subfunction(res, f, m) would put the same thing at the
  address referred to by res and return a boolean integer representing true. In any other case, it
  would let res unchanged and return a boolean integer representing false. Notice that the sub-
  functions are numbered starting from 1 (as opposed to, e.g., arrays in C), hence in the expression
  $f = e_1 + e_2$, the subexpression $e_1$ corresponds to $m = 1$ and the subexpression $e_2$ corresponds to
  $m = 2$. Accordingly, in an expression like $f = \sin(e)$, the subexpression $e$ corresponds to $m = 1$.

- $\text{int sollya_lib_decompose_function(sollya_obj_t f, sollya_base_function_t } *\text{type, }
  \text{int } *n, \ldots )$: this function is a all-in-one function equivalent to using sollya_lib_get_head_function
  and sollya_lib_get_subfunctions in only one function call.

- $\text{int sollya_lib_v_decompose_function(sollya_obj_t f, sollya_base_function_t } *\text{type, }
  \text{int } *n, \text{ va_list va)}$: the same as the previous function, but with a va_list.
To construct a functional expression, functions are provided that precisely undo what `sollya_lib_decompose_function` does. These functions are the following:

- **int sollya_lib_construct_function(sollya_obj_t *res, sollya_base_function_t type, ...):**
  
  let us denote by \(g_1, \ldots, g_k\) the arguments following the argument \(type\). They must be of type \(sollya_obj_t\). The function creates a functional expression whose head function corresponds to the basic function represented by variable \(type\) and whose arguments are \(g_1, \ldots, g_s\) where \(s\) denotes the arity of the considered basic function. It is the responsibility of the user to provide enough arguments with respect to the required arity. As a particular case, when the desired type corresponds to a library function, a constant, the constant \(\pi\), a library constant or a procedure function, the user **must** provide an extra argument \(g_t\) after \(g_s\) corresponding to what `sollya_lib_decompose_function` would store in this extra argument on such a case (namely, a Sollya object corresponding to the expression \(f_0(x)\) in the case of a library function or procedure function, and \(f_0\) itself in the case of a constant, the constant \(\pi\) or a library constant). As a particular case, and to make it more useful in practice, the argument \(g_t\) is allowed to be equal to **NULL** whenever \(type\) is equal to `SOLLYA_BASE_FUNC_PI`, in which case the function will succeed, even though \(g_t\) does not contain the constant \(\pi\) as it theoretically should. Notice however that any other value than **NULL** leads to a failure if it does not contain the constant \(\pi\) itself. If everything goes well the functional expression is created and stored at the address referred to by \(res\) and a boolean integer representing true is returned. Notice that the arguments \(g_1, \ldots, g_k\) are not eaten up by this function and the user must subsequently manually clear these objects. If something goes wrong (bad number of arguments, arguments not having the proper type, etc.) \(res\) is left unchanged and a boolean integer representing false is returned.

- **int sollya_lib_v_construct_function(sollya_obj_t *res, sollya_base_function_t type, va_list varlist):**
  
  the same as the previous function, but with a `va_list`.

As an example of use of the functions described in the present section, the following code returns 1 if \(f\) denotes a functional expression made only of constants (i.e., without the free variable), and returns 0 otherwise:
```c
#include <sollya.h>

/* Note: we suppose that the library has already been initialized */
int is_made_of_constants(sollya_obj_t f) {
    sollya_obj_t tmp1 = NULL;
    sollya_obj_t tmp2 = NULL;
    int n, r, res;
    sollya_base_function_t type;
    r = sollya_lib_decompose_function(f, &type, &n, &tmp1, &tmp2, NULL);
    if (!r) { sollya_lib_printf("Not a mathematical function\n"); res = 0; }
    else if (n >= 3) {
        sollya_lib_printf("Unexpected error: %b has more than two arguments.\n", f);
        res = 0;
    } else {
        switch (type) {
            case SOLLYA_BASE_FUNC_FREE_VARIABLE: res = 0; break;
            case SOLLYA_BASE_FUNC_PI: res = 1; break;
            case SOLLYA_BASE_FUNC_CONSTANT: res = 1; break;
            case SOLLYA_BASE_FUNC_LIBRARYCONSTANT: res = 1; break;
            default:
                res = is_made_of_constants(tmp1);
                if ((res) & (n==2)) res = is_made_of_constants(tmp2);
        }
    }
    if (tmp1) sollya_lib_clear_obj(tmp1);
    if (tmp2) sollya_lib_clear_obj(tmp2);
    return res;
}
```

Functions are provided to allow the user to retrieve further information from library function, library constant, procedure function and external procedure objects:

- **int sollya_lib_decompose_libraryfunction(int (**f)(mpfi_t, mpfi_t, int),
  int *deriv, sollya_obj_t *e,
  sollya_obj_t g):**

  Assume that g represents an expression \( f_0(f_1) \) where \( f_0 \) is a library function. Then, \( f_0 \) is the \( n \)-th derivative (for some \( n \)) of a function provided within Sollya via an external C function `int func(mpfi_t, mpfi_t, int)`. As a result of a call to `sollya_lib_decompose_libraryfunction`, the value \( n \) is stored at the address referred to by `deriv`, a pointer to `func` is stored at the address referred to by `f` and a Sollya object representing \( f_1 \) is stored at the address referred to by `e`. Please notice that the object stored in `e` must manually be cleared once it becomes useless. Upon success, a boolean integer representing true is returned. If `g` is not a library function object, nothing happens and false is returned.

- **int sollya_lib_decompose_libraryfunction_with_data(int (**f)(mpfi_t, mpfi_t, int, void *),
  int *deriv, sollya_obj_t *e,
  void **data, void (**dealloc)(void *),
  sollya_obj_t g):**

  Works exactly as the previous function but additionally returns a pointer to the `void *` data field and to the pointer to the deallocation function that had been provided when the library

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function was created. Notice that, in the case when \( g \) represents an expression \( f_0(f_1) \) where
\( f_0 \) is indeed a library function, but has been constructed with \texttt{sollya\_lib\_libraryfunction} or
\texttt{sollya\_lib\_build\_function\_libraryfunction} and not with one of the \_with_data variants, this function will fail and return false without touching any of its argument.

- \texttt{int sollya\_lib\_decompose\_procedurefunction(sollya\_obj\_t *f, int *deriv,}
\texttt{sollya\_obj\_t *e, sollya\_obj\_t g):}

  assume that \( g \) represents an expression \( f_0(f_1) \) where \( f_0 \) is the \( n \)-th derivative (for some \( n \)) of a function provided within Sollya via a procedure \texttt{proc(X, n, p) \{\ldots\}}.

  As a result of a call to \texttt{sollya\_lib\_decompose\_procedurefunction}, the value \( n \) is stored at the address referred to by \texttt{deriv}, a Sollya object representing the procedure is stored at the address referred to by \texttt{f}, a Sollya object representing \( f_1 \) is stored at the address referred to by \texttt{e}. Please notice that the objects stored in \texttt{f} and \texttt{e} must manually be cleared once they become useless. Upon success, a boolean integer representing true is returned. If \( g \) is not a procedure function object, nothing happens and false is returned.

- \texttt{int sollya\_lib\_decompose\_libraryconstant(void (**f)(mpfr\_t, mp\_prec\_t),}
\texttt{sollya\_obj\_t c):}

  assume that \( c \) is a constant provided via an external C function \texttt{void func(mpfr\_t, mp\_prec\_t).}

  As a result of a call to \texttt{sollya\_lib\_decompose\_libraryconstant}, a pointer to \texttt{func} is stored at the address referred to by \texttt{f} and a boolean integer representing true is returned. Otherwise, nothing happens and false is returned.

- \texttt{int sollya\_lib\_decompose\_libraryconstant\_with\_data(}
\texttt{ void (**f)(mpfr\_t, mp\_prec\_t, void *),}
\texttt{ void **data, void (**dealloc)(void *),}
\texttt{sollya\_obj\_t c):}

  works exactly as the previous function but additionally returns a pointer to the \texttt{void \* data} field and the pointer to the deallocation function that had been provided when the library constant was created. Similarly to \texttt{sollya\_lib\_decompose\_libraryfunction\_with\_data}, this function fails on library constants that have been created with \texttt{sollya\_lib\_libraryfunction} or \texttt{sollya\_lib\_build\_function\_libraryconstant} instead of using the _with_data variant of these constructors.

- \texttt{int sollya\_lib\_decompose\_externalprocedure(sollya\_externalprocedure\_type\_t *res,}
\texttt{sollya\_externalprocedure\_type\_t **args,}
\texttt{ int *arity, void **f,}
\texttt{sollya\_obj\_t p):}

  assume that \( p \) is an external procedure provided via an external C function \texttt{func} (of appropriate type) bound to Sollya by one of the means provided for that purpose. As a result of a call to \texttt{sollya\_lib\_decompose\_externalprocedure}, a pointer to \texttt{func} is stored at the address pointed to by \texttt{f}, the result type of the external procedure is stored at \texttt{res}, an array of its argument types is allocated, filled and stored at the address pointed to by \texttt{args} (unless the procedure function takes no argument in which case the \texttt{args} argument is ignored), the arity of the external procedure (and hence number of elements of the array allocated and stored at \texttt{args}) is stored at the integer pointed by \texttt{arity} and true is returned. If \( p \) is no external procedure object, nothing happens and false is returned.

- \texttt{int sollya\_lib\_decompose\_externalprocedure\_with\_data(}
\texttt{ sollya\_externalprocedure\_type\_t *res,}
\texttt{ sollya\_externalprocedure\_type\_t **args,}
\texttt{ int *arity, void **f,}
\texttt{ void **data, void (**dealloc)(void *),}
\texttt{sollya\_obj\_t p):}

  works exactly as the previous function but additionally returns a pointer to the \texttt{void \* data} field and the pointer to the deallocation function that had been provided when the external procedure was created. The same remark as with \texttt{sollya\_lib\_decompose\_libraryfunction\_with\_data} and \texttt{sollya\_lib\_decompose\_libraryconstant\_with\_data} also applies: this function fails when
used on an external procedure that has been constructed without the _with_data variant of the constructor.

10.13 Faithfully evaluate a functional expression

Let us suppose that \( f \) is a functional expression and \( a \) is a numerical value or a constant expression. One of the very convenient features of the interactive tool is that the user can simply write \( f(a) \) at the prompt: the tool automatically adapts its internal precision in order to compute a value that is a faithful rounding (at the current tool precision) of the true value \( f(a) \). Sometimes it does not achieve to find a faithful rounding, but in any case, if the result is not proved to be exact, a warning is displayed explaining how confident one should be with respect to the returned value. The object \( a \) can also be an interval, in which case Sollya automatically performs the evaluation using an enhanced interval arithmetic, e.g., using L’Hopital’s rule to produce finite (yet valid of course) enclosures even in cases when \( f \) exhibits removable singularities (for instance \( \sin(x)/x \) over an interval containing 0). This behavior is reproduced in the library with the \texttt{sollya\_lib\_apply} function (this function is in fact to be used to reproduce any construction of the form \texttt{obj1(obj2, obj3, ...)} within the library; for instance \texttt{obj1} might also be a procedure. See Section [10.17] for a more detailed description of this function). More precisely if \( f \) and \( a \) are two \texttt{sollya\_obj\_t} representing respectively a univariate function and a constant or an interval, the following call returns a new \texttt{sollya\_obj\_t} representing the object that would be produced as a result of typing \( f(a) \); at the interactive prompt:

\[ b = \texttt{sollya\_lib\_apply}(f, a, \text{NULL}); \]

However, when using the library, it might be interesting to have access to this feature when the argument \( a \) is not a Sollya object but rather directly a multiprecision constant of type \texttt{mpfr\_t} or \texttt{mpfi\_t}. Also, in this case, one may want to have a finer-grain access to the evaluation algorithm, e.g., to correctly react to cases where a faithful rounding has not been achieved without having to catch warning messages emitted by Sollya. This is the reason why the library proposes the following functions.

To evaluate a unary function at a constant expression or constant value, the library provides the two following functions:

- \texttt{sollya\_fp\_result\_t}
  \texttt{sollya\_lib\_evaluate\_function\_at\_constant\_expression}(mpfr\_t res, sollya\_obj\_t f, sollya\_obj\_t a, mpfr\_t *cutoff),

- \texttt{sollya\_fp\_result\_t}
  \texttt{sollya\_lib\_evaluate\_function\_at\_point}(mpfr\_t res, sollya\_obj\_t f, mpfr\_t a, mpfr\_t *cutoff).

In the former, the argument \( a \) is any \texttt{sollya\_obj\_t} containing a numerical constant or a constant expression, while in the latter \( a \) is a constant already stored in a \texttt{mpfr\_t}. These functions store the result in \( \text{res} \) and return a \texttt{sollya\_fp\_result\_t} which is an enum type described in Table [7]. In order to understand the role of the \texttt{cutoff} parameter and the value returned by the function, it is necessary to describe the algorithm in a nutshell:

\textbf{Input:} a functional expression \( f \), a constant expression \( a \), a target precision \( q \), a parameter \( \varepsilon \).

1. Choose an initial working precision \( p \).
2. Evaluate \( a \) with interval arithmetic, performing the computations at precision \( p \).
3. Replace the occurrences of the free variable in \( f \) by the interval obtained at step 2. Evaluate the resulting expression with interval arithmetic, performing the computations at precision \( p \). This yields an interval \( I = [x, y] \).
4. Examine the following cases successively (RN denotes rounding to nearest at precision \( q \)):
(a) If \( \text{RN}(x) = \text{RN}(y) \), set \( \text{res} \) to that value and return.
(b) If \( I \) does not contain any floating-point number at precision \( q \), set \( \text{res} \) to one of both floating-point numbers enclosing \( I \) and return.
(c) If \( I \) contains exactly one floating-point number at precision \( q \), set \( \text{res} \) to that number and return.
(d) If all numbers in \( I \) are smaller than \( \varepsilon \) in absolute value, then set \( \text{res} \) to 0 and return.
(e) If \( p \) has already been increased many times, then set \( \text{res} \) to some value in \( I \) and return.
(f) Otherwise, increase \( p \) and go back to step 2.

The target precision \( q \) is chosen to be the precision of the \( \text{mpfr}_t \) variable \( \text{res} \). The parameter \( \varepsilon \) corresponds to the parameter \( \text{cutoff} \). The reason why \( \text{cutoff} \) is a pointer is that, most of the time, the user may not want to provide it, and using a pointer makes it possible to pass NULL instead. So, if \( \text{NULL} \) is given, \( \varepsilon \) is set to 0. If \( \text{cutoff} \) is not \( \text{NULL} \), the absolute value of *cutoff* is used as value for \( \varepsilon \). Using a non-zero value for \( \varepsilon \) can be useful when one does not care about the precise value of \( f(a) \) whenever its absolute value is below a given threshold. Typically, if one wants to compute the maximum of \( |f(a_1)|, \ldots, |f(a_n)| \), it is not necessary to spend too much effort on the computation of \( |f(a)| \) if one already knows that it is smaller than \( \varepsilon = \max\{|f(a_1)|, \ldots, |f(a_n)|\} \).

To evaluate a unary function on an interval, the following function is provided:

```c
int sollya_lib_evaluate_function_over_interval(mpfi_t res, sollya_obj_t f, mpfi_t a).
```

This function returns a boolean integer: false means failure (i.e., \( f \) is not a functional expression), in which case \( \text{res} \) is left unchanged, and true means success, in which case \( \text{res} \) contains the result of the evaluation. The function might succeed, and yet \( \text{res} \) might contain something useless such as an unbounded interval or even \( [\text{NaN}, \text{NaN}] \) (this happens for instance when a contains points that lie in the interior of the complement of the definition domain of \( f \)). It is the user’s responsibility to check afterwards whether the computed interval is bounded, unbounded or NaN.

### 10.14 Comparing objects structurally and computing hashes on Sollya objects

The library provides function

```c
int sollya_lib_cmp_objs_structurally(sollya_obj_t obj1, sollya_obj_t obj2)
```

to allow the user to perform a structural comparison of any two Sollya objects. It returns an integer (interpreted as a boolean) that is true if and only if \( \text{obj1} \) and \( \text{obj2} \) are syntactically the same (as opposed to mathematically). For instance the fractions 2/3 and 4/6 are recognized as mathematically equal by Sollya when compared with \( == \) (or \( \text{sollya_lib_cmp_equal} \) with the library) but are syntactically different.

Certain language bindings require hashes to be available for any object represented. In order to help with such language bindings, the Sollya library supports a function that computes a 64 bit unsigned integer as a hash for a given Sollya object:

```c
uint64_t sollya_lib_hash(sollya_obj_t obj).
```

The Sollya library guarantees that any two objects that are syntactically equal (as when compared with \( \text{sollya_lib_cmp_objs_structurally} \)) will have the same hash value. For some particular objects (e.g., polynomials) Sollya can normalize the expression before computing the hash value and in this case two objects that are mathematically equal (even though they are not structurally equal) will have the same hash value. However, except in such particular cases, two objects that are syntactically different are likely to have different hashes (although this is not guaranteed, of course).

Computing the hash of an object takes a time proportional to the size of the directed acyclic graph internally used to represent that object. However, Sollya will cache an object’s hash value for further use after it has been computed, so the cost of computing the hash of a given object is paid only once.

The user should also be aware that the hash value for a given object is currently not guaranteed to be portable between platforms nor over consecutive Sollya versions.
Table 7: List of values defined in type `sollya_fp_result_t`

<table>
<thead>
<tr>
<th>Value</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOLLYA_FP_OBJ_NO_FUNCTION</td>
<td>( f ) is not a functional expression.</td>
</tr>
<tr>
<td>SOLLYA_FP_EXPRESSION_NOT_CONSTANT</td>
<td>( a ) is not a constant expression.</td>
</tr>
<tr>
<td>SOLLYA_FP_FAILURE</td>
<td>The algorithm ended up at step (e) and ( I ) contained NaN. This typically happens when ( a ) is not in the definition domain of ( f ).</td>
</tr>
<tr>
<td>SOLLYA_FP_CUTOFF_IS_NAN</td>
<td>( \text{cutoff} ) was not NULL and the value of <code>\*cutoff</code> is NaN.</td>
</tr>
<tr>
<td>SOLLYA_FP_INFINITY</td>
<td>The algorithm ended up at step (a) with ( I ) of the form ([+\infty, +\infty]) or ([-\infty, -\infty]). Hence ( f(a) ) is proved to be an exact infinity.</td>
</tr>
<tr>
<td>SOLLYA_FP_PROVEN_EXACT</td>
<td>The algorithm ended up at step (a) with a finite value and ( x = \text{RN}(x) = \text{RN}(y) = y ).</td>
</tr>
<tr>
<td>SOLLYA_FP_CORRECTLY_ROUNDED_PROVEN_INEXACT</td>
<td>The algorithm ended up at step (b) with a finite value and ( \text{res} &lt; x \leq y ) or ( x \leq y &lt; \text{res} ).</td>
</tr>
<tr>
<td>SOLLYA_FP_CORRECTLY_ROUNDED</td>
<td>The algorithm ended up at step (a) with a finite value and ( x \leq \text{res} \leq y ). (^a)</td>
</tr>
<tr>
<td>SOLLYA_FP_FAITHFUL_PROVEN_INEXACT</td>
<td>The algorithm ended up at step (b) with a finite value and ( \text{res} &lt; x \leq y ) or ( x \leq y &lt; \text{res} ).</td>
</tr>
<tr>
<td>SOLLYA_FP_FAITHFUL</td>
<td>The algorithm ended up at step (c) with a finite value. (^a)</td>
</tr>
<tr>
<td>SOLLYA_FP_BELOW_CUTOFF</td>
<td>The algorithm ended up at step (d).</td>
</tr>
<tr>
<td>SOLLYA_FP_NOT_FAITHFUL_ZERO_CONTAINED_BELOW_THRESHOLD</td>
<td>The algorithm ended up at step (e) and ( I ) was of the form ([-\delta_1, \delta_2]) where ( 0 &lt; \delta_i \ll 1 ) (below some threshold of the algorithm). This typically happens when ( f(a) ) exactly equals zero, but the algorithm does not manage to prove this exact equality.</td>
</tr>
<tr>
<td>SOLLYA_FP_NOT_FAITHFUL_ZERO_CONTAINED_NOT_BELOW_THRESHOLD</td>
<td>The algorithm ended up at step (e) with an interval ( I ) containing 0 but too large to fall in the above case. (^b)</td>
</tr>
<tr>
<td>SOLLYA_FP_NOT_FAITHFUL_ZERO_NOT_CONTAINED</td>
<td>The algorithm ended up at step (e) with an interval ( I ) that does not contain 0. (^b)</td>
</tr>
<tr>
<td>SOLLYA_FP_NOT_FAITHFUL_INFINITY_CONTAINED</td>
<td>The algorithm ended up at step (e) and (at least) one of the bounds of ( I ) was infinite. This typically happens when the limit of ( f(x) ) when ( x ) goes to ( a ) is infinite.</td>
</tr>
</tbody>
</table>

\(^a\)Please notice that this means that the algorithm did not manage to conclude whether the result is exact or not. However, it might have been able to conclude if the working precision had been increased.

\(^b\)In general, this should be considered as a case of failure and the value stored in \( \text{res} \) might be completely irrelevant.
10.15 Executing Sollya procedures

Objects representing procedures written in Sollya language (see also Section 7.1) can be created using the Sollya library functions `sollya_lib_parse_string` and `sollya_lib_parse` or through execution of a Sollya script using `sollya_lib_execute`

In order to execute such procedure objects on arguments, available as Sollya objects, too, the functions

- `sollya_obj_t sollya_lib_execute_procedure(sollya_obj_t proc, ...)`
- `sollya_obj_t sollya_lib_v_execute_procedure(sollya_obj_t proc, va_list arglist)`

may be used. These functions apply the given procedure `proc` on the following arguments (or the elements in the argument list `arglist`). If no argument is needed to execute the procedure, the variadic argument list shall immediately be terminated using `NULL`; otherwise the argument list shall be terminated with an extra `NULL` argument. An arity test is performed by Sollya before the procedure is executed: if the arity of the given procedure does not correspond to the actual number of given arguments (and the Sollya procedure is not variadic), an error object is returned instead of the procedure’s result.

When the functions are used to execute procedures that return a Sollya object, the object is returned by the function. When the procedure does not use the Sollya `return` statement or returns the Sollya `void` object, a Sollya `void` object is returned. The user should not forget to deallocate that `void` object.

10.16 Name of the free variable

The default name for the free variable is the same in the library and in the interactive tool: it is `_x_`. In the interactive tool, this name is automatically changed at the first use of an undefined symbol. Accordingly in library mode, if an object is defined by `sollya_lib_parse_string` with an expression containing an undefined symbol, that symbol will become the free variable name if it has not already been changed before. But what if one does not use `sollya_lib_parse_string` (because it is not efficient) but one wants to change the name of the free variable? The name can be changed with `sollya_lib_name_free_variable("some_name")`.

It is possible to get the current name of the free variable with `sollya_lib_get_free_variable_name()`. This function returns a `char *` containing the current name of the free variable. Please note that this `char *` is dynamically allocated on the heap and should be cleared after its use with `sollya_lib_free()` (see below).

10.17 Commands and functions

Besides some exceptions, every command and every function available in the Sollya interactive tool has its equivalent (with a very close syntax) in the library. Section 8 of the present documentation gives the library syntax as well as the interactive tool syntax of each commands and functions. The same information is available within the interactive tool by typing `help some_command`. So if one knows the name of a command or function in the interactive tool, it is easy to recover its library name and signature.

There are some commands and functions available in interactive mode which, for syntactical reasons, have a different function name in the Sollya library:

- The Sollya language construction `(obj1)(obj2, obj3, ...)` which applies the object `obj1` to the objects `obj2, obj3`, etc. is expressed in the Sollya library through a call to `sollya_obj_t sollya_lib_apply(sollya_obj_t obj1, sollya_obj_t obj2, ...)` resp. `sollya_obj_t sollya_lib_v_apply(sollya_obj_t obj1, sollya_obj_t obj2, va_list)`. 

A particular point is worth mentioning: some functions of the tool such as `remez` for instance have a variable number of arguments. For instance, one might call `remez(exp(x), 4, [0,1])` or `remez(1, 4, [0,1], 1/exp(x))`. This feature is rendered in the C library by the use of variadic functions (functions with an arbitrary number of arguments), as they are permitted by the C standard. The notable difference is that there must always be an explicit NULL argument at the end of the function call. Hence one can write `sollya_lib_remez(a, b, c, NULL)` or `sollya_lib_remez(a, b, c, d, NULL)`. It is very easy to forget the NULL argument and to use for instance `sollya_lib_remez(a, b, c)`. This is
completely wrong because the memory will be read until a NULL pointer is found. In the best case, this will lead to an error or a result obviously wrong, but it could also lead to subtle, not-easy-to-debug errors. The user is advised to be particularly careful with respect to this point.

Each command or function accepting a variable number of arguments comes in a sollya\_lib\_v\_version accepting a va\_list parameter containing the list of optional arguments. For instance, one might write a function that takes as arguments a function $f$, an interval $I$, optionally a weight function $w$, optionally a quality parameter $q$. That function would display the minimax obtained when approximating $f$ over $I$ (possibly with weight $w$ and quality $q$) by polynomials of degree $n = 2$ to 20. So, that function would get a variable number of arguments (i.e., a va\_list in fact) and pass them straight to remez. In that case, one needs to use the v\_remez version, as the following code shows:

```c
#include <sollya.h>
#include <stdarg.h>

/* Note: we suppose that the library has already been initialized */
void my_function(sollya_obj_t f, sollya_obj_t I, ...) {
    sollya_obj_t n, res;
    int i;
    va_list va;

    for(i=2;i<=20;i++) {
        n = SOLLYA_CONST(i);
        va_start(va, I);
        res = sollya_lib_v_remez(f, n, I, va);
        sollya_lib_printf("Approximation of degree %b is %b\n", n, res);
        va_end(va);
        sollya_lib_clear_obj(n);
        sollya_lib_clear_obj(res);
    }

    return;
}
```

10.18 Warning messages in library mode

10.18.1 Catching warning messages

The philosophy of Sollya is “whenever something is not exact, explicitly warn about that”. This is a nice feature since this ensures that the user always perfectly knows the degree of confidence they can have in a result (is it exact? or only faithful? or even purely numerical, without any warranty?) However, it is sometimes desirable to hide some (or all) of these messages. This is especially true in library mode where messages coming from Sollya are intermingled with the messages of the main program. The library hence provides a specific mechanism to catch all messages emitted by the Sollya core and handle each of them specifically: installation of a callback for messages.

Before describing the principle of the message callback, it seems appropriate to recall that several mechanisms are available in the interactive tool to filter the messages emitted by Sollya. These mechanisms are also available in library mode for completeness. When a message is emitted, it has two characteristics: a verbosity level and an id (a number uniquely identifying the message). After it has been emitted, it passes through the following steps where it can be filtered. If it has not been filtered (and only in this case) it is displayed.

1. If the verbosity level of the message is greater than the value of the environment variable verbosity, it is filtered.

2. If the environment variable roundingwarnings is set to off and if the message informs the user that a rounding occurred, it is filtered.
3. If the id of the message has been registered with the `suppressmessage` command, the message is filtered.

4. If a message callback has been installed and if the message has not been previously filtered, it is handled by the callback, which decides to filter it or to permit its displaying.

A message callback is a function of the form `int my_callback(sollya_msg_t msg, void *data)`. It receives as input an object representing the message and a user-defined pointer. It performs whatever treatment seems appropriate and returns an integer interpreted as a boolean. If the returned value is false, the message is not displayed. If, on the contrary, the returned value is true, the message is displayed as usual. By default, no callback is installed and all messages are displayed. To install a callback, use `sollya_lib_install_msg_callback(my_callback, data)`. The `(void *)` pointer `data` is arbitrary (it can be `NULL`) and is simply transmitted as second argument at each call of the callback. It can be used, e.g., to point to a segment of memory where some information should be stored from a call of the callback to another.

Please remember that, if a message is filtered because of one of the three other mechanisms, it will never be transmitted to the callback. Hence, in library mode, if one wants to catch every single message through the callback, one should set the value of `verbosity` to `MAX_INT`, set `roundingwarnings` to `on` (this is the default anyway) and one should not use the `suppressmessage` mechanism.

It is possible to come back to the default behavior, using `sollya_lib_uninstall_msg_callback()`. Please notice that callbacks do not stack over each other: i.e., if some callback `callback1` is installed, and if one installs another one `callback2`, then the effect of `sollya_lib_uninstall_msg_callback()` is to come back to the default behavior, and not to come back to `callback1`.

Both `sollya_lib_install_msg_callback` and `sollya_lib_uninstall_msg_callback` return an integer interpreted as a boolean: false means failure and true means success.

It is possible to get the current callback using `sollya_lib_get_msg_callback(cb_ptr, data_ptr)`. This stores the current callback at the address referred to by `cb_ptr` (the type of `cb_ptr` is hence `int (*)(sollya_msg_t, void *)`) and stores the current data pointer at the address referred to by `data_ptr` (which has hence `(void **)` type). The arguments `cb_ptr` and `data_ptr` can be `NULL` in which case the corresponding argument is not retrieved (please take care of the difference between `data_ptr` being `NULL` and `data_ptr` pointing to a `(void *)` pointer which value is `NULL`). If no callback is currently installed, the `NULL` value is stored at the addresses referred to by `cb_ptr` and `data_ptr`.

The type `sollya_msg_t` is indeed a pointer and its content is only accessible during the callback call: it does not make sense to keep it for further use after the callback call. Currently the type has only two accessors:

- `int sollya_lib_get_msg_id(sollya_msg_t msg)` returns an integer that identifies the type of the message. The message types are listed in the file `sollya-messages.h`. Please note that this file not only lists the possible identifiers but also defines meaningful names to each possible message number (e.g., `SOLLYA_MSG_UNDEFINED_ERROR` is an alias for the number 2 but is more meaningful to understand what the message is about). It is recommended to use these names instead of numerical values.

- `char *sollya_lib_msg_to_text(sollya_msg_t msg)` returns a generic string briefly summarizing the contents of the message. Please note that this `char *` is dynamically allocated on the heap and should manually be cleared with `sollya_lib_free` when it becomes useless.

In the future, other accessors could be added (to get the verbosity level at which the message has been emitted, to get data associated with the message, etc.) The developers of Sollya are open to suggestions and feature requests on this subject.

As an illustration let us give a few examples of possible use of callbacks:

**Example 1:** A callback that filters everything.

```c
int hide_everything(sollya_msg_t msg, void *data) {
    return 0;
}
```
Example 2: filter everything but the messages indicating that a comparison is uncertain.

```c
int keep_comparison_warnings(sollya_msg_t msg, void *data) {
    switch(sollya_lib_get_msg_id(msg)) {
        case SOLLYA_MSG_TEST_RELIES_ON_FP_RESULT_THAT_IS_NOT_FAITHFUL:
        case SOLLYA_MSG_TEST_RELIES_ON_FP_RESULT:
        case SOLLYA_MSG_TEST_RELIES_ON_FP_RESULT_FAITHFUL_BUT_UNDECIDED:
        case SOLLYA_MSG_TEST_RELIES_ON_FP_RESULT_FAITHFUL_BUT_NOT_REAL:
            return 1;
        default:
            return 0;
    }
}
```

Example 3: ensuring perfect silence for a particular function call (uses the callback defined in Example 1).

```c
... int (*old_callback)(sollya_msg_t, void *); void *old_data; sollya_lib_get_msg_callback(&old_callback, &old_data); sollya_lib_install_msg_callback(hide_everything, NULL); /* Here takes place the function call that must be completely silent */ if (old_callback) sollya_lib_install_msg_callback(old_callback, old_data); ...
```

Example 4: using the (void *) data argument to store information from a call to another.

```c
int set_flag_on_problem(sollya_msg_t msg, void *data) {  
    switch(sollya_lib_get_msg_id(msg)) {  
        case SOLLYA_MSG_DOUBLE_ROUNDING_ON_CONVERSION:  
            *((int *)(data)) = 1;  
        }  
        return 1;  
    }
...  
int main() {  
    int flag_double_rounding = 0;  
    ...  
    sollya_lib_init();  
    sollya_lib_install_msg_callback(set_flag_on_problem, &flag_double_rounding);  
    ...  
}
```

More involved examples are possible: for instance, instead of setting a flag, it is possible to keep in some variable what the last message was. One may even implement a stack mechanism and store the messages in a stack, in order to handle them later. (Please remember however that sollya_msg_t is a pointer type and that the sollya_msg_t object received as argument of a callback call has no more meaning once the callback call returned. If a stack mechanism is implemented it should store information such as the message ID, or the message text, as given by sollya_lib_get_msg_id and sollya_lib_msg_to_text, but not the sollya_msg_t object itself.)
10.18.2 Emitting warning messages

The Sollya library offers a way to print a message, as if it were produced by the Sollya core. Such a message will go through the entire process described in the previous section, and can eventually provoke a callback call if a callback is installed. The function supporting this feature is

```c
void sollya_lib_printlibrarymessage(int verb, const char *str);
```

The first argument `verb` is the least verbosity level at which that warning shall be displayed. The second argument `str` is the message to be displayed.

When a message is produced with this function, its message ID (when caught by a callback) is `SOLLYA_MSG_GENERIC_SOLLYA_LIBRARY_MSG`. An important notice is that the character string returned by `sollya_lib_msg_to_text` when such a message is caught by a callback is currently not the argument `str` provided to `sollya_lib_printlibrarymessage`, but instead a generic message. This behavior might change in the future.

10.19 Using Sollya in a program that has its own allocation functions

Sollya uses its own allocation functions: as a consequence, pointers that have been allocated by Sollya functions must be freed using `sollya_lib_free` instead of the usual `free` function. Another consequence is that Sollya registers its own allocation functions to the GMP library, using the mechanism provided by GMP, so that GMP also uses Sollya allocation functions behind the scene, when the user performs a call to, e.g., `mpz_init`, `mpfr_init2`, etc.

In general, this is completely harmless and the user might even not notice it. However, this is a problem if Sollya is used in a program that also uses its own allocation functions and that has already registered these functions to GMP. Actually:

- If the main program has already registered allocation functions to GMP and if Sollya is naively initialized with `sollya_lib_init()`, Sollya will register its own allocation functions, thus overriding the previously registered functions.

- If the user initializes first Sollya, and then registers its own allocation functions to GMP, the exact opposite happens: Sollya allocation functions are overridden by those of the user, and this will likely cause Sollya to crash (or worst, silently behave not reliably).

In order to solve this issue, Sollya provides a chaining mechanism that we are now going to describe. The idea is the following: suppose that the main program should use a function `custom_malloc`. The user should not use `mp_set_memory_functions` as usual, but should instead initialize Sollya with the initializing function described above. This will cause Sollya to register an allocation function `sollya_lib_malloc` to GMP. This function overloads `custom_malloc`: when called, it uses `custom_malloc` to perform the actual allocation and does nothing else but some internal accounting and verification for that allocation. To repeat, the actual allocation is done by `custom_malloc`; hence from the point of view of the user, the mechanism is completely transparent and equivalent to directly registering `custom_malloc` to GMP. The same holds for all other allocation functions: in particular, this is true for `free` as well: if a function `custom_free` is given at the initialization of Sollya, then the function `sollya_lib_free` eventually uses `custom_free` to free the memory.

The initialization function providing this mechanism is:

```c
int sollya_lib_init_with_custom_memory_functions(
    void *(*custom_malloc)(size_t),
    void *(*custom_calloc)(size_t, size_t),
    void *(*custom_realloc)(void *, size_t),
    void (*custom_free)(void *),
    void *(*custom_realloc_with_size)(void *, size_t, size_t),
    void (*custom_free_with_size)(void *, size_t));
```

None of the arguments is mandatory: if the user does not want to provide an argument, they may use NULL as a placeholder for that argument. In that case, the corresponding Sollya default function will be used. Indeed, the default initializing function `sollya_lib_init()` is just an alias to `sollya_lib_init_with_custom_memory_functions(NULL, NULL, NULL, NULL, NULL, NULL).`
Please notice, that if `custom_malloc` is provided, then the function `sollya_lib malloc` will be defined as an overloaded version of `custom malloc`. Hence, `custom malloc` will eventually be used for all the allocations performed by Sollya (including the allocation of memory for its own purpose). This is true also for `custom calloc`, `custom realloc` and `custom free`. However, this is not the case for `custom realloc with size` and `custom free with size`: these functions are only required for the registration to GMP and are not used by Sollya itself (except of course when Sollya allocates function through a call to a GMP, MPFR or MPFI function). Thus, to sum up:

- If the user only wants to register their own functions to GMP through Sollya, they only need to provide `custom malloc`, `custom realloc with size` and `custom free with size` at the initialization of Sollya (actually an overloaded version will be registered to GMP but this is transparent for the user, as explained above).

- If the user also wants Sollya to use their custom allocation functions for all allocations of memory by Sollya, then they also need to provide `custom calloc`, `custom realloc` and `custom free`.

Of course, even if the user registers `custom malloc`, `custom free`, etc., at the initialization of Sollya, they stay free to use them for their own allocation needs: only allocations performed by GMP (and consequently MPFR and MPFI) and allocations performed by Sollya have to use the chaining mechanism. However, for the convenience of the user, the library also provides access to the allocation functions of Sollya. They are the following:

- `void sollya_lib_free(void *)`
- `void *sollya_lib malloc(size_t)`
- `void *sollya_lib calloc(size_t, size_t)`
- `void *sollya_lib realloc(void *, size_t)`.

No access to the overloaded version of `custom realloc with size` and `custom free with size` is provided, but if the user really wants to retrieve them, they can do it with `mp_get_memory_functions` since they are registered to GMP.