

# **Algorithmic C (AC) Math Release Notes**

Software Version v3.2.0

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## Release 3.2.3

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The following topics describes the changes that were made to the *ac\_math* library since the last release. This release provides new functionality, enhancements and bug fixes. This version of *ac\_math* was included in Catapult releases 10.4a, 10.4b, 10.4c, 10.5 and 10.5a.

### Removed Using-Declarations

Using-declarations to the *std* namespace for some of the *ac\_math* header files were removed. This was done to avoid any unwanted pulling of namespaces into any implementation files where the headers might be included, and thereby avoid any ensuing ambiguity. The *ac\_math* header files where this was applicable were those that used *cout* statements to display debug information. The following files now use the scope resolution operator to access members of the *std* namespace:

- *ac\_atan\_pwl.h*
- *ac\_chol\_d.h*
- *ac\_determinant.h*
- *ac\_hcordic.h*
- *ac\_inverse\_sqrt\_pwl.h*
- *ac\_log\_pwl.h*
- *ac\_normalize.h*
- *ac\_pow\_pwl.h*
- *ac\_qrd.h*
- *ac\_reciprocal\_pwl.h*
- *ac\_sigmoid\_pwl.h*
- *ac\_sincos\_lut.h*
- *ac\_sqrt\_pwl.h*
- *ac\_tan\_pwl.h*
- *ac\_tanh\_pwl.h*

### Added High-Accuracy Files

Associated Jira ticket: CAT-24022.

High-accuracy versions of the *ac\_atan\_pwl* and *ac\_reciprocal\_pwl* header files were added to facilitate high-accuracy calculation of the arctangent function. The new versions use more fractional bits and PWL segments. The following are the names of the files added:

- *ac\_atan\_pwl\_ha.h*
- *ac\_reciprocal\_pwl\_ha.h*

## Corrected Issues

The following issues were fixed in this release:

- **(CAT-24269, CAT-24362):** File: `ac_qrd.h` – QR decomposition calculations for complex inputs were rectified to give the correct output.
- **(no bug #):** File: `ac_sqrt.h` – An extra set of parentheses were added to remove compile-time warnings and reduce ambiguity.

## Release 3.1.2

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The following topics describes the changes that were made to the *ac\_math* library since the last release. This release provides new functionality and bug fixes. This version of *ac\_math* was included in Catapult release 10.3a.

### Improved Bitwidth Calculation

The following PWL functions had the calculations for parameterized bitwidths of *ac\_fixed* variables improved in order to eliminate redundant bits and reduce area:

- *ac\_inverse\_sqrt\_pwl.h*
- *ac\_log\_pwl.h*
- *ac\_pow\_pwl.h*
- *ac\_reciprocal\_pwl.h*
- *ac\_sqrt\_pwl.h*
- *ac\_tan\_pwl.h*

### Cleanup Sine/Cosine Cordic

The *ac\_sincos\_cordic.h* file was updated to rename a typedef so as to avoid a redeclaration conflict.

### Removed Direct Access to AC Float Member Data

The *ac\_reciprocal\_pwl()*, *ac\_inverse\_sqrt\_pwl()* and *ac\_sqrt\_pwl()* functions now no longer directly access the mantissa and exponent data members in the *ac\_float* class for inputs. Instead, the functions use the *.mantissa()* and *.exp()* member functions to indirectly access (read-only) the data members of the input floating point variables.

### Added New Power Function

A generic *ac\_pow\_pwl()* function was which accepted variable bases as well as exponents.

### Default Template Parameter Changed

*ac\_exp\_pwl()* function now uses more fractional bits by default for an intermediate variable, to minimize error.

### Corrected Issues

The following user-reported problems were fixed in this release:

- **(no bug #):** File: ac\_matrix.h – Transpose() member function was incorrect.
- **(no bug #):** File ac\_sqrt\_pwl.h – Fixed bug in output near normalized 1 by adding extra bit to account for upward shifting of segments against the direction of concavity for ac\_float types.
- **(no bug #):** File ac\_sincos\_cordic.h – Renamed the typedef to avoid redeclaration conflict with ac\_atan2\_cordic.h



# Release 3.1.0

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The following topics describes the changes that were made to the *ac\_math* library since the last release. This release provides new functionality and bug fixes. This version of *ac\_math* was included in Catapult release 10.3.

## Hyperbolic Tangent File Renamed

The file `ac_hyperbolic_tan_pwl.h` was renamed to `ac_tanh_pwl.h` for consistency with the other header files.

## Improved AC Complex Support

The file `ac_reciprocal_pwl.h` was changed to use better bitwidth calculation for intermediate variables in the `ac_complex<ac_float>` version.

## Corrected Issues

The following user-reported problems were fixed in this release:

- **(bug #51400):** File: `ac_abs.h` – Function for `ac_int` values results in hardware that uses an  $XW + 1$  bit adder instead of an  $XW + 2$  bit adder, where  $XW$  is the input bitwidth, thereby reducing area and improving QofR.
- **(bug #51145):** Files: `ac_inverse_sqrt_pwl.h`, `ac_reciprocal_pwl.h` and `ac_sqrt_pwl.h` – Fixed expressions that directly manipulated the mantissa and exponent for `ac_float` outputs, replacing it with an `ac_float` constructor that performed normalization first and then modified the mantissa and exponent.
- **(no bug #):** File: `ac_sqrt.h` – Fixed expression that could cause overflow.
- **(no bug #):** Files: `ac_arccos_cordic.h` and `ac_arcsin_cordic.h` – Used different names for the class, function and variable in both the files to avoid name conflicts.

# Release 2.0.10

This is the first official open-source release of the *ac\_math* library. The following table lists the functions available in this release. For details about how to use the *ac\_math* library consult the AC Math Reference Manual. This version of *ac\_math* was included in Catapult release 10.2d.

## Basic Math Functions

Function Type	Function Call	Approximation Method	Supported Data Types		
			ac_fixed	ac_float	ac_complex
<b>Absolute Value</b>	<i>ac_abs()</i>	N/A	Yes	Yes	No
<b>Division</b>	<i>ac_div()</i>	N/A	Yes	Yes	Yes
<b>Normalization</b>	<i>ac_normalize()</i>	N/A	Yes	No	Yes
<b>Reciprocal</b>	<i>ac_reciprocal_pwl()</i>	PWL	Yes	Yes	Yes
<b>Logarithm Base e</b>	<i>ac_log_pwl()</i>	PWL	Yes	No	No
	<i>ac_log_cordic()</i>	CORDIC	Yes	No	No
<b>Logarithm Base 2</b>	<i>ac_log2_pwl()</i>	PWL	Yes	No	No
	<i>ac_log2_cordic()</i>	CORDIC	Yes	No	No
<b>Exponent Base e</b>	<i>ac_exp_pwl()</i>	PWL	Yes	No	No
	<i>ac_exp_cordic()</i>	CORDIC	Yes	No	No
<b>Exponent Base 2</b>	<i>ac_pow2_pwl()</i>	PWL	Yes	No	No
	<i>ac_exp2_cordic()</i>	CORDIC	Yes	No	No
<b>Generic Exponent</b>	<i>ac_pow_pwl()</i>	PWL	Yes	No	No
	<i>ac_pow_cordic()</i>	CORDIC	Yes	No	No
<b>Square Root</b>	<i>ac_sqrt_pwl()</i>	PWL	Yes	Yes	Yes
	<i>ac_sqrt()</i>	N/A	Yes	No	No
<b>Inverse Square Root</b>	<i>ac_inverse_sqrt_pwl()</i>	PWL	Yes	Yes	Yes
<b>Sine/Cosine</b>	<i>ac_sincos()</i>	LUT	Yes	No	No
	<i>ac_cos_cordic()</i>	CORDIC	Yes	No	No
	<i>ac_sin_cordic()</i>	CORDIC	Yes	No	No
	<i>ac_sincos_cordic()</i>	CORDIC	Yes	No	No
<b>Tangent</b>	<i>ac_tan_pwl()</i>	PWL	Yes	No	No
<b>Inverse Trig</b>	<i>ac_atan_pwl()</i>	PWL	Yes	No	No
	<i>ac_arccos_cordic()</i>	CORDIC	Yes	No	No

Function Type	Function Call	Approximation Method	Supported Data Types		
			ac_fixed	ac_float	ac_complex
	<i>ac_arcsin_cordic()</i>	CORDIC	Yes	No	No
	<i>ac_arctan_cordic()</i>	CORDIC	Yes	No	No
<b>Shift Left/Right</b>	<i>ac_shift_left</i>	N/A	Yes	No	Yes
	<i>ac_shift_right</i>	N/A	Yes	No	Yes
<b>Hyperbolic Tangent</b>	<i>ac_tanh_pwl</i>	PWL	Yes	No	No
<b>Sigmoid</b>	<i>ac_sigmoid_pwl</i>	PWL	Yes	No	No
<b>Softmax</b>	<i>ac_softmax_pwl</i>	PWL	Yes	No	No

## AC Matrix Class

The class `ac_matrix` implements a 2-D container class with a template parameter to specify the data type of the internal storage.

The class has member functions to implement some common operations including

- Assignment: `operator=()`
- Read-Only and Read-Write Element Access: `*this(<row>,<col>)`
- Comparison: `operator!=()`, `operator==()`
- Piecewise Addition: `operator+()`, `operator+=()`
- Piecewise Subtraction: `operator-()`, `operator-=()`
- Piecewise Multiplication: `pwisemult()`
- Matrix Multiplication (nested loops): `operator*()`
- Matrix Transpose: `transpose()`
- Sum All Elements: `sum()`
- Scale All Elements: `scale(value)`
- Formatted Stream Output: `ostream &operator<<()`

When using the computational functions with AC Datatypes, the form that returns a value is designed in such a way as to determine the full precision required in the output type in order to preserve accuracy during the operation. So using `operator+` between two 10 bit `ac_fixed` matrices will return an 11 bit `ac_fixed` matrix. If you wish to prevent the bit growth and accept the truncation, you can use the compound operators `+=`, `-=`, etc. so that the target object receives the truncated values.

In addition to the built-in member functions, the `ac_math` library also includes stand-alone functions for more complicated linear algebra operations as described in the next section.

# Linear Algebra Functions

The `ac_math` library includes several linear algebra functions that operate on either `ac_matrix` or plain C-style arrays. These functions, when used with AC Datatypes, are designed to give the user greater control over the bit precision of internal variables and the return value.

- Matrix Multiplication
- Matrix Determinant
- Cholesky Decomposition
- Cholesky Inverse
- QR Decomposition

## Supported Compilers

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The PWL functions use default template arguments. This requires using a C++ compiler that support the C++11 or newer standard.