librapid

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CONTENTS

CHAPTER

ONE

WHAT IS LIBRAPID?

LibRapid is a high performance Array library for C++. It supports a wide range of calculations and operations, useful classes and functions, and even supports CUDA! It uses SIMD instructions and multithreading where possible, achieving incredible performance on all operations.

Getting Started   Write your first program with LibRapid.

CMake Integration   See all available CMake options to make the most of LibRapid's features.

API Reference   View LibRapid's API and documentation.

Tutorials   Learn how to use some of LibRapid's features.

Performance and Benchmarks   View LibRapid's benchmark results.

Caution   **Learn about potential issues that may occur with LibRapid**

1.1 Getting Started

1.1.1 Installation

To use LibRapid in your CMake project, first clone the project:

`git clone --recursive https://github.com/LibRapid/libRapid.git`

> **Warning:** Make sure to use the `--recursive` flag when cloning the repository. This will ensure that all submodules are cloned as well!

Make sure you have a structure similar to the following:

```
yourProject/
    CMakeLists.txt
    main.cpp
    librapid/
        CMakeLists.txt
        ...
    ...
```

Next, add the following to your `CMakeLists.txt`

```
add_subdirectory(librapid)
target_link_libraries(yourTarget PUBLIC librapid)
```

Note: If you are not familiar with CMake, I suggest you follow a quick tutorial on it just to get the hang of the basics. After that, check out the sample `CMakeLists.txt` file in the `examples` directory of the repository.

(`examples/templateCMakeLists.txt`)[https://github.com/LibRapid/librapid/blob/master/examples/templateCMakeLists.txt]

That's it! LibRapid will now be compiled and linked with your project!

1.1.2 Your First Program

```
#include <librapid>
namespace lrc = librapid;

int main() {
    lrc::Array<int> myFirstArray = lrc::fromData({{1, 2, 3, 4},
                                                  {5, 6, 7, 8}});

    lrc::Array<int> mySecondArray = lrc::fromData({{8, 7, 6, 5},
                                                   {4, 3, 2, 1}});

    fmt::print("{}\n\n", myFirstArray);
    fmt::print("{}\n", mySecondArray);

    fmt::print("Sum of two Arrays:\n{}\n", myFirstArray + mySecondArray);
    fmt::print("First row of my Array: {}\n", myFirstArray[0]);
    fmt::print("First row of my Array: {}\n", myFirstArray[0] + mySecondArray[1]);

    return 0;
}
```

1.1.3 Your First Program: Explained

```
#include <librapid>
namespace lrc = librapid;
```

The first line here allows you to use all of LibRapid's features in your file. The second line isn't required, but it makes your code shorter and quicker to type.

```
lrc::Array<int> myFirstArray = lrc::fromData({{1, 2, 3, 4},
                                              {5, 6, 7, 8}});

lrc::Array<int> mySecondArray = lrc::fromData({{8, 7, 6, 5},
                                               {4, 3, 2, 1}});
```

These lines create two Array instances from a list of values. Both arrays are 2-dimensional and have 2 rows and 4 columns.

```
fmt::print("{}\n\n", myFirstArray);
fmt::print("{}\n", mySecondArray);
```

Here, we print out the Arrays we just created. Try changing the numbers to see how the formatting changes!

```
fmt::print("Sum of two Arrays:\n{}\n", myFirstArray + mySecondArray);
```

This line performs a simple arithmetic operation on our Arrays and prints the result.

```
fmt::print("First row of my Array: {}\n", myFirstArray[0]);
fmt::print("First row of my Array: {}\n", myFirstArray[0] + mySecondArray[1]);
```

As you can see, Array instances can be indexed with the traditional square bracket notation. This means you can easily access sub-arrays of higher-dimensional array objects.

Now that you've seen how easy it is to use LibRapid, check out the rest of the documentation to learn more about the library's features! There are more example programs in the `examples` directory of the repository.

(`examples/`)[https://github.com/LibRapid/librapid/tree/master/examples]

1.2 CMake Integration

1.2.1 Installation

Link librapid like any other CMake library:

Clone the repository: `git clone --recursive https://github.com/LibRapid/libRapid.git`

Add the following to your `CMakeLists.txt`

```
add_subdirectory(librapid)
target_link_libraries(yourTarget PUBLIC librapid)
```

Tip: For a template `CMakelists.txt` file, see the `examples` directory: examples/CMakeLists.txt

1.2.2 CMake Options

1.2.2.1 `LIBRAPID_BUILD_EXAMPLES`

```
DEFAULT: OFF
```

Build the suite of example programs in the `examples` directory.

1.2.2.2 LIBRAPID_BUILD_TESTS

```
DEFAULT: OFF
```

Build LibRapid's unit tests.

1.2.2.3 LIBRAPID_CODE_COV

```
DEFAULT: OFF
```

Enable code coverage for LibRapid's unit tests.

1.2.2.4 LIBRAPID_STRICT

```
DEFAULT: OFF
```

Enable strict compilation flags, turn on all warnings, and treat warnings as errors.

1.2.2.5 LIBRAPID_QUIET

```
DEFAULT: OFF
```

Disable all warnings from LibRapid. This is useful if you are using LibRapid as a dependency and want a cleaner compilation output. Warnings should be minimal in the first place, but this option is provided just in case.

1.2.2.6 LIBRAPID_GET_FFTW

```
DEFAULT: OFF
```

Add FFTW as a dependency and link it with LibRapid. This is required for FFT support unless CUDA is enabled.

> **Danger:** FFTW is licensed under the GPL, which is not compatible with LibRapid's MIT license. If you are using LibRapid as a dependency in an open source project, you may need to use LibRapid under a GPL license. If you forget, you'll ***probably*** be fine, but I can't guarantee anything. I'm not a lawyer, so don't take my word for it.

1.2.2.7 LIBRAPID_GET_BLAS

```
DEFAULT: OFF
```

Download a precompiled OpenBLAS build for your platform, and link it with LibRapid. This is useful if you don't (or can't) have BLAS installed on your system.

> **Warning:** Always prefer to use your system's BLAS installation if possible.

1.2.2.8 LIBRAPID_USE_OMP

```
DEFAULT: ON
```

If OpenMP is found on the system, link LibRapid with it. This is required for multi-threading support and can significantly improve performance.

> **Warning:** If this flag is enabled and OpenMP is not found installed on the system, the build will continue without OpenMP support.

1.2.2.9 LIBRAPID_USE_OPENCL

```
DEFAULT: ON
```

Search for OpenCL and link LibRapid with it. This is required for OpenCL support.

```
If this flag is enabled and OpenCL is not found installed on the system, the build will
↪continue without OpenCL support.
```

> **Danger:** If you are using OpenCL as a backend in your code, you must call `librapid::configureOpenCL()` before using any OpenCL arrays. This function will initialise the OpenCL context and queue, compile the OpenCL kernels and configure the OpenCL device for optimal performance. See the documentation for this function for more information.

1.2.2.10 LIBRAPID_USE_CUDA

```
DEFAULT: ON
```

Search for CUDA and link LibRapid with it. This is required for GPU support.

```
If this flag is enabled and CUDA is not found installed on the system, the build will
↪continue without CUDA support.
```

> **Danger:** LibRapid's CUDA support appears to only works on Windows, for some reason. I have no way of testing it on Linux or MacOS, so I can't guarantee that it will work. If you have experience in this area, please feel free to contact me and we can work together to get it working.

1.2.2.11 LIBRAPID_USE_MULTIPREC

```
DEFAULT: OFF
```

If MPIR and MPFR are found on the system, LibRapid will automatically link with them. If not, LibRapid will build custom, modified versions of these libraries. This is required for arbitrary precision support.

> **Warning:** This can lead to longer build times and larger binaries.

1.2.2.12 LIBRAPID_OPTIMISE_SMALL_ARRAYS

```
DEFAULT: OFF
```

Enabling this flag removes multithreading support for trivial array operations. For relatively small arrays (on the order of 1,000,000 elements), this can lead to a significant performance boost. For arrays larger than this, multithreading can be more efficient.

1.2.2.13 LIBRAPID_FAST_MATH

```
DEFAULT: OFF
```

Enabling this flag enables fast math mode for all LibRapid functions. This can lead to a significant performance boost, but may cause some functions to return slightly incorrect results due to lower precision operations being performed.

1.2.2.14 LIBRAPID_NATIVE_ARCH

```
DEFAULT: OFF
```

Enabling this flag compiles librapid with the most advanced instruction set available on the system. This can lead to significant performance boosts, but may cause the library to be incompatible with older systems.

```
Compiling with this flag may also cause the binaries to be incompatible with other CPU␣
↪architectures, so be careful
when distributing your programs.
```

1.2.2.15 LIBRAPID_CUDA_FLOAT_VECTOR_WIDTH and LIBRAPID_CUDA_DOUBLE_VECTOR_WIDTH

```
DEFAULT: 4
```

Set the default vector width for SIMD CUDA kernels. This must be in the range $[1, 4]$. Higher values will lead to better performance in most cases, but can increase register pressure which may lead to lower performance than expected. For optimal performance, you should try changing this value to suit your specific use case.

> **Warning:** This setting requires CUDA support to be enabled.

1.2.2.16 LIBRAPID_NO_WINDOWS_H

```
DEFAULT: OFF
```

Prevent the inclusion of `windows.h` in LibRapid's headers. Sometimes the macros and functions defined in this header can cause conflicts with other libraries, so this option is provided to prevent this.

> **Danger:** It is not possible to fully remove `windows.h` when compiling with CUDA support on Windows, but many of the modules are still disabled. There is a possiblity that conflicts will still arise, but I am yet to encounter any.

1.2.2.17 LIBRAPID_MKL_CONFIG_PATH

```
DEFAULT: ""
```

If you have Intel's OneAPI Math Kernel Library installed on your system, you can provide the path to the `MKLConfig.cmake` file here. This will force LibRapid to link with MKL and ignore any other BLAS libraries. On systems with Intel CPUs, this can result in a significant performance boost.

1.3 API Reference

Important: This list is **INCOMPLETE**! If you think something is missing, try searching for it first. If you still can't find it, please open an issue on the LibRapid GitHub repository.

Arrays, Matrices and Linear Algebra Multidimensional arrays, matrices, linear algebra and more.

Machine Learning Machine learning in LibRapid.

Vectors Fixed-size vectors and supported operations.

Complex Numbers Complex numbers and their operations.

Mathematics General mathematical operations that work on most data types.

Multi-Precision Arithmetic Arbitrary-precision integers, floating points and rationals.

Utilities Utility functions and classes to support development.

1.3.1 Topics and Usage Examples

1.3.1.1 Array Iterators

LibRapid provides many methods to iterate over the elements of an array. Each one has its own advantages and disadvantages, and the best one to use depends heavily upon the situation.

Implicit Iteration

This is the **simplest and easiest** way to iterate over an array, but is also the **slowest**. This method should only be used when performance is not a concern or when the array is known to be relatively small.

```
auto a = lrc::Array<int>(lrc::Shape({4, 5}));

for (auto val : a) {
    for (auto val2 : val) {
        val2 = lrc::randint(1, 10);
    }
}

for (const auto &val : a) {
    for (const auto &val2 : val) {
        fmt::print("{} ", val2);
    }
    fmt::print("\n");
}
```

> **Warning:** Due to the way LibRapid works internally, the iterator type returned by `Array::begin()` and `Array::end()` makes use of the `ArrayView` class. Since this is ***not a direct C++ reference*** many IDEs will claim that the value is unused and will suggest removing it. **Do not remove it!** The `ArrayView` is still referencing the original array and your data will still be updated correctly :)
>
> Keep in mind that this issue only comes up when you're using the non-const iterator, which is when you're assigning to the iterator.
>
> I am currently looking into ways to fix this issue, but it is proving to be quite difficult…

Subscript Iteration

This method of iterating over an array is slightly faster than implicit iteration, but is still slow compared to other methods. This involves using a `for` loop to iterate over each axis of the array and then using the `operator[]` to access the elements.

```
auto a = lrc::Array<int>(lrc::Shape({4, 5}));

for (auto i = 0; i < a.shape()[0]; i++) {
    for (auto j = 0; j < a.shape()[1]; j++) {
        a[i][j] = lrc::randint(1, 10);
    }
}

for (auto i = 0; i < a.shape()[0]; i++) {
    for (auto j = 0; j < a.shape()[1]; j++) {
        fmt::print("{} ", a[i][j]);
    }
    fmt::print("\n");
}
```

Direct Iteration

This approach is the fastest safe way to iterate over an array. Again, using a `for` loop to iterate over each axis of the array, but this time using the `operator()` method to access the elements.

This method is ***much faster*** than using the `operator[]` method because no temporary `ArrayView` objects are created.

```
auto a = lrc::Array<int>(lrc::Shape({4, 5}));

for (auto i = 0; i < a.shape()[0]; i++) {
    for (auto j = 0; j < a.shape()[1]; j++) {
        a(i, j) = lrc::randint(1, 10);
    }
}

for (auto i = 0; i < a.shape()[0]; i++) {
    for (auto j = 0; j < a.shape()[1]; j++) {
        fmt::print("{} ", a(i, j));
    }
    fmt::print("\n");
}
```

Direct Storage Access

LibRapid's array types have a `Storage` object which stores the actual data of the array. This object can be accessed via the `Array::storage()` method. This method is the fastest way to iterate over an array, but it is also the most dangerous, and you should ***only use it if you know what you are doing***.

> **Danger:** This method only works on `ArrayContainer` instances (Array types which own their own data). If you try to use this approach on any other datatype, such as an `ArrayView` or `Function`, your code will not compile because these types do not store their own data and hence do not have a `storage()` method.
>
> Note also that this does not give any information about the shape of the array, so you must be careful to ensure that you are accessing the correct elements.

```
auto a = lrc::Array<int>(lrc::Shape({4, 5}));

for (auto i = 0; i < a.shape().size(); i++) {
        a.storage()[i] = lrc::randint(1, 10);
}

for (auto i = 0; i < a.shape().size(); i++) {
    fmt::print("{} ", a.storage()[i]);
}
```

> **Warning:** The `Storage` object stores the data in row-major order, so you must be careful that you are accessing the correct elements.
>
> For example, if you have a 3D array with shape `{2, 3, 4}`, the elements will be accessed in the following order:

```
(0, 0, 0)
(0, 0, 1)
(0, 1, 0)
(0, 1, 1)
(0, 2, 0)
(0, 2, 1)
(1, 0, 0)
(1, 0, 1)
(1, 1, 0)
(1, 1, 1)
(1, 2, 0)
(1, 2, 1)
```

Benchmarks

These benchmarks were performed on a Ryzen 9 3950x CPU with 64GB of RAM. The code used is included below.

25000×25000 array of `floats`

MSVC

```
Iterator Timer [     ITERATOR     ] -- Elapsed: 1.25978m | Average: 25.19570s
Iterator Timer [ FOR LOOP INDEXED ] -- Elapsed: 1.06851m | Average: 10.68511s
Iterator Timer [ FOR LOOP DIRECT  ] -- Elapsed: 1.03243m | Average: 2.13607s
Iterator Timer [     STORAGE      ] -- Elapsed: 1.00972m | Average: 712.74672ms
```

GCC (WSL2)

```
Iterator Timer [     ITERATOR     ] -- Elapsed: 1.30497m | Average: 26.09936s
Iterator Timer [ FOR LOOP INDEXED ] -- Elapsed: 1.00171m | Average: 12.02046s
Iterator Timer [ FOR LOOP DIRECT  ] -- Elapsed: 1.00257m | Average: 222.79388ms
Iterator Timer [     STORAGE      ] -- Elapsed: 1.00265m | Average: 268.56730ms
```

1000×1000 array of `floats`

MSVC

```
Iterator Timer [     ITERATOR     ] -- Elapsed: 20.03113s | Average: 60.51699ms
Iterator Timer [ FOR LOOP INDEXED ] -- Elapsed: 20.01374s | Average: 20.56911ms
Iterator Timer [ FOR LOOP DIRECT  ] -- Elapsed: 20.00305s | Average: 3.65019ms
Iterator Timer [     STORAGE      ] -- Elapsed: 20.00049s | Average: 1.45257ms
```

GCC (WSL2)

```
Iterator Timer [     ITERATOR     ] -- Elapsed: 20.03222s | Average: 75.30909ms
Iterator Timer [ FOR LOOP INDEXED ] -- Elapsed: 20.00276s | Average: 23.67190ms
Iterator Timer [ FOR LOOP DIRECT  ] -- Elapsed: 20.00003s | Average: 62.70073us
Iterator Timer [     STORAGE      ] -- Elapsed: 20.00014s | Average: 242.00937us
```

100×100 array of `floats`

MSVC

```
Iterator Timer [     ITERATOR     ] -- Elapsed: 10.00005s | Average: 594.18031us
Iterator Timer [ FOR LOOP INDEXED ] -- Elapsed: 10.00007s | Average: 210.48345us
Iterator Timer [ FOR LOOP DIRECT  ] -- Elapsed: 10.00003s | Average: 14.38816us
Iterator Timer [     STORAGE      ] -- Elapsed: 10.00001s | Average: 14.94997us
```

GCC (WSL2)

```
Iterator Timer [     ITERATOR     ] -- Elapsed: 10.00055s | Average: 621.22918us
Iterator Timer [ FOR LOOP INDEXED ] -- Elapsed: 10.00001s | Average: 235.57702us
Iterator Timer [ FOR LOOP DIRECT  ] -- Elapsed: 10.00000s | Average: 650.03031ns
Iterator Timer [     STORAGE      ] -- Elapsed: 10.00000s | Average: 2.44980us
```

Code

```
lrc::Shape benchShape({25000, 25000});

{
    auto a = lrc::Array<float>(benchShape);
    lrc::Timer iteratorTimer(fmt::format("Iterator Timer [ {:^16} ]", "ITERATOR"));
    iteratorTimer.setTargetTime(10);

    while (iteratorTimer.isRunning()) {
        for (auto val : a) {
            for (auto val2 : val) { val2 = 1; }
        }
    }

    fmt::print("{:.5f}\n", iteratorTimer);
}

{
    auto a = lrc::Array<float>(benchShape);
    lrc::Timer iteratorTimer(fmt::format("Iterator Timer [ {:^16} ]", "FOR LOOP INDEXED
↪"));
    iteratorTimer.setTargetTime(10);
```

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```
    while (iteratorTimer.isRunning()) {
        for (int64_t i = 0; i < a.shape()[0]; i++) {
            for (int64_t j = 0; j < a.shape()[1]; j++) { a[i][j] = 1; }
        }
    }

    fmt::print("{:.5f}\n", iteratorTimer);
}

{
    auto a = lrc::Array<float>(benchShape);
    lrc::Timer iteratorTimer(fmt::format("Iterator Timer [ {:^16} ]", "FOR LOOP DIRECT
↪"));
    iteratorTimer.setTargetTime(10);

    while (iteratorTimer.isRunning()) {
        for (int64_t i = 0; i < a.shape()[0]; i++) {
            for (int64_t j = 0; j < a.shape()[1]; j++) { a(i, j) = 1; }
        }
    }

    fmt::print("{:.5f}\n", iteratorTimer);
}

{
    auto a = lrc::Array<float>(benchShape);
    lrc::Timer iteratorTimer(fmt::format("Iterator Timer [ {:^16} ]", "STORAGE"));
    iteratorTimer.setTargetTime(10);

    while (iteratorTimer.isRunning()) {
        for (int64_t i = 0; i < a.shape().size(); i++) { a.storage()[i] = 1; }
    }

    fmt::print("{:.5f}\n", iteratorTimer);
}
```

1.3.2 Arrays, Matrices and Linear Algebra

The main feature of LibRapid is its high-performance array library. It provides an intuitive way to perform highly efficient operations on arrays and matrices in C++.

1.3.2.1 Linear Algebra

Level 1 (Vector-Vector)

Level 2 (Matrix-Vector)

GEMV

> **Warning:** doxygenfile: Cannot find file "librapid/include/librapid/array/linalg/level3/gemv.hpp

Level 3 (Matrix-Matrix)

GEMM

namespace **librapid**

namespace **linalg**

Functions

template<typename **Int**, typename **Alpha**, typename **A**, typename **B**, typename **Beta**, typename **C**>
void **gemm**(bool transA, bool transB, Int m, Int n, Int k, Alpha alpha, A *a, Int lda, B *b, Int ldb, Beta beta, C *c, Int ldc, backend::CPU backend = backend::CPU())

General matrix-matrix multiplication.

Computes $\mathbf{C} = \alpha \mathrm{OP}_A(\mathbf{A}) \mathrm{OP}_B(\mathbf{B}) + \beta \mathbf{C}$ for matrices $\mathbf{A}$, $\mathbf{B}$ and $\mathbf{C}$. OP_A and OP_B are either the identity or the transpose operation.

Template Parameters

- **Int** – Integer type for matrix dimensions
- **Alpha** – Type of α
- **A** – Type of $\mathbf{A}$
- **B** – Type of $\mathbf{B}$
- **Beta** – Type of β
- **C** – Type of $\mathbf{C}$

Parameters

- **transA** – Whether to transpose $\mathbf{A}$ (determines OP_A)
- **transB** – Whether to transpose $\mathbf{B}$ (determines OP_B)
- **m** – Rows of $\mathbf{A}$ and $\mathbf{C}$
- **n** – Columns of $\mathbf{B}$ and $\mathbf{C}$
- **k** – Columns of $\mathbf{A}$ and rows of $\mathbf{B}$
- **alpha** – Scalar α
- **a** – Pointer to $\mathbf{A}$
- **lda** – Leading dimension of $\mathbf{A}$
- **b** – Pointer to $\mathbf{B}$
- **ldb** – Leading dimension of $\mathbf{B}$
- **beta** – Scalar β
- **c** – Pointer to $\mathbf{C}$
- **ldc** – Leading dimension of $\mathbf{C}$

- **backend** – Backend to use for computation

CuBLASGemmComputeType **cublasGemmComputeType**(cublasDataType_t a, cublasDataType_t b, cublasDataType_t c)

template<typename **Int**, typename **Alpha**, typename **A**, typename **B**, typename **Beta**, typename **C**>
void **gemm**(bool transA, bool transB, Int m, Int n, Int k, Alpha alpha, A *a, Int lda, B *b, Int ldb, Beta beta, C *c, Int ldc, backend::CUDA)

struct **CuBLASGemmComputeType**

#include <gemm.hpp>

Public Members

cublasComputeType_t **computeType**

cublasDataType_t **scaleType**

1.3.2.2 Array Class Listing

Defines

SINIT(SUB_TYPE)

SVEC(SUB_TYPE)

ARRAY_FROM_DATA_DEF(TYPE_INIT, TYPE_VEC)

template<typename **ShapeType_**, typename **StorageType_**>

struct **TypeInfo**<*array*::ArrayContainer<ShapeType_, StorageType_>>

#include <arrayContainer.hpp>

Public Types

using **Scalar** = typename TypeInfo<StorageType_>::Scalar

using **Packet** = std::false_type

using **Backend** = typename TypeInfo<StorageType_>::Backend

Public Static Attributes

static constexpr detail::LibRapidType **type** = detail::LibRapidType::ArrayContainer

static constexpr int64_t **packetWidth** = 1

static constexpr bool **supportsArithmetic** = TypeInfo<Scalar>::supportsArithmetic

static constexpr bool **supportsLogical** = TypeInfo<Scalar>::supportsLogical

static constexpr bool **supportsBinary** = TypeInfo<Scalar>::supportsBinary

static constexpr bool **allowVectorisation** = TypeInfo<Scalar>::packetWidth > 1

static constexpr cudaDataType_t **CudaType** = TypeInfo<Scalar>::CudaType

static constexpr int64_t **cudaPacketWidth** = 1

static constexpr bool **canAlign** = false

static constexpr int64_t **canMemcpy** = false

template<typename **SizeType**, size_t **dims**, typename **StorageScalar**>

struct **IsArrayContainer**<*array*::ArrayContainer<Shape<SizeType, dims>, StorageScalar>> : public std::true_type

#include <arrayContainer.hpp>

template<typename **T**>

struct **IsArrayType**<*array*::ArrayView<T>>

#include <arrayContainer.hpp>

Public Static Attributes

static constexpr bool **val** = true

namespace **librapid**

namespace **array**

template<typename **ShapeType_**, typename **StorageType_**>

class **ArrayContainer**

#include <arrayContainer.hpp>

Public Types

using **StorageType** = StorageType_

using **ShapeType** = ShapeType_

using **StrideType** = Stride<size_t, 32>

using **SizeType** = typename ShapeType::SizeType

using **Scalar** = typename StorageType::Scalar

using **Packet** = typename *typetraits*::TypeInfo<Scalar>::Packet

using **Backend** = typename *typetraits*::TypeInfo<ArrayContainer>::Backend

using **Iterator** = detail::ArrayIterator<ArrayView<ArrayContainer>>

using **DirectSubscriptType** = typename detail::SubscriptType<StorageType>::Direct

using **DirectRefSubscriptType** = typename detail::SubscriptType<StorageType>::Ref

Public Functions

ArrayContainer()

Default constructor.

template<typename **T**>
ArrayContainer(const std::initializer_list<T> &data)

template<typename **T**>
explicit **ArrayContainer**(const std::vector<T> &data)

explicit **ArrayContainer**(const ShapeType &shape)

Constructs an array container from a shape

Parameters **shape** – The shape of the array container

ArrayContainer(const ShapeType &shape, const Scalar &value)

Create an array container from a shape and a scalar value. The scalar value represents the value the memory is initialized with.

Parameters

- **shape** – The shape of the array container
- **value** – The value to initialize the memory with

explicit **ArrayContainer**(const Scalar &value)

Allows for a fixed-size array to be constructed with a fill value

Parameters **value** – The value to fill the array with explicit **ArrayContainer**(ShapeType &&shape)

Construct an array container from a shape, which is moved, not copied.

Parameters `shape` – The shape of the array container

ArrayContainer(const ArrayContainer &other) = default

Reference an existing array container.

This constructor does not copy the data, but instead references the data of the input array container. This means that the input array container must outlive the constructed array container. Please use `ArrayContainer::copy()` if you want to copy the data.

Parameters `other` – The array container to reference

ArrayContainer(ArrayContainer &&other) noexcept = default

Construct an array container from a temporary array container.

Parameters `other` – The array container to move.

template<typename **TransposeType**>
ArrayContainer(const Transpose<TransposeType> &trans)

template<typename **ShapeTypeA**, typename **StorageTypeA**, typename **ShapeTypeB**, typename **StorageTypeB**, typename **Alpha**, typename **Beta**>
ArrayContainer(const *linalg*::ArrayMultiply<ShapeTypeA, StorageTypeA, ShapeTypeB, StorageTypeB, Alpha, Beta> &multiply)

template<typename **desc**, typename **Functor_**, typename ...**Args**>
ArrayContainer &**assign**(const detail::Function<desc, Functor_, Args...> &function)

template<typename desc, typename Functor_, typename... Args> ArrayContainer (const detail::Function< desc, Functor_, Args... > &function) LIBRAPID_RELEASE_NOEXCEPT

Construct an array container from a function object. This will assign the result of the function to the array container, evaluating it accordingly.

Template Parameters

- `desc` – The assignment descriptor
- `Functor_` – The function type
- `Args` – The argument types of the function

Parameters `function` – The function to assign

ArrayContainer &**operator=**(const ArrayContainer &other) = default

Reference an existing array container.

This assignment operator does not copy the data, but instead references the data of the input array container. This means that the input array container must outlive the constructed array container. Please use `ArrayContainer::copy()` if you want to copy the data.

Parameters `other` – The array container to reference

ArrayContainer &**operator=**(const Scalar &value)

ArrayContainer &**operator=**(ArrayContainer &&other) noexcept = default

Assign a temporary array container to this array container.

Parameters `other` – The array container to move.

Returns A reference to this array container.

template<typename **desc**, typename **Functor_**, typename ...**Args**>
ArrayContainer &**operator=**(const detail::Function<desc, Functor_, Args...> &function)

Assign a function object to this array container. This will assign the result of the function to the array container, evaluating it accordingly.

Template Parameters
- **`Functor_`** – The function type
- **`Args`** – The argument types of the function

Parameters **`function`** – The function to assign

Returns A reference to this array container.

template<typename **`TransposeType`**>
ArrayContainer &**`operator=`**(const Transpose<TransposeType> &transpose)

template<typename **`ShapeTypeA`**, typename **`StorageTypeA`**, typename **`ShapeTypeB`**, typename **`StorageTypeB`**, typename **`Alpha`**, typename **`Beta`**>
ArrayContainer &**`operator=`**(const *linalg*::ArrayMultiply<ShapeTypeA, StorageTypeA, ShapeTypeB, StorageTypeB, Alpha, Beta> &multiply)

template<typename **`T`**>
detail::CommaInitializer<ArrayContainer> **`operator<<`**(const T &value)

Allow ArrayContainer objects to be initialized with a comma separated list of values. This makes use of the CommaInitializer class

Template Parameters **`T`** – The type of the values

Parameters **`value`** – The value to set in the Array object

Returns The comma initializer object

ArrayContainer **`copy`**() const

auto **`operator[]`**(int64_t index) const

Access a sub-array of this ArrayContainer instance. The sub-array will reference the same memory as this ArrayContainer instance.

See also:

ArrayView

Parameters **`index`** – The index of the sub-array

Returns A reference to the sub-array (*ArrayView*)

auto **`operator[]`**(int64_t index)

template<typename ...**`Indices`**>
DirectSubscriptType **`operator()`**(Indices... indices) const

template<typename ...**`Indices`**>
DirectRefSubscriptType **`operator()`**(Indices... indices)

Scalar **`get`**() const

ShapeType::SizeType **`ndim`**() const noexcept

Return the number of dimensions of the ArrayContainer object

Returns Number of dimensions of the ArrayContainer

const ShapeType &**`shape`**() const noexcept

Return the shape of the array container. This is an immutable reference.

Returns The shape of the array container.

const StorageType &**`storage`**() const noexcept

Return the StorageType object of the ArrayContainer

Returns The StorageType object of the ArrayContainer

StorageType &**storage**() noexcept

Return the StorageType object of the ArrayContainer

Returns The StorageType object of the ArrayContainer

Packet **packet**(size_t index) const

Return a Packet object from the array's storage at a specific index.

Parameters **index** – The index to get the packet from

Returns A Packet object from the array's storage at a specific index

Scalar **scalar**(size_t index) const

Return a Scalar from the array's storage at a specific index.

Parameters **index** – The index to get the scalar from

Returns A Scalar from the array's storage at a specific index

void **writePacket**(size_t index, const Packet &value)

Write a Packet object to the array's storage at a specific index

Parameters

- **index** – The index to write the packet to
- **value** – The value to write to the array's storage

void **write**(size_t index, const Scalar &value)

Write a Scalar to the array's storage at a specific index

Parameters

- **index** – The index to write the scalar to
- **value** – The value to write to the array's storage

template<typename **T**>
ArrayContainer &**operator+=**(const T &other)

template<typename **T**>
ArrayContainer &**operator-=**(const T &other)

template<typename **T**>
ArrayContainer &**operator*=**(const T &other)

template<typename **T**>
ArrayContainer &**operator/=**(const T &other)

template<typename **T**>
ArrayContainer &**operator%=**(const T &other)

template<typename **T**>
ArrayContainer &**operator&=**(const T &other)

template<typename **T**>
ArrayContainer &**operator|=**(const T &other)

template<typename **T**>
ArrayContainer &**operator^=**(const T &other)

template<typename **T**>
ArrayContainer &**operator<<=**(const T &other)

template<typename **T**>
ArrayContainer &**operator>>=**(const T &other)

Iterator **begin**() const noexcept

Return an iterator to the beginning of the array container.

Returns Iterator

Iterator **end**() const noexcept

Return an iterator to the end of the array container.

Returns Iterator

Iterator **begin**()

Return an iterator to the beginning of the array container.

Returns Iterator

Iterator **end**()

Return an iterator to the end of the array container.

Returns Iterator

std::string **str**(const std::string &format = "{}") const

Return a string representation of the array container \format The format to use for the string representation

Returns A string representation of the array container

template<typename **desc**, typename **Functor_**, typename ...**Args**>
auto **assign**(const detail::Function<desc, Functor_, Args...> &function) -> ArrayContainer&

template<typename **desc**, typename **Functor_**, typename ...**Args**>
auto **operator=**(const detail::Function<desc, Functor_, Args...> &function) -> ArrayContainer&

template<typename **TransposeType**>
auto **operator=**(const Transpose<TransposeType> &transpose) -> ArrayContainer&

template<typename **ShapeTypeA**, typename **StorageTypeA**, typename **ShapeTypeB**, typename **StorageTypeB**, typename **Alpha**, typename **Beta**>
auto **operator=**(const *linalg*::ArrayMultiply<ShapeTypeA, StorageTypeA, ShapeTypeB, StorageTypeB, Alpha, Beta> &arrayMultiply) -> ArrayContainer&

template<typename **T**>
auto **operator<<**(const T &value) -> detail::CommaInitializer<ArrayContainer>

template<typename ...**Indices**>
auto **operator()**(Indices... indices) const -> DirectSubscriptType

template<typename ...**Indices**>
auto **operator()**(Indices... indices) -> DirectRefSubscriptType

template<typename **T**>
auto **operator+=**(const T &value) -> ArrayContainer&

template<typename **T**>
auto **operator-=**(const T &value) -> ArrayContainer&

template<typename **T**>
auto **operator*=**(const T &value) -> ArrayContainer&

template<typename **T**>
auto **operator/=**(const T &value) -> ArrayContainer&

template<typename **T**>

auto **operator%=**(const T &value) -> ArrayContainer&

template<typename **T**>
auto **operator&=**(const T &value) -> ArrayContainer&

template<typename **T**>
auto **operator|=**(const T &value) -> ArrayContainer&

template<typename **T**>
auto **operator^=**(const T &value) -> ArrayContainer&

template<typename **T**>
auto **operator<<=**(const T &value) -> ArrayContainer&

template<typename **T**>
auto **operator>>=**(const T &value) -> ArrayContainer&

Public Static Functions

static auto **fromData**(const std::initializer_list<Scalar> &data) -> ArrayContainer

Create an array from a list of values (possibly multi-dimensional)

Create a new array from a potentially nested list of values. It is possible to specify the data type of the Array with the `Scalar` template parameter. If no type is specified, the type will be inferred from the data. The backend on which the Array is created can also be specified with the `Backend` template parameter. If no backend is specified, the Array will be created on the CPU.

Template Parameters
- **`Scalar`** – The type of the Array
- **`Backend`** – The backend on which the Array is created

Parameters **`data`** – The data from which the Array is created

Returns The created Array

static auto **fromData**(const std::vector<Scalar> &data) -> ArrayContainer

static auto **fromData**(const std::initializer_list<std::initializer_list<Scalar>> &data) -> ArrayContainer

static auto **fromData**(const std::vector<std::vector<Scalar>> &data) -> ArrayContainer

static auto **fromData**(const std::initializer_list<std::initializer_list<std::initializer_list<Scalar>>> &data) -> ArrayContainer

static auto **fromData**(const std::vector<std::vector<std::vector<Scalar>>> &data) -> ArrayContainer

static auto **fromData**(const std::initializer_list<std::initializer_list<std::initializer_list<std::initializer_list<Scalar>>>> &data) -> ArrayContainer

static auto **fromData**(const std::vector<std::vector<std::vector<std::vector<Scalar>>>> &data) -> ArrayContainer

static auto **fromData**(const std::initializer_list<std::initializer_list<std::initializer_list<std::initializer_list<std::initializer_list<std::initializer_list
&data) -> ArrayContainer

static auto **fromData**(const std::vector<std::vector<std::vector<std::vector<std::vector<Scalar>>>>> &data) -> ArrayContainer

static auto **fromData**(const std::initializer_list<std::initializer_list<std::initializer_list<std::initializer_list<std::initializer_list<std::initializer_list
&data) -> ArrayContainer

static auto **fromData**(const std::vector<std::vector<std::vector<std::vector<std::vector<std::vector<Scalar>>>>>> &data) -> ArrayContainer

static auto **fromData**(const std::initializer_list<std::initializer_list<std::initializer_list<std::initializer_list<std::initializer_list<std::initializer_list
&data) -> ArrayContainer

static auto **fromData**(const std::vector<std::vector<std::vector<std::vector<std::vector<std::vector<std::vector<Scalar>>>>>
&data) -> ArrayContainer

static auto **fromData**(const std::initializer_list<std::initializer_list<std::initializer_list<std::initializer_list<std::initializer_list<std::initializer_list
&data) -> ArrayContainer

static auto **fromData**(const std::vector<std::vector<std::vector<std::vector<std::vector<std::vector<std::vector<std::vector<S
&data) -> ArrayContainer

Private Members

ShapeType **m_shape**

StorageType **m_storage**

namespace **detail**

template<typename **T**>

struct **SubscriptType**

#include <arrayContainer.hpp>

Public Types

using **Scalar** = T

using **Direct** = const Scalar&

using **Ref** = Scalar&

template<typename **T**>

struct **SubscriptType**<Storage<T>>

#include <arrayContainer.hpp>

Public Types

using **Scalar** = T

using **Direct** = const Scalar&

using **Ref** = Scalar&

template<typename **T**, size_t... **Dims**>

struct **SubscriptType**<FixedStorage<T, Dims...>>

#include <arrayContainer.hpp>

Public Types

using **Scalar** = T

using **Direct** = const Scalar&

using **Ref** = Scalar&

template<typename **T**>

struct **SubscriptType**<CudaStorage<T>>

#include <arrayContainer.hpp>

Public Types

using **Scalar** = T

using **Direct** = const detail::CudaRef<Scalar>

using **Ref** = detail::CudaRef<Scalar>

template<typename **T**>

struct **IsArrayType**

#include <arrayContainer.hpp>

Public Static Attributes

static constexpr bool **val** = false

template<typename **T**>

struct **IsArrayType**<ArrayRef<T>>

#include <arrayContainer.hpp>

Public Static Attributes

static constexpr bool **val** = true

template<typename ...**T**>

struct **IsArrayType**<FunctionRef<T...>>

#include <arrayContainer.hpp>

Public Static Attributes

static constexpr bool **val** = true

template<typename T> ArrayView< T > >

#include <arrayContainer.hpp>

Public Static Attributes

static constexpr bool **val** = true

template<typename **First**, typename ...**Types**>

struct **ContainsArrayType**

#include <arrayContainer.hpp>

Public Static Functions

static inline constexpr auto **evaluator**()

Public Static Attributes

static constexpr bool **val** = evaluator()

namespace **typetraits**

Functions

LIBRAPID_DEFINE_AS_TYPE (typename SizeType COMMA size_t dims COMMA typename StorageScalar, array::ArrayContainer< Shape< SizeType COMMA dims > COMMA StorageScalar >)

template<typename ShapeType_, typename StorageType_> ArrayContainer< ShapeType_, StorageType_ > >

#include <arrayContainer.hpp>

Public Types

using **Scalar** = typename TypeInfo<StorageType_>::Scalar

using **Packet** = std::false_type

using **Backend** = typename TypeInfo<StorageType_>::Backend

Public Static Attributes

static constexpr detail::LibRapidType **type** = detail::LibRapidType::ArrayContainer

static constexpr int64_t **packetWidth** = 1

static constexpr bool **supportsArithmetic** = TypeInfo<*Scalar*>::supportsArithmetic

static constexpr bool **supportsLogical** = TypeInfo<*Scalar*>::supportsLogical

static constexpr bool **supportsBinary** = TypeInfo<*Scalar*>::supportsBinary

static constexpr bool **allowVectorisation** = TypeInfo<*Scalar*>::packetWidth > 1

static constexpr cudaDataType_t **CudaType** = TypeInfo<*Scalar*>::CudaType

static constexpr int64_t **cudaPacketWidth** = 1 static constexpr bool **canAlign** = false

static constexpr int64_t **canMemcpy** = false

template<typename **T**>

struct **IsArrayContainer** : public std::false_type

#include <arrayContainer.hpp> Evaluates as true if the input type is an ArrayContainer instance

Template Parameters T – Input type

template<typename SizeType, size_t dims, typename StorageScalar> ArrayContainer< Shape< SizeType, dims >, StorageScalar > > : public std::true_type

#include <arrayContainer.hpp>

1.3.2.3 Array From Data

Defines

HIGHER_DIMENSIONAL_FROM_DATA(TYPE)

SINIT(SUB_TYPE)

SVEC(SUB_TYPE)

namespace **librapid**

1.3.2.4 Pseudoconstructors

> **Warning:** doxygenfile: Cannot find file "librapid/include/librapid/array/pseudoconstructors.hpp

1.3.2.5 Array View

template<typename **T**>

struct **TypeInfo**<*array*::ArrayView<T>>

#include <arrayView.hpp>

Public Types

using **Scalar** = typename TypeInfo<std::decay_t<T>>::Scalar

using **Backend** = typename TypeInfo<std::decay_t<T>>::Backend

Public Static Attributes

static constexpr detail::LibRapidType **type** = detail::LibRapidType::ArrayView

static constexpr bool **allowVectorisation** = false

namespace **librapid**

namespace **array**

template<typename **T**>

class **ArrayView**

#include <arrayView.hpp> An intermediate type to represent a slice or view of an array.

Template Parameters **T** – The type of the array.

Public Types

using **BaseType** = typename std::decay_t<T>

using **Scalar** = typename *typetraits*::TypeInfo<BaseType>::Scalar

using **Reference** = BaseType&

using **ConstReference** = const BaseType&

using **Backend** = typename *typetraits*::TypeInfo<BaseType>::Backend

using **ArrayType** = Array<Scalar, Backend>

using **StrideType** = typename ArrayType::StrideType

using **ShapeType** = typename ArrayType::ShapeType

using **Iterator** = detail::ArrayIterator<ArrayView>

Public Functions

ArrayView() = delete

Default constructor should never be used.

explicit **ArrayView**(T &array)

Copy an *ArrayView* object

Parameters **array** – The array to copy explicit **ArrayView**(T &&array) = delete

Copy an *ArrayView* object (not const)

Parameters **array** – The array to copy

ArrayView(const ArrayView &other) = default

Copy an *ArrayView* object (const)

Parameters **other** – The array to copy

ArrayView(ArrayView &&other) = default

Constructs an *ArrayView* from a temporary instance

Parameters **other** – The *ArrayView* to move

ArrayView &**operator=**(const ArrayView &other) = default

Assigns another *ArrayView* object to this *ArrayView*.

Parameters **other** – The *ArrayView* to assign.

Returns A reference to this

ArrayView &**operator=**(const Scalar &scalar)

Assigns a temporary *ArrayView* to this *ArrayView*.

Parameters

- **other** – The *ArrayView* to move.
- **scalar** – The scalar value to assign

Returns A reference to this *ArrayView*. Assign a scalar value to this *ArrayView*. This function should only be used to assign to a zero-dimensional "scalar" *ArrayView*, and will throw an error if used incorrectly.

Returns A reference to this

template<typename **RefType**>
ArrayView &**operator=**(const ArrayRef<RefType> &other)

const ArrayView<T> **operator[]**(int64_t index) const

Access a sub-array of this *ArrayView*.

Parameters **index** – The index of the sub-array.

Returns An *ArrayView* from this

ArrayView<T> **operator[]**(int64_t index)

template<typename **CAST** = Scalar>
CAST **get**() const

Since even scalars are represented as an *ArrayView* object, it can be difficult to operate on them directly. This allows you to extract the scalar value stored by a zero-dimensional *ArrayView* object

Template Parameters **CAST** – Type to cast to

Returns The scalar represented by the *ArrayView* object

template<typename **CAST**>
explicit **operator CAST**() const

Same functionality as "get", except slightly less robust for user-defined types.

Template Parameters **CAST** – Type to cast to

Returns The scalar represented by the *ArrayView* object

ShapeType **shape**() const

Access the underlying shape of this *ArrayView*

Returns Shape object

StrideType **stride**() const

Access the stride of this *ArrayView*

Returns *Stride* object

int64_t **offset**() const

Access the offset of this *ArrayView*. This is the offset, in elements, from the referenced Array's first element.

Returns Offset

void **setShape**(const ShapeType &shape)

Set the Shape of this *ArrayView* to something else. Intended for internal use only.

Parameters shape – The new shape of this *ArrayView*

void **setStride**(const StrideType &stride)

Set the *Stride* of this *ArrayView* to something else. Intended for internal use only.

Parameters stride – The new stride of this *ArrayView*

void **setOffset**(const int64_t &offset)

Set the offset of this *ArrayView* object. Intended for internal use only.

Parameters offset – The new offset of this *ArrayView*

int64_t **ndim**() const

Returns the number of dimensions of this *ArrayView*

Returns Number of dimensions

auto **scalar**(int64_t index) const

Return the Scalar at a given index in this *ArrayView*. This is intended for use internally, but can be used externally too.

Parameters index – The index of the Scalar to return

Returns Scalar at the given index

ArrayType **eval**() const

Evaluate the contents of this *ArrayView* object and return an Array instance from it. Depending on your use case, this may result in more performant code, but the new Array will not reference the original data in the *ArrayView*.

Returns A new Array instance

Iterator **begin**() const

Iterator **end**() const

std::string **str**(const std::string &format = "{}") const

Cast an *ArrayView* to a std::string, aligning items down the columns. A format string can also be specified, which will be used to format the items to strings

Parameters format – The format string

Returns A std::string representation of this *ArrayView*

template<typename **RefType**>
ArrayView<T> &**operator=**(const ArrayRef<RefType> &other)

Private Members

T &**m_ref**

ShapeType **m_shape**

StrideType **m_stride**

int64_t **m_offset** = 0

namespace **typetraits**

Functions

LIBRAPID_DEFINE_AS_TYPE(typename T, *array*::ArrayView<T>)

template<typename T> ArrayView< T > >

#include <arrayView.hpp>

Public Types

using **Scalar** = typename TypeInfo<std::decay_t<T>>::Scalar

using **Backend** = typename TypeInfo<std::decay_t<T>>::Backend

Public Static Attributes

static constexpr detail::LibRapidType **type** = detail::LibRapidType::ArrayView

static constexpr bool **allowVectorisation** = false

1.3.2.6 Array Operations

Defines

LIBRAPID_BINARY_FUNCTOR(NAME_, OP_)

LIBRAPID_BINARY_COMPARISON_FUNCTOR(NAME_, OP_)

LIBRAPID_UNARY_KERNEL_GETTER

LIBRAPID_BINARY_KERNEL_GETTER

LIBRAPID_UNARY_SHAPE_EXTRACTOR

LIBRAPID_BINARY_SHAPE_EXTRACTOR

LIBRAPID_UNARY_FUNCTOR(NAME, OP)

IS_ARRAY_OP

IS_ARRAY_OP_ARRAY

IS_ARRAY_OP_WITH_SCALAR

template<typename **ShapeType**, typename **StorageType**>

struct **DescriptorExtractor**<*array*::ArrayContainer<ShapeType, StorageType>>

#include <operations.hpp> Extracts the Descriptor type of an ArrayContainer object. In this case, the Descriptor is Trivial

Template Parameters

- **ShapeType** – The shape type of the ArrayContainer
- **StorageType** – The storage type of the ArrayContainer

Public Types

using **Type** = ::librapid::detail::descriptor::Trivial

template<typename **T**>

struct **DescriptorExtractor**<*array*::ArrayView<T>>

#include <operations.hpp> Extracts the Descriptor type of an ArrayView object

Template Parameters **T** – The Array type of the ArrayView

Public Types

using **Type** = ::librapid::detail::descriptor::Trivial

template<typename **Descriptor**, typename **Functor**, typename ...**Args**>

struct **DescriptorExtractor**<::librapid::detail::Function<Descriptor, Functor, Args...>>

#include <operations.hpp> Extracts the Descriptor type of a Function object

Template Parameters

- **Descriptor** – The descriptor of the Function
- **Functor** – The functor type of the Function
- **Args** – The argument types of the Function

Public Types

using **Type** = Descriptor

template<>

struct **TypeInfo**<::librapid::detail::Plus>

#include <operations.hpp>

Public Static Functions

template<typename **T1**, typename **T2**>
static inline constexpr const char ***getKernelNameImpl**(std::tuple<T1, T2> args)

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<Args...> args)

template<typename **First**, typename **Second**>
static inline auto **getShapeImpl**(const std::tuple<First, Second> &tup)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<Args...> &args)

Public Static Attributes

static constexpr const char ***name** = "plus"

static constexpr const char ***filename** = "arithmetic"

static constexpr const char ***kernelName** = "addArrays"

static constexpr const char ***kernelNameScalarRhs** = "addArraysScalarRhs"

static constexpr const char ***kernelNameScalarLhs** = "addArraysScalarLhs"

template<>

struct **TypeInfo**<::librapid::detail::Minus>

#include <operations.hpp>

Public Static Functions

template<typename **T1**, typename **T2**>
static inline constexpr const char ***getKernelNameImpl**(std::tuple<T1, T2> args)

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<Args...> args)

template<typename **First**, typename **Second**>
static inline auto **getShapeImpl**(const std::tuple<First, Second> &tup)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<Args...> &args)

Public Static Attributes

static constexpr const char ***name** = "minus"

static constexpr const char ***filename** = "arithmetic"

static constexpr const char ***kernelName** = "subArrays"

static constexpr const char ***kernelNameScalarRhs** = "subArraysScalarRhs"

static constexpr const char ***kernelNameScalarLhs** = "subArraysScalarLhs"

template<>

struct **TypeInfo**<::librapid::detail::Multiply>

#include <operations.hpp>

Public Static Functions

template<typename **T1**, typename **T2**>
static inline constexpr const char ***getKernelNameImpl**(std::tuple<T1, T2> args)

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<Args...> args)

template<typename **First**, typename **Second**>
static inline auto **getShapeImpl**(const std::tuple<First, Second> &tup)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<Args...> &args)

Public Static Attributes

static constexpr const char ***name** = "multiply"

static constexpr const char ***filename** = "arithmetic"

static constexpr const char ***kernelName** = "mulArrays"

static constexpr const char ***kernelNameScalarRhs** = "mulArraysScalarRhs"

static constexpr const char ***kernelNameScalarLhs** = "mulArraysScalarLhs"

template<>

struct **TypeInfo**<::librapid::detail::Divide>

#include <operations.hpp>

Public Static Functions

template<typename **T1**, typename **T2**>
static inline constexpr const char ***getKernelNameImpl**(std::tuple<T1, T2> args)

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<Args...> args)

template<typename **First**, typename **Second**>
static inline auto **getShapeImpl**(const std::tuple<First, Second> &tup)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<Args...> &args)

Public Static Attributes

static constexpr const char ***name** = "divide"

static constexpr const char ***filename** = "arithmetic"

static constexpr const char ***kernelName** = "divArrays"

static constexpr const char ***kernelNameScalarRhs** = "divArraysScalarRhs"

static constexpr const char ***kernelNameScalarLhs** = "divArraysScalarLhs"

template<>

struct **TypeInfo**<::librapid::detail::LessThan>

#include <operations.hpp>

Public Static Functions

template<typename **T1**, typename **T2**>
static inline constexpr const char ***getKernelNameImpl**(std::tuple<T1, T2> args)

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<Args...> args)

template<typename **First**, typename **Second**>
static inline auto **getShapeImpl**(const std::tuple<First, Second> &tup)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<Args...> &args)

Public Static Attributes

static constexpr const char ***name** = "less than"

static constexpr const char ***filename** = "arithmetic"

static constexpr const char ***kernelName** = "lessThanArrays"

static constexpr const char ***kernelNameScalarRhs** = "lessThanArraysScalarRhs"

static constexpr const char ***kernelNameScalarLhs** = "lessThanArraysScalarLhs"

template<>

struct **TypeInfo**<::librapid::detail::GreaterThan>

#include <operations.hpp>

Public Static Functions

template<typename **T1**, typename **T2**>
static inline constexpr const char ***getKernelNameImpl**(std::tuple<T1, T2> args)

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<Args...> args)

template<typename **First**, typename **Second**>
static inline auto **getShapeImpl**(const std::tuple<First, Second> &tup)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<Args...> &args)

Public Static Attributes

static constexpr const char ***name** = "greater than"

static constexpr const char ***filename** = "arithmetic"

static constexpr const char ***kernelName** = "greaterThanArrays"

static constexpr const char ***kernelNameScalarRhs** = "greaterThanArraysScalarRhs"

static constexpr const char ***kernelNameScalarLhs** = "greaterThanArraysScalarLhs"

template<>

struct **TypeInfo**<::librapid::detail::LessThanEqual>

#include <operations.hpp>

Public Static Functions

template<typename **T1**, typename **T2**>
static inline constexpr const char ***getKernelNameImpl**(std::tuple<T1, T2> args)

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<Args...> args)

template<typename **First**, typename **Second**>
static inline auto **getShapeImpl**(const std::tuple<First, Second> &tup)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<Args...> &args)

Public Static Attributes

static constexpr const char ***name** = "less than or equal"

static constexpr const char ***filename** = "arithmetic"

static constexpr const char ***kernelName** = "lessThanEqualArrays"

static constexpr const char ***kernelNameScalarRhs** = "lessThanEqualArraysScalarRhs"

static constexpr const char ***kernelNameScalarLhs** = "lessThanEqualArraysScalarLhs"

template<>

struct **TypeInfo**<::librapid::detail::GreaterThanEqual>

#include <operations.hpp>

Public Static Functions

template<typename **T1**, typename **T2**>
static inline constexpr const char ***getKernelNameImpl**(std::tuple<T1, T2> args)

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<Args...> args)

template<typename **First**, typename **Second**>
static inline auto **getShapeImpl**(const std::tuple<First, Second> &tup)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<Args...> &args)

Public Static Attributes

static constexpr const char ***name** = "greater than or equal"

static constexpr const char ***filename** = "arithmetic"

static constexpr const char ***kernelName** = "greaterThanEqualArrays"

static constexpr const char ***kernelNameScalarRhs** = "greaterThanEqualArraysScalarRhs"

static constexpr const char ***kernelNameScalarLhs** = "greaterThanEqualArraysScalarLhs"

template<>

struct **TypeInfo**<::librapid::detail::ElementWiseEqual>

#include <operations.hpp>

Public Static Functions

template<typename **T1**, typename **T2**>
static inline constexpr const char ***getKernelNameImpl**(std::tuple<T1, T2> args)

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<Args...> args)

template<typename **First**, typename **Second**>
static inline auto **getShapeImpl**(const std::tuple<First, Second> &tup)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<Args...> &args)

Public Static Attributes

static constexpr const char ***name** = "element wise equal"

static constexpr const char ***filename** = "arithmetic"

static constexpr const char ***kernelName** = "elementWiseEqualArrays"

static constexpr const char ***kernelNameScalarRhs** = "elementWiseEqualArraysScalarRhs"

static constexpr const char ***kernelNameScalarLhs** = "elementWiseEqualArraysScalarLhs"

template<>

struct **TypeInfo**<::librapid::detail::ElementWiseNotEqual>

#include <operations.hpp>

Public Static Functions

template<typename **T1**, typename **T2**>
static inline constexpr const char ***getKernelNameImpl**(std::tuple<T1, T2> args)

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<Args...> args)

template<typename **First**, typename **Second**>
static inline auto **getShapeImpl**(const std::tuple<First, Second> &tup)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<Args...> &args)

Public Static Attributes

static constexpr const char ***name** = "element wise not equal"

static constexpr const char ***filename** = "arithmetic"

static constexpr const char ***kernelName** = "elementWiseNotEqualArrays"

static constexpr const char ***kernelNameScalarRhs** = "elementWiseNotEqualArraysScalarRhs"

static constexpr const char ***kernelNameScalarLhs** = "elementWiseNotEqualArraysScalarLhs"

template<>

struct **TypeInfo**<::librapid::detail::Neg>

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<Args...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<Args...> &args)

Public Static Attributes

static constexpr const char ***name** = "negate"

static constexpr const char ***filename** = "negate"

static constexpr const char ***kernelName** = "negateArrays"

template<>

struct **TypeInfo**<::librapid::detail::Sin>

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<Args...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<Args...> &args)

Public Static Attributes

static constexpr const char ***name** = "sin"

static constexpr const char ***filename** = "trigonometry"

static constexpr const char ***kernelName** = "sinArrays"

template<>

struct **TypeInfo**<::librapid::detail::Cos>

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<Args...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<Args...> &args)

Public Static Attributes

static constexpr const char ***name** = "cos"

static constexpr const char ***filename** = "trigonometry"

static constexpr const char ***kernelName** = "cosArrays"

template<>

struct **TypeInfo**<::librapid::detail::Tan>

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<Args...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<Args...> &args)

Public Static Attributes

static constexpr const char ***name** = "tan"

static constexpr const char ***filename** = "trigonometry"

static constexpr const char ***kernelName** = "tanArrays"

template<>

struct **TypeInfo**<::librapid::detail::Asin>

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<Args...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<Args...> &args)

Public Static Attributes

static constexpr const char ***name** = "arcsin"

static constexpr const char ***filename** = "trigonometry"

static constexpr const char ***kernelName** = "asinArrays"

template<>

struct **TypeInfo**<::librapid::detail::Acos>

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<Args...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<Args...> &args)

Public Static Attributes

static constexpr const char ***name** = "arcos"

static constexpr const char ***filename** = "trigonometry"

static constexpr const char ***kernelName** = "acosArrays"

template<>

struct **TypeInfo**<::librapid::detail::Atan>

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<Args...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<Args...> &args)

Public Static Attributes

static constexpr const char ***name** = "arctan"

static constexpr const char ***filename** = "trigonometry"

static constexpr const char ***kernelName** = "atanArrays"

template<>

struct **TypeInfo**<::librapid::detail::Sinh>

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<Args...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<Args...> &args)

Public Static Attributes

static constexpr const char ***name** = "hyperbolic sine"

static constexpr const char ***filename** = "trigonometry"

static constexpr const char ***kernelName** = "sinhArrays"

template<>

struct **TypeInfo**<::librapid::detail::Cosh>

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<Args...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<Args...> &args)

Public Static Attributes

static constexpr const char ***name** = "hyperbolic cosine"

static constexpr const char ***filename** = "trigonometry"

static constexpr const char ***kernelName** = "coshArrays"

template<>

struct **TypeInfo**<::librapid::detail::Tanh>

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<Args...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<Args...> &args)

Public Static Attributes

static constexpr const char ***name** = "hyperbolic tangent"

static constexpr const char ***filename** = "trigonometry"

static constexpr const char ***kernelName** = "tanhArrays"

template<>

struct **TypeInfo**<::librapid::detail::Exp>

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<Args...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<Args...> &args)

Public Static Attributes

static constexpr const char ***name** = "exponent"

static constexpr const char ***filename** = "expLogPow"

static constexpr const char ***kernelName** = "expArrays"

template<>

struct **TypeInfo**<::librapid::detail::Log>

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<Args...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<Args...> &args)

Public Static Attributes

static constexpr const char ***name** = "logarithm"

static constexpr const char ***filename** = "expLogPow"

static constexpr const char ***kernelName** = "logArrays"

template<>

struct **TypeInfo**<::librapid::detail::Log2>

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<Args...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<Args...> &args)

Public Static Attributes

static constexpr const char ***name** = "logarithm base 2"

static constexpr const char ***filename** = "expLogPow"

static constexpr const char ***kernelName** = "log2Arrays"

template<>

struct **TypeInfo**<::librapid::detail::Log10>

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<Args...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<Args...> &args)

Public Static Attributes

static constexpr const char ***name** = "logarithm base 10"

static constexpr const char ***filename** = "expLogPow"

static constexpr const char ***kernelName** = "log10Arrays"

template<>

struct **TypeInfo**<::librapid::detail::Sqrt>

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<Args...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<Args...> &args)

Public Static Attributes

static constexpr const char ***name** = "square root"

static constexpr const char ***filename** = "expLogPow"

static constexpr const char ***kernelName** = "sqrtArrays"

template<>

struct **TypeInfo**<::librapid::detail::Cbrt>

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<Args...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<Args...> &args)

Public Static Attributes

static constexpr const char ***name** = "cube root"

static constexpr const char ***filename** = "expLogPow"

static constexpr const char ***kernelName** = "cbrtArrays"

template<>

struct **TypeInfo**<::librapid::detail::Abs>

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<Args...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<Args...> &args)

Public Static Attributes

static constexpr const char ***name** = "absolute value"

static constexpr const char ***filename** = "abs"

static constexpr const char ***kernelName** = "absArrays"

template<>

struct **TypeInfo**<::librapid::detail::Floor>

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<Args...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<Args...> &args)

Public Static Attributes

static constexpr const char ***name** = "floor"

static constexpr const char ***filename** = "floorCeilRound"

static constexpr const char ***kernelName** = "floorArrays"

template<>

struct **TypeInfo**<::librapid::detail::Ceil>

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<Args...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<Args...> &args)

Public Static Attributes

static constexpr const char ***name** = "ceiling"

static constexpr const char ***filename** = "floorCeilRound"

static constexpr const char ***kernelName** = "ceilArrays"

namespace **librapid**

Functions

```
template<class VAL, typename std::enable_if_t< detail::isArrayOp< VAL >(),
int > = 0> auto sin (VAL &&val) LIBRAPID_RELEASE_NOEXCEPT -> detail::Function< typetraits::Descript
detail::Sin, VAL >
```

Calculate the sine of each element in the array.

$R = \{R_0, R_1, R_2, ...\}$ \text{ where } $R_i = \sin(A_i)$

Template Parameters `VAL` – Type of the input

Parameters `val` – The input array or function

Returns Sine function object

```
template<class VAL, typename std::enable_if_t< detail::isArrayOp< VAL >(),
int > = 0> auto cos (VAL &&val) LIBRAPID_RELEASE_NOEXCEPT -> detail::Function< typetraits::Descript
detail::Cos, VAL >
```

Calculate the cosine of each element in the array.

$R = \{R_0, R_1, R_2, ...\}$ \text{ where } $R_i = \cos(A_i)$

Template Parameters `VAL` – Type of the input

Parameters `val` – The input array or function

Returns Cosine function object

```
template<class VAL, typename std::enable_if_t< detail::isArrayOp< VAL >(),
int > = 0> auto tan (VAL &&val) LIBRAPID_RELEASE_NOEXCEPT -> detail::Function< typetraits::Descript
detail::Tan, VAL >
```

Calculate the tangent of each element in the array.

$R = \{R_0, R_1, R_2, ...\}$ \text{ where } $R_i = \tan(A_i)$

Template Parameters `VAL` – Type of the input

Parameters `val` – The input array or function

Returns Tangent function object

```
template<class VAL, typename std::enable_if_t< detail::isArrayOp< VAL >(),
int > = 0> auto asin (VAL &&val) LIBRAPID_RELEASE_NOEXCEPT -> detail::Function< typetraits::Descrip
detail::Asin, VAL >
```

Calculate the arcsine of each element in the array.

$R = \{R_0, R_1, R_2, ...\}$ \text{ where } $R_i = \sin^{-1}(A_i)$

Template Parameters `VAL` – Type of the input

Parameters `val` – The input array or function

Returns Arcsine function object

```
template<class VAL, typename std::enable_if_t< detail::isArrayOp< VAL >(),
int > = 0> auto acos (VAL &&val) LIBRAPID_RELEASE_NOEXCEPT -> detail::Function< typetraits::Descrip
detail::Acos, VAL >
```

Calculate the arccosine of each element in the array.

$R = \{R_0, R_1, R_2, ...\}$ \text{ where } $R_i = \cos^{-1}(A_i)$

Template Parameters `VAL` – Type of the input

Parameters `val` – The input array or function

Returns Arccosine function object

template<class VAL, typename std::enable_if_t< detail::isArrayOp< VAL >(), int > = 0> auto atan (VAL &&val) LIBRAPID_RELEASE_NOEXCEPT -> detail::Function< typetraits::Descrip detail::Atan, VAL >

Calculate the arctangent of each element in the array.

$R = \{R_0, R_1, R_2, ...\}$ \text{ where } $R_i = \tan^{-1}(A_i)$

Template Parameters `VAL` – Type of the input

Parameters `val` – The input array or function

Returns Arctangent function object

template<class VAL, typename std::enable_if_t< detail::isArrayOp< VAL >(), int > = 0> auto sinh (VAL &&val) LIBRAPID_RELEASE_NOEXCEPT -> detail::Function< typetraits::Descrip detail::Sinh, VAL >

Calculate the hyperbolic sine of each element in the array.

$R = \{R_0, R_1, R_2, ...\}$ \text{ where } $R_i = \sinh(A_i)$

Template Parameters `VAL` – Type of the input

Parameters `val` – The input array or function

Returns Hyperbolic sine function object

template<class VAL, typename std::enable_if_t< detail::isArrayOp< VAL >(), int > = 0> auto cosh (VAL &&val) LIBRAPID_RELEASE_NOEXCEPT -> detail::Function< typetraits::Descrip detail::Cosh, VAL >

Calculate the hyperbolic cosine of each element in the array.

$R = \{R_0, R_1, R_2, ...\}$ \text{ where } $R_i = \cosh(A_i)$

Template Parameters `VAL` – Type of the input

Parameters `val` – The input array or function

Returns Hyperbolic cosine function object

template<class VAL, typename std::enable_if_t< detail::isArrayOp< VAL >(), int > = 0> auto tanh (VAL &&val) LIBRAPID_RELEASE_NOEXCEPT -> detail::Function< typetraits::Descrip detail::Tanh, VAL >

Calculate the hyperbolic tangent of each element in the array.

$R = \{R_0, R_1, R_2, ...\}$ \text{ where } $R_i = \tanh(A_i)$

Template Parameters `VAL` – Type of the input

Parameters `val` – The input array or function

Returns Hyperbolic tangent function object

template<class VAL, typename std::enable_if_t< detail::isArrayOp< VAL >(), int > = 0> auto exp (VAL &&val) LIBRAPID_RELEASE_NOEXCEPT -> detail::Function< typetraits::Descript detail::Exp, VAL >

Raise e to the power of each element in the array.

$R = \{R_0, R_1, R_2, ...\}$ \text{ where } $R_i = e^{A_i}$

Template Parameters `VAL` – Type of the input

Parameters `val` – The input array or function

Returns Exponential function object

```
template<class VAL, typename std::enable_if_t< detail::isArrayOp< VAL >(),
int > = 0> auto log (VAL &&val) LIBRAPID_RELEASE_NOEXCEPT -> detail::Function< typetraits::Descript
detail::Log, VAL >
```

$R = \{R_0, R_1, R_2, ...\}$ \text{ where } $R_i = \ln(A_i)$

Template Parameters `VAL` – Type of the input

Parameters `val` – The input array or function

Returns Natural logarithm function object

```
template<class VAL, typename std::enable_if_t< detail::isArrayOp< VAL >(),
int > = 0> auto log10 (VAL &&val) LIBRAPID_RELEASE_NOEXCEPT -> detail::Function< typetraits::Descri
detail::Log10, VAL >
```

Compute the base 10 logarithm of each element in the array.

$R = \{R_0, R_1, R_2, ...\}$ \text{ where } $R_i = \log_{10}(A_i)$

Template Parameters `VAL` – Type of the input

Parameters `val` – The input array or function

Returns Base 10 logarithm function object

```
template<class VAL, typename std::enable_if_t< detail::isArrayOp< VAL >(),
int > = 0> auto log2 (VAL &&val) LIBRAPID_RELEASE_NOEXCEPT -> detail::Function< typetraits::Descrip
detail::Log2, VAL >
```

Compute the base 2 logarithm of each element in the array.

$R = \{R_0, R_1, R_2, ...\}$ \text{ where } $R_i = \log_2(A_i)$

Template Parameters `VAL` – Type of the input

Parameters `val` – The input array or function

Returns Base 2 logarithm function object

```
template<class VAL, typename std::enable_if_t< detail::isArrayOp< VAL >(),
int > = 0> auto sqrt (VAL &&val) LIBRAPID_RELEASE_NOEXCEPT -> detail::Function< typetraits::Descrip
detail::Sqrt, VAL >
```

Compute the square root of each element in the array.

$R = \{R_0, R_1, R_2, ...\}$ \text{ where } $R_i = \sqrt{A_i}$

Template Parameters `VAL` – Type of the input

Parameters `val` – The input array or function

Returns Square root function object

```
template<class VAL, typename std::enable_if_t< detail::isArrayOp< VAL >(),
int > = 0> auto cbrt (VAL &&val) LIBRAPID_RELEASE_NOEXCEPT -> detail::Function< typetraits::Descrip
detail::Cbrt, VAL >
```

Compute the cube root of each element in the array.

$R = \{R_0, R_1, R_2, ...\}$ \text{ where } $R_i = \sqrt[3]{A_i}$

Template Parameters `VAL` – Type of the input

Parameters `val` – The input array or function

Returns Cube root function object

```
template<class VAL, typename std::enable_if_t< detail::isArrayOp< VAL >(),
int > = 0> auto abs (VAL &&val) LIBRAPID_RELEASE_NOEXCEPT -> detail::Function< typetraits::Descript
detail::Abs, VAL >
```

Compute the absolute value of each element in the array.

$R = \{R_0, R_1, R_2, ...\}$ \text{ where } $R_i = |A_i|$

Template Parameters `VAL` – Type of the input

Parameters `val` – The input array or function

Returns Absolute value function object

```
template<class VAL, typename std::enable_if_t< detail::isArrayOp< VAL >(),
int > = 0> auto floor (VAL &&val) LIBRAPID_RELEASE_NOEXCEPT -> detail::Function< typetraits::Descri
detail::Floor, VAL >
```

Compute the floor of each element in the array.

$R = \{R_0, R_1, R_2, ...\}$ \text{ where } $R_i = \lfloor A_i \rfloor$

Template Parameters `VAL` – Type of the input

Parameters `val` – The input array or function

Returns Floor function object

```
template<class VAL, typename std::enable_if_t< detail::isArrayOp< VAL >(),
int > = 0> auto ceil (VAL &&val) LIBRAPID_RELEASE_NOEXCEPT -> detail::Function< typetraits::Descrip
detail::Ceil, VAL >
```

Compute the ceiling of each element in the array.

$R = \{R_0, R_1, R_2, ...\}$ \text{ where } $R_i = \lceil A_i \rceil$

Template Parameters `VAL` – Type of the input

Parameters `val` – The input array or function

Returns Ceiling function object

namespace **array**

Functions

```
template<class LHS, class RHS,
typename std::enable_if_t< detail::isArrayOpArray< LHS, RHS >(),
int > = 0> auto operator+ (LHS &&lhs,
RHS &&rhs) LIBRAPID_RELEASE_NOEXCEPT -> detail::Function< typetraits::DescriptorType_t< LHS,
RHS >, detail::Plus, LHS, RHS >
```

Element-wise array addition.

Performs element-wise addition on two arrays. They must both be the same size and of the same data type.

Template Parameters

- `LHS` – Type of the LHS element
- `RHS` – Type of the RHS element

Parameters

- `lhs` – The first array
- `rhs` – The second array

Returns The element-wise sum of the two arrays

```
template<class LHS, class RHS,
typename std::enable_if_t< detail::isArrayOpArray< LHS, RHS >(),
int > = 0> auto operator- (LHS &&lhs,
RHS &&rhs) LIBRAPID_RELEASE_NOEXCEPT -> detail::Function< typetraits::DescriptorType_t< LHS,
RHS >, detail::Minus, LHS, RHS >
```

Element-wise array subtraction.

Performs element-wise subtraction on two arrays. They must both be the same size and of the same data type.

Template Parameters

- `LHS` – Type of the LHS element
- `RHS` – Type of the RHS element

Parameters

- `lhs` – The first array
- `rhs` – The second array

Returns The element-wise difference of the two arrays

```
template<class LHS, class RHS,
typename std::enable_if_t< detail::isArrayOpArray< LHS, RHS >(),
int > = 0> auto operator* (LHS &&lhs,
RHS &&rhs) LIBRAPID_RELEASE_NOEXCEPT -> detail::Function< typetraits::DescriptorType_t< LHS,
RHS >, detail::Multiply, LHS, RHS >
```

Element-wise array multiplication.

Performs element-wise multiplication on two arrays. They must both be the same size and of the same data type.

Template Parameters

- `LHS` – Type of the LHS element
- `RHS` – Type of the RHS element

Parameters

- `lhs` – The first array
- `rhs` – The second array

Returns The element-wise product of the two arrays

```
template<class LHS, class RHS,
typename std::enable_if_t< detail::isArrayOpArray< LHS, RHS >(),
int > = 0> auto operator/ (LHS &&lhs,
RHS &&rhs) LIBRAPID_RELEASE_NOEXCEPT -> detail::Function< typetraits::DescriptorType_t< LHS,
RHS >, detail::Divide, LHS, RHS >
```

Element-wise array division.

Performs element-wise division on two arrays. They must both be the same size and of the same data type.

Template Parameters

- `LHS` – Type of the LHS element
- `RHS` – Type of the RHS element

Parameters

- `lhs` – The first array
- `rhs` – The second array

Returns The element-wise division of the two arrays

```
template<class LHS, class RHS,
typename std::enable_if_t< detail::isArrayOpArray< LHS, RHS >(),
int > = 0> auto operator< (LHS &&lhs,
RHS &&rhs) LIBRAPID_RELEASE_NOEXCEPT -> detail::Function< typetraits::DescriptorType_t< LHS,
RHS >, detail::LessThan, LHS, RHS >
```

Element-wise array comparison, checking whether a < b for all a, b in input arrays.

Performs an element-wise comparison on two arrays, checking if the first value is less than the second. They must both be the same size and of the same data type.

Template Parameters

- `LHS` – Type of the LHS element
- `RHS` – Type of the RHS element

Parameters

- `lhs` – The first array
- `rhs` – The second array

Returns The element-wise comparison of the two arrays

```
template<class LHS, class RHS,
typename std::enable_if_t< detail::isArrayOpArray< LHS, RHS >(),
int > = 0> auto operator> (LHS &&lhs,
RHS &&rhs) LIBRAPID_RELEASE_NOEXCEPT -> detail::Function< typetraits::DescriptorType_t< LHS,
RHS >, detail::GreaterThan, LHS, RHS >
```

Element-wise array comparison, checking whether a > b for all a, b in input arrays.

Performs an element-wise comparison on two arrays, checking if the first value is greater than the second. They must both be the same size and of the same data type.

Template Parameters

- `LHS` – Type of the LHS element
- `RHS` – Type of the RHS element

Parameters

- `lhs` – The first array
- `rhs` – The second array

Returns The element-wise comparison of the two arrays

```
template<class LHS, class RHS,
typename std::enable_if_t< detail::isArrayOpArray< LHS, RHS >(),
int > = 0> auto operator<= (LHS &&lhs,
RHS &&rhs) LIBRAPID_RELEASE_NOEXCEPT -> detail::Function< typetraits::DescriptorType_t< LHS,
RHS >, detail::LessThanEqual, LHS, RHS >
```

Element-wise array comparison, checking whether a <= b for all a, b in input arrays.

Performs an element-wise comparison on two arrays, checking if the first value is less than or equal to the second. They must both be the same size and of the same data type.

Template Parameters
- `LHS` – Type of the LHS element
- `RHS` – Type of the RHS element

Parameters
- `lhs` – The first array
- `rhs` – The second array

Returns The element-wise comparison of the two arrays

```
template<class LHS, class RHS,
typename std::enable_if_t< detail::isArrayOpArray< LHS, RHS >(),
int > = 0> auto operator>= (LHS &&lhs,
RHS &&rhs) LIBRAPID_RELEASE_NOEXCEPT -> detail::Function< typetraits::DescriptorType_t< LHS,
RHS >, detail::GreaterThanEqual, LHS, RHS >
```

Element-wise array comparison, checking whether a >= b for all a, b in input arrays.

Performs an element-wise comparison on two arrays, checking if the first value is greater than or equal to the second. They must both be the same size and of the same data type.

Template Parameters
- `LHS` – Type of the LHS element
- `RHS` – Type of the RHS element

Parameters
- `lhs` – The first array
- `rhs` – The second array

Returns The element-wise comparison of the two arrays

```
template<class LHS, class RHS,
typename std::enable_if_t< detail::isArrayOpArray< LHS, RHS >(),
int > = 0> auto operator== (LHS &&lhs,
RHS &&rhs) LIBRAPID_RELEASE_NOEXCEPT -> detail::Function< typetraits::DescriptorType_t< LHS,
RHS >, detail::ElementWiseEqual, LHS, RHS >
```

Element-wise array comparison, checking whether a == b for all a, b in input arrays.

Performs an element-wise comparison on two arrays, checking if the first value is equal to the second. They must both be the same size and of the same data type.

Template Parameters
- `LHS` – Type of the LHS element
- `RHS` – Type of the RHS element

Parameters
- `lhs` – The first array
- `rhs` – The second array

Returns The element-wise comparison of the two arrays

```
template<class LHS, class RHS,
typename std::enable_if_t< detail::isArrayOpArray< LHS, RHS >(),
int > = 0> auto operator!= (LHS &&lhs,
RHS &&rhs) LIBRAPID_RELEASE_NOEXCEPT -> detail::Function< typetraits::DescriptorType_t< LHS,
RHS >, detail::ElementWiseNotEqual, LHS, RHS >
```

Element-wise array comparison, checking whether a != b for all a, b in input arrays.

Performs an element-wise comparison on two arrays, checking if the first value is not equal to the second. They must both be the same size and of the same data type.

Template Parameters

- **LHS** – Type of the LHS element
- **RHS** – Type of the RHS element

Parameters

- **lhs** – The first array
- **rhs** – The second array

Returns The element-wise comparison of the two arrays

```
template<class VAL, typename std::enable_if_t< detail::isArrayOp< VAL >(),
int > = 0> auto operator- (VAL &&val) LIBRAPID_RELEASE_NOEXCEPT -> detail::Function< typetrait
detail::Neg, VAL >
```

Negate each element in the array.

Template Parameters **VAL** – Type to negate

Parameters **val** – The input array or function

Returns Negation function object

namespace **detail**

Functions

```
template<typename desc, typename Functor, typename ...Args>
auto makeFunction(Args&&... args)
```

Construct a new function object with the given functor type and arguments.

Template Parameters

- **desc** – Functor descriptor
- **Functor** – Function type
- **Args** – Argument types

Parameters **args** – Arguments passed to the function (forwarded)

Returns A new Function instance

```
template<typename VAL>
constexpr bool isArrayOp()
```

```
template<typename LHS, typename RHS>
constexpr bool isArrayOpArray()
```

```
template<typename LHS, typename RHS>
constexpr bool isArrayOpWithScalar()
```

struct **Plus**

#include <operations.hpp>

Public Functions

template<typename **T**, typename **V**>
inline auto **operator()**(const T &lhs, const V &rhs) const

template<typename **Packet**>
inline auto **packet**(const Packet &lhs, const Packet &rhs) const

struct **Minus**

#include <operations.hpp>

Public Functions

template<typename **T**, typename **V**>
inline auto **operator()**(const T &lhs, const V &rhs) const

template<typename **Packet**>
inline auto **packet**(const Packet &lhs, const Packet &rhs) const

struct **Multiply**

#include <operations.hpp>

Public Functions

template<typename **T**, typename **V**>
inline auto **operator()**(const T &lhs, const V &rhs) const

template<typename **Packet**>
inline auto **packet**(const Packet &lhs, const Packet &rhs) const

struct **Divide**

#include <operations.hpp>

Public Functions

template<typename **T**, typename **V**>
inline auto **operator()**(const T &lhs, const V &rhs) const

template<typename **Packet**>
inline auto **packet**(const Packet &lhs, const Packet &rhs) const

struct **LessThan**

#include <operations.hpp>

Public Functions

template<typename **T**, typename **V**>
inline auto **operator()**(const T &lhs, const V &rhs) const

template<typename **Packet**>
inline auto **packet**(const Packet &lhs, const Packet &rhs) const

struct **GreaterThan**

#include <operations.hpp>

Public Functions

template<typename **T**, typename **V**>
inline auto **operator()**(const T &lhs, const V &rhs) const

template<typename **Packet**>
inline auto **packet**(const Packet &lhs, const Packet &rhs) const

struct **LessThanEqual**

#include <operations.hpp>

Public Functions

template<typename **T**, typename **V**>
inline auto **operator()**(const T &lhs, const V &rhs) const

template<typename **Packet**>
inline auto **packet**(const Packet &lhs, const Packet &rhs) const

struct **GreaterThanEqual**

#include <operations.hpp>

Public Functions

template<typename **T**, typename **V**>
inline auto **operator()**(const T &lhs, const V &rhs) const

template<typename **Packet**>
inline auto **packet**(const Packet &lhs, const Packet &rhs) const

struct **ElementWiseEqual**

#include <operations.hpp>

Public Functions

template<typename **T**, typename **V**>
inline auto **operator()**(const T &lhs, const V &rhs) const

template<typename **Packet**>
inline auto **packet**(const Packet &lhs, const Packet &rhs) const

struct **ElementWiseNotEqual**

#include <operations.hpp>

Public Functions

template<typename **T**, typename **V**>
inline auto **operator()**(const T &lhs, const V &rhs) const

template<typename **Packet**>
inline auto **packet**(const Packet &lhs, const Packet &rhs) const

struct **Neg**

#include <operations.hpp>

Public Functions

template<typename **T**>
inline auto **operator()**(const T &arg) const

template<typename **Packet**>
inline auto **packet**(const Packet &arg) const

struct **Sin**

#include <operations.hpp>

Public Functions

template<typename **T**>
inline auto **operator()**(const T &arg) const

template<typename **Packet**>
inline auto **packet**(const Packet &arg) const

struct **Cos**

#include <operations.hpp>

Public Functions

template<typename **T**>
inline auto **operator()**(const T &arg) const

template<typename **Packet**>
inline auto **packet**(const Packet &arg) const

struct **Tan**

#include <operations.hpp>

Public Functions

template<typename **T**>
inline auto **operator()**(const T &arg) const

template<typename **Packet**>
inline auto **packet**(const Packet &arg) const

struct **Asin**

#include <operations.hpp>

Public Functions

template<typename **T**>
inline auto **operator()**(const T &arg) const

template<typename **Packet**>
inline auto **packet**(const Packet &arg) const

struct **Acos**

#include <operations.hpp>

Public Functions

template<typename **T**>
inline auto **operator()**(const T &arg) const

template<typename **Packet**>
inline auto **packet**(const Packet &arg) const

struct **Atan**

#include <operations.hpp>

Public Functions

template<typename **T**>
inline auto **operator()**(const T &arg) const

template<typename **Packet**>
inline auto **packet**(const Packet &arg) const

struct **Sinh**

#include <operations.hpp>

Public Functions

template<typename **T**>
inline auto **operator()**(const T &arg) const

template<typename **Packet**>
inline auto **packet**(const Packet &arg) const

struct **Cosh**

#include <operations.hpp>

Public Functions

template<typename **T**>
inline auto **operator()**(const T &arg) const

template<typename **Packet**>
inline auto **packet**(const Packet &arg) const

struct **Tanh**

#include <operations.hpp>

Public Functions

template<typename **T**>
inline auto **operator()**(const T &arg) const

template<typename **Packet**>
inline auto **packet**(const Packet &arg) const

struct **Exp**

#include <operations.hpp>

Public Functions

template<typename **T**>
inline auto **operator()**(const T &arg) const

template<typename **Packet**>
inline auto **packet**(const Packet &arg) const

struct **Log**

#include <operations.hpp>

Public Functions

template<typename **T**>
inline auto **operator()**(const T &arg) const

template<typename **Packet**>
inline auto **packet**(const Packet &arg) const

struct **Log2**

#include <operations.hpp>

Public Functions

template<typename **T**>
inline auto **operator()**(const T &arg) const

template<typename **Packet**>
inline auto **packet**(const Packet &arg) const

struct **Log10**

#include <operations.hpp>

Public Functions

template<typename **T**>
inline auto **operator()**(const T &arg) const

template<typename **Packet**>
inline auto **packet**(const Packet &arg) const

struct **Sqrt**

#include <operations.hpp>

Public Functions

template<typename **T**>
inline auto **operator()**(const T &arg) const

template<typename **Packet**>
inline auto **packet**(const Packet &arg) const

struct **Cbrt**

#include <operations.hpp>

Public Functions

template<typename **T**>
inline auto **operator()**(const T &arg) const

template<typename **Packet**>
inline auto **packet**(const Packet &arg) const

struct **Abs**

#include <operations.hpp>

Public Functions

template<typename **T**>
inline auto **operator()**(const T &arg) const

template<typename **Packet**>
inline auto **packet**(const Packet &arg) const

struct **Floor**

#include <operations.hpp>

Public Functions

template<typename **T**>
inline auto **operator()**(const T &arg) const

template<typename **Packet**>
inline auto **packet**(const Packet &arg) const

struct **Ceil**

#include <operations.hpp>

Public Functions

template<typename **T**>
inline auto **operator()**(const T &arg) const

template<typename **Packet**>
inline auto **packet**(const Packet &arg) const

namespace **typetraits**

Typedefs

template<typename ...**Args**>

using **DescriptorType_t** = typename DescriptorType<Args...>::Type

A simplification of the *DescriptorType* to reduce code size

See also:

DescriptorType

Template Parameters **Args** – Input types

template<typename **Descriptor1**, typename **Descriptor2**>

struct **DescriptorMerger**

#include <operations.hpp> Merge together two Descriptor types. Two trivial operations will result in another trivial operation, while any other combination will result in a Combined operation.

Template Parameters

- **Descriptor1** – The first descriptor
- **Descriptor2** – The second descriptor

Public Types

using **Type** = ::librapid::detail::descriptor::Combined

template<typename **Descriptor1**>

struct **DescriptorMerger**<Descriptor1, Descriptor1>

#include <operations.hpp>

Public Types

using **Type** = Descriptor1

template<typename **T**>

struct **DescriptorExtractor**

#include <operations.hpp> Extracts the Descriptor type of the provided type.

Template Parameters **T** – The type to extract the descriptor from

Public Types

using **Type** = ::librapid::detail::descriptor::Trivial

template<typename ShapeType, typename StorageType> ArrayContainer< ShapeType, StorageType > >

#include <operations.hpp> Extracts the Descriptor type of an ArrayContainer object. In this case, the Descriptor is Trivial

Template Parameters

- **ShapeType** – The shape type of the ArrayContainer
- **StorageType** – The storage type of the ArrayContainer

Public Types

using **Type** = ::librapid::detail::descriptor::Trivial

template<typename T> ArrayView< T > >

#include <operations.hpp> Extracts the Descriptor type of an ArrayView object

Template Parameters **T** – The Array type of the ArrayView

Public Types

using **Type** = ::librapid::detail::descriptor::Trivial

template<typename Descriptor, typename Functor, typename... Args> Function< Descriptor, Functor, Args... > >

#include <operations.hpp> Extracts the Descriptor type of a Function object

Template Parameters

- **Descriptor** – The descriptor of the Function
- **Functor** – The functor type of the Function
- **Args** – The argument types of the Function

Public Types

using **Type** = Descriptor

template<typename **First**, typename ...**Rest**>

struct **DescriptorType**

#include <operations.hpp>

Return the combined Descriptor type of the provided types

Allows a number of Descriptor types to be merged together into a single Descriptor type. The Descriptors used are extracted from the of the provided types.

Template Parameters

- **First** – The first type to merge
- **Rest** – The remaining types

- **First** – The first type to merge
- **Rest** – The remaining types

Public Types

using **FirstType** = std::decay_t<First>

using **FirstDescriptor** = typename DescriptorExtractor<FirstType>::Type

using **RestDescriptor** = decltype(*impl*::descriptorExtractor<Rest...>())

using **Type** = typename DescriptorMerger<FirstDescriptor, RestDescriptor>::Type

template<> Plus >

#include <operations.hpp>

Public Static Functions

template<typename **T1**, typename **T2**>
static inline constexpr const char ***getKernelNameImpl**(std::tuple<*T1*, *T2*> args)

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<*Args*...> args)

template<typename **First**, typename **Second**>
static inline auto **getShapeImpl**(const std::tuple<*First*, *Second*> &tup)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<*Args*...> &args)

Public Static Attributes

static constexpr const char ***name** = "plus"

static constexpr const char ***filename** = "arithmetic"

static constexpr const char ***kernelName** = "addArrays"

static constexpr const char ***kernelNameScalarRhs** = "addArraysScalarRhs"

static constexpr const char ***kernelNameScalarLhs** = "addArraysScalarLhs"

template<> Minus >

#include <operations.hpp>

Public Static Functions

template<typename **T1**, typename **T2**>
static inline constexpr const char ***getKernelNameImpl**(std::tuple<*T1*, *T2*> args)

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<*Args*...> args)

template<typename **First**, typename **Second**>
static inline auto **getShapeImpl**(const std::tuple<*First*, *Second*> &tup)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<*Args*...> &args)

Public Static Attributes

static constexpr const char ***name** = "minus"

static constexpr const char ***filename** = "arithmetic"

static constexpr const char ***kernelName** = "subArrays"

static constexpr const char ***kernelNameScalarRhs** = "subArraysScalarRhs"

static constexpr const char ***kernelNameScalarLhs** = "subArraysScalarLhs"

template<> Multiply >

#include <operations.hpp>

Public Static Functions

template<typename **T1**, typename **T2**>
static inline constexpr const char ***getKernelNameImpl**(std::tuple<*T1*, *T2*> args)

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<*Args*...> args)

template<typename **First**, typename **Second**>
static inline auto **getShapeImpl**(const std::tuple<*First*, *Second*> &tup)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<*Args*...> &args)

Public Static Attributes

static constexpr const char ***name** = "multiply"

static constexpr const char ***filename** = "arithmetic"

static constexpr const char ***kernelName** = "mulArrays"

static constexpr const char ***kernelNameScalarRhs** = "mulArraysScalarRhs"

static constexpr const char ***kernelNameScalarLhs** = "mulArraysScalarLhs"

template<> Divide >

#include <operations.hpp>

Public Static Functions

template<typename **T1**, typename **T2**>
static inline constexpr const char ***getKernelNameImpl**(std::tuple<*T1*, *T2*> args)

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<*Args*...> args)

template<typename **First**, typename **Second**>
static inline auto **getShapeImpl**(const std::tuple<*First*, *Second*> &tup)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<*Args*...> &args)

Public Static Attributes

static constexpr const char ***name** = "divide"

static constexpr const char ***filename** = "arithmetic"

static constexpr const char ***kernelName** = "divArrays"

static constexpr const char ***kernelNameScalarRhs** = "divArraysScalarRhs"

static constexpr const char ***kernelNameScalarLhs** = "divArraysScalarLhs"

template<> LessThan >

#include <operations.hpp>

Public Static Functions

template<typename **T1**, typename **T2**>
static inline constexpr const char ***getKernelNameImpl**(std::tuple<*T1*, *T2*> args)

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<*Args*...> args)

template<typename **First**, typename **Second**>
static inline auto **getShapeImpl**(const std::tuple<*First*, *Second*> &tup)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<*Args*...> &args)

Public Static Attributes

static constexpr const char ***name** = "less than"

static constexpr const char ***filename** = "arithmetic"

static constexpr const char ***kernelName** = "lessThanArrays"

static constexpr const char ***kernelNameScalarRhs** = "lessThanArraysScalarRhs"

static constexpr const char ***kernelNameScalarLhs** = "lessThanArraysScalarLhs"

template<> GreaterThan >

#include <operations.hpp>

Public Static Functions

template<typename **T1**, typename **T2**>
static inline constexpr const char ***getKernelNameImpl**(std::tuple<*T1*, *T2*> args)

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<*Args*...> args)

template<typename **First**, typename **Second**>
static inline auto **getShapeImpl**(const std::tuple<*First*, *Second*> &tup)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<*Args*...> &args)

Public Static Attributes

static constexpr const char ***name** = "greater than"

static constexpr const char ***filename** = "arithmetic"

static constexpr const char ***kernelName** = "greaterThanArrays"

static constexpr const char ***kernelNameScalarRhs** = "greaterThanArraysScalarRhs"

static constexpr const char ***kernelNameScalarLhs** = "greaterThanArraysScalarLhs"

template<> LessThanEqual >

#include <operations.hpp>

Public Static Functions

template<typename **T1**, typename **T2**>
static inline constexpr const char ***getKernelNameImpl**(std::tuple<*T1*, *T2*> args)

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<*Args*...> args)

template<typename **First**, typename **Second**>
static inline auto **getShapeImpl**(const std::tuple<*First*, *Second*> &tup)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<*Args*...> &args)

Public Static Attributes

static constexpr const char ***name** = "less than or equal"

static constexpr const char ***filename** = "arithmetic"

static constexpr const char ***kernelName** = "lessThanEqualArrays"

static constexpr const char ***kernelNameScalarRhs** = "lessThanEqualArraysScalarRhs"

static constexpr const char ***kernelNameScalarLhs** = "lessThanEqualArraysScalarLhs"

template<> GreaterThanEqual >

#include <operations.hpp>

Public Static Functions

template<typename **T1**, typename **T2**>
static inline constexpr const char ***getKernelNameImpl**(std::tuple<*T1*, *T2*> args)

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<*Args*...> args)

template<typename **First**, typename **Second**>
static inline auto **getShapeImpl**(const std::tuple<*First*, *Second*> &tup)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<*Args*...> &args)

Public Static Attributes

static constexpr const char ***name** = "greater than or equal"

static constexpr const char ***filename** = "arithmetic"

static constexpr const char ***kernelName** = "greaterThanEqualArrays"

static constexpr const char ***kernelNameScalarRhs** = "greaterThanEqualArraysScalarRhs"

static constexpr const char ***kernelNameScalarLhs** = "greaterThanEqualArraysScalarLhs"

template<> ElementWiseEqual >

#include <operations.hpp>

Public Static Functions

template<typename **T1**, typename **T2**>
static inline constexpr const char ***getKernelNameImpl**(std::tuple<*T1*, *T2*> args)

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<*Args*...> args)

template<typename **First**, typename **Second**>
static inline auto **getShapeImpl**(const std::tuple<*First*, *Second*> &tup)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<*Args*...> &args)

Public Static Attributes

static constexpr const char ***name** = "element wise equal"

static constexpr const char ***filename** = "arithmetic"

static constexpr const char ***kernelName** = "elementWiseEqualArrays"

static constexpr const char ***kernelNameScalarRhs** = "elementWiseEqualArraysScalarRhs"

static constexpr const char ***kernelNameScalarLhs** = "elementWiseEqualArraysScalarLhs"

template<> ElementWiseNotEqual >

#include <operations.hpp>

Public Static Functions

template<typename **T1**, typename **T2**>
static inline constexpr const char ***getKernelNameImpl**(std::tuple<*T1*, *T2*> args)

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<*Args*...> args)

template<typename **First**, typename **Second**>
static inline auto **getShapeImpl**(const std::tuple<*First*, *Second*> &tup)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<*Args*...> &args)

Public Static Attributes

static constexpr const char ***name** = "element wise not equal"

static constexpr const char ***filename** = "arithmetic"

static constexpr const char ***kernelName** = "elementWiseNotEqualArrays"

static constexpr const char ***kernelNameScalarRhs** = "elementWiseNotEqualArraysScalarRhs"

static constexpr const char ***kernelNameScalarLhs** = "elementWiseNotEqualArraysScalarLhs"

template<> Neg >

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<*Args*...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<*Args*...> &args)

Public Static Attributes

static constexpr const char ***name** = "negate"

static constexpr const char ***filename** = "negate"

static constexpr const char ***kernelName** = "negateArrays"

template<> Sin >

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<*Args*...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<*Args*...> &args)

Public Static Attributes

static constexpr const char ***name** = "sin"

static constexpr const char ***filename** = "trigonometry"

static constexpr const char ***kernelName** = "sinArrays"

template<> Cos >

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<*Args*...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<*Args*...> &args)

Public Static Attributes

static constexpr const char ***name** = "cos"

static constexpr const char ***filename** = "trigonometry"

static constexpr const char ***kernelName** = "cosArrays"

template<> Tan >

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<*Args*...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<*Args*...> &args)

Public Static Attributes

static constexpr const char ***name** = "tan"

static constexpr const char ***filename** = "trigonometry"

static constexpr const char ***kernelName** = "tanArrays"

template<> Asin >

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<*Args*...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<*Args*...> &args)

Public Static Attributes

static constexpr const char ***name** = "arcsin"

static constexpr const char ***filename** = "trigonometry"

static constexpr const char ***kernelName** = "asinArrays"

template<> Acos >

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<*Args*...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<*Args*...> &args)

Public Static Attributes

static constexpr const char ***name** = "arcos"

static constexpr const char ***filename** = "trigonometry"

static constexpr const char ***kernelName** = "acosArrays"

template<> Atan >

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<*Args*...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<*Args*...> &args)

Public Static Attributes

static constexpr const char ***name** = "arctan"

static constexpr const char ***filename** = "trigonometry"

static constexpr const char ***kernelName** = "atanArrays"

template<> Sinh >

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<*Args*...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<*Args*...> &args)

Public Static Attributes

static constexpr const char ***name** = "hyperbolic sine"

static constexpr const char ***filename** = "trigonometry"

static constexpr const char ***kernelName** = "sinhArrays"

template<> Cosh >

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<*Args*...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<*Args*...> &args)

Public Static Attributes

static constexpr const char ***name** = "hyperbolic cosine"

static constexpr const char ***filename** = "trigonometry"

static constexpr const char ***kernelName** = "coshArrays"

template<> Tanh >

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<*Args*...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<*Args*...> &args)

Public Static Attributes

static constexpr const char ***name** = "hyperbolic tangent"

static constexpr const char ***filename** = "trigonometry"

static constexpr const char ***kernelName** = "tanhArrays"

template<> Exp >

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<*Args*...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<*Args*...> &args)

Public Static Attributes

static constexpr const char ***name** = "exponent"

static constexpr const char ***filename** = "expLogPow"

static constexpr const char ***kernelName** = "expArrays"

template<> Log >

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<*Args*...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<*Args*...> &args)

Public Static Attributes

static constexpr const char ***name** = "logarithm"

static constexpr const char ***filename** = "expLogPow"

static constexpr const char ***kernelName** = "logArrays"

template<> Log2 >

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<*Args*...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<*Args*...> &args)

Public Static Attributes

static constexpr const char ***name** = "logarithm base 2"

static constexpr const char ***filename** = "expLogPow"

static constexpr const char ***kernelName** = "log2Arrays"

template<> Log10 >

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<*Args*...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<*Args*...> &args)

Public Static Attributes

static constexpr const char ***name** = "logarithm base 10"

static constexpr const char ***filename** = "expLogPow"

static constexpr const char ***kernelName** = "log10Arrays"

template<> Sqrt >

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<*Args*...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<*Args*...> &args)

Public Static Attributes

static constexpr const char ***name** = "square root"

static constexpr const char ***filename** = "expLogPow"

static constexpr const char ***kernelName** = "sqrtArrays"

template<> Cbrt >

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<*Args*...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<*Args*...> &args)

Public Static Attributes

static constexpr const char ***name** = "cube root"

static constexpr const char ***filename** = "expLogPow"

static constexpr const char ***kernelName** = "cbrtArrays"

template<> Abs >

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<*Args*...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<*Args*...> &args)

Public Static Attributes

static constexpr const char ***name** = "absolute value"

static constexpr const char ***filename** = "abs"

static constexpr const char ***kernelName** = "absArrays"

template<> Floor >

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<*Args*...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<*Args*...> &args)

Public Static Attributes

static constexpr const char ***name** = "floor"

static constexpr const char ***filename** = "floorCeilRound"

static constexpr const char ***kernelName** = "floorArrays"

template<> Ceil >

#include <operations.hpp>

Public Static Functions

template<typename ...**Args**>
static inline constexpr const char ***getKernelName**(std::tuple<*Args*...> args)

template<typename ...**Args**>
static inline auto **getShape**(const std::tuple<*Args*...> &args)

Public Static Attributes

static constexpr const char ***name** = "ceiling"

static constexpr const char ***filename** = "floorCeilRound"

static constexpr const char ***kernelName** = "ceilArrays"

namespace **impl**

Functions

template<typename ...**Rest**>
constexpr auto **descriptorExtractor**()

A `constexpr` function which supports the *DescriptorType* for multi-type inputs

Template Parameters Rest –

Returns

1.3.2.7 Size Type

> **Warning:** doxygenfile: Cannot find file "librapid/include/librapid/array/sizeType.hpp

1.3.2.8 Stride Tools

namespace **librapid**

template<typename **T** = size_t, size_t **N** = 32>

class **Stride** : public librapid::Shape<size_t, 32>

#include <strideTools.hpp> A *Stride* is a vector of integers that describes the distance between elements in each dimension of an ArrayContainer object. This can be used to access elements in a non-trivial order, or to access a sub-array of an ArrayContainer object. The *Stride* class inherits from the Shape class.

See also:

Shape

Template Parameters

- **T** – The type of the *Stride*. Must be an integer type.

- **N** – The number of dimensions in the *Stride*.

Public Functions

Stride() = default

Default Constructor.

Stride(const Shape<T, N> &shape)

Construct a *Stride* from a Shape object. This will assume that the data represented by the Shape object is a contiguous block of memory, and will calculate the corresponding strides based on this.

Parameters **shape** –

Stride(const Stride &other) = default

Copy a *Stride* object

Parameters **other** – The *Stride* object to copy.

Stride(Stride &&other) noexcept = default

Move a *Stride* object

Parameters **other** – The *Stride* object to move.

Stride &**operator=**(const Stride &other) = default

Assign a *Stride* object to this *Stride* object.

Parameters **other** – The *Stride* object to assign.

Stride &**operator=**(Stride &&other) noexcept = default

Move a *Stride* object to this *Stride* object.

Parameters **other** – The *Stride* object to move.

namespace **typetraits**

Functions

LIBRAPID_DEFINE_AS_TYPE (typename T COMMA size_t N, Stride< T COMMA N >)

1.3.2.9 Storage

namespace **librapid**

template<typename **Scalar_**>

class **Storage**

#include <storage.hpp>

Public Types

using **Scalar** = Scalar_

using **RawPointer** = Scalar*

using **ConstRawPointer** = const Scalar*

using **Pointer** = std::shared_ptr<Scalar>

using **ConstPointer** = std::shared_ptr<const Scalar>

using **Reference** = Scalar&

using **ConstReference** = const Scalar&

using **SizeType** = size_t

using **DifferenceType** = ptrdiff_t

using **Iterator** = RawPointer

using **ConstIterator** = ConstRawPointer

using **ReverseIterator** = std::reverse_iterator<Iterator>

using **ConstReverseIterator** = std::reverse_iterator<ConstIterator>

Public Functions

Storage() = default

Default constructor.

explicit **Storage**(SizeType size)

Create a *Storage* object with `size` elements

Parameters **size** – Number of elements to allocate

explicit **Storage**(Scalar *begin, Scalar *end, bool ownsData)

Storage(SizeType size, ConstReference value)

Create a *Storage* object with `size` elements, each initialized to `value`.

Parameters

- **size** – Number of elements to allocate
- **value** – Value to initialize each element to

Storage(const Storage &other)

Create a *Storage* object from another *Storage* object. Additionally a custom allocator can be used. The data is **NOT** copied — it is referenced by the new *Storage* object. For a deep copy, use the `copy()` method.

Parameters **other** – *Storage* object to copy

Storage(Storage &&other) noexcept

Move a *Storage* object into this object.

Parameters **other** – *Storage* object to move

template<typename **V**>
Storage(const std::initializer_list<V> &list)

Create a *Storage* object from an std::initializer_list

Template Parameters **V** – Type of the elements in the initializer list

Parameters

- **list** – Initializer list to copy
- **alloc** – Allocator to use

template<typename **V**>
explicit **Storage**(const std::vector<V> &vec)

Create a *Storage* object from a std::vector

Template Parameters **V** – Type of the elements in the vector

Parameters **vec** – Vector to copy

Storage &**operator=**(const Storage &other)

Assignment operator for a *Storage* object

Parameters **other** – *Storage* object to copy

Returns *this

Storage & operator= (Storage &&other) LIBRAPID_RELEASE_NOEXCEPT

Move assignment operator for a *Storage* object

Parameters **other** – *Storage* object to move

Returns *this

~Storage()

Free a *Storage* object.

void **set**(const Storage &other)

Set this storage object to reference the same data as `other`.

Parameters **other** – *Storage* object to reference

Storage **toHostStorage**() const

Return a *Storage* object on the host with the same data as this *Storage* object (mainly for use with CUDA or OpenCL)

Returns

Storage **toHostStorageUnsafe**() const

Same as `toHostStorage()` but does not necessarily copy the data.

Returns *Storage* object on the host

Storage **copy**() const

Create a deep copy of this *Storage* object.

Returns Deep copy of this *Storage* object void **resize**(SizeType newSize)

Resize a *Storage* object to `size` elements. Existing elements are preserved.

Parameters **size** – New size of the *Storage* object

void **resize**(SizeType newSize, int)

Resize a *Storage* object to `size` elements. Existing elements are not preserved

Parameters **size** – New size of the *Storage* object

SizeType **size**() const noexcept

Return the number of elements in the *Storage* object

Returns

ConstReference **operator[]**(SizeType index) const

Const access to the element at index `index`

Parameters **index** – Index of the element to access

Returns Const reference to the element at index `index`

Reference **operator[]**(SizeType index)

Access to the element at index `index`

Parameters **index** – Index of the element to access

Returns Reference to the element at index `index`

Pointer **data**() const noexcept

RawPointer **begin**() noexcept

RawPointer **end**() noexcept

ConstIterator **begin**() const noexcept

ConstIterator **end**() const noexcept

ConstIterator **cbegin**() const noexcept

ConstIterator **cend**() const noexcept

ReverseIterator **rbegin**() noexcept

ReverseIterator **rend**() noexcept

ConstReverseIterator **rbegin**() const noexcept

ConstReverseIterator **rend**() const noexcept

ConstReverseIterator **crbegin**() const noexcept

ConstReverseIterator **crend**() const noexcept

template<typename **V**>
auto **fromData**(const std::initializer_list<V> &list) -> Storage

template<typename **V**>
auto **fromData**(const std::vector<V> &vec) -> Storage

template<typename **ShapeType**>
auto **defaultShape**() -> ShapeType

Public Static Functions

template<typename **V**>
static Storage **fromData**(const std::initializer_list<V> &vec)

template<typename **V**>
static Storage **fromData**(const std::vector<V> &vec)

template<typename **ShapeType**>
static ShapeType **defaultShape**()

Private Functions

template<typename **P**>
void **initData**(*P* begin, *P* end)

Copy data from `begin` to `end` into this *Storage* object

Template Parameters P – Pointer type

Parameters

- **begin** – Beginning of data to copy
- **end** – End of data to copy

template<typename **P**>
void **initData**(*P* begin, SizeType size)

void **resizeImpl**(SizeType newSize, int)

Resize the *Storage* Object to `newSize` elements, retaining existing data.

Parameters newSize – New size of the *Storage* object

void **resizeImpl**(SizeType newSize)

Resize the *Storage* object to `newSize` elements. Note this does not initialize the new elements or maintain existing data.

Parameters newSize – New size of the *Storage* object

Private Members

Pointer **m_begin** = nullptr

SizeType **m_size** = 0

bool **m_ownsData** = true

template<typename **Scalar_**, size_t... **Size_**>

class **FixedStorage**

#include <storage.hpp>

Public Types

using **Scalar** = Scalar_

using **Pointer** = Scalar*

using **ConstPointer** = const Scalar*

using **Reference** = Scalar&

using **ConstReference** = const Scalar&

using **SizeType** = size_t

using **DifferenceType** = ptrdiff_t

using **Iterator** = typename std::array<Scalar, product<Size_...>()>::iterator

using **ConstIterator** = typename std::array<Scalar, product<Size_...>()>::const_iterator

using **ReverseIterator** = std::reverse_iterator<Iterator>

using **ConstReverseIterator** = std::reverse_iterator<ConstIterator>

Public Functions

FixedStorage()

Default constructor.

explicit **FixedStorage**(const Scalar &value)

Create a *FixedStorage* object filled with `value`

Parameters **value** – Value to fill the *FixedStorage* object with

FixedStorage(const FixedStorage &other)

Create a *FixedStorage* object from another *FixedStorage* object

Parameters **other** – *FixedStorage* object to copy

FixedStorage(FixedStorage &&other) noexcept

Move constructor for a *FixedStorage* object

Parameters **other** – *FixedStorage* object to move

explicit **FixedStorage**(const std::initializer_list<Scalar> &list)

Create a *FixedStorage* object from a std::initializer_list

Template Parameters **V** – Type of the elements in the initializer list

Parameters **list** – Initializer list to copy explicit **FixedStorage**(const std::vector<Scalar> &vec)

Create a *FixedStorage* object from a std::vector

Template Parameters **V** – Type of the elements in the vector

Parameters **vec** – Vector to copy

FixedStorage &**operator=**(const FixedStorage &other)

Assignment operator for a *FixedStorage* object

Parameters **other** – *FixedStorage* object to copy

Returns *this

FixedStorage &**operator=**(FixedStorage &&other) noexcept

Move assignment operator for a *FixedStorage* object

Parameters **other** – *FixedStorage* object to move

Returns *this

~FixedStorage() = default

Free a *FixedStorage* object.

void **resize**(SizeType newSize)

Resize a *Storage* object to `size` elements. Existing elements are preserved.

Parameters **size** – New size of the *Storage* object

void **resize**(SizeType newSize, int)

Resize a *Storage* object to `size` elements. Existing elements are not preserved

Parameters **size** – New size of the *Storage* object

SizeType **size**() const noexcept

Return the number of elements in the *FixedStorage* object

Returns Number of elements in the *FixedStorage* object

FixedStorage **copy**() const

Create a copy of the *FixedStorage* object.

Returns Copy of the *FixedStorage* object

ConstReference **operator[]**(SizeType index) const

Const access to the element at index `index`

Parameters **index** – Index of the element to access

Returns Const reference to the element at index `index`

Reference **operator[]**(SizeType index)

Access to the element at index `index`

Parameters **index** – Index of the element to access

Returns Reference to the element at index `index`

Pointer **data**() const noexcept

Iterator **begin**() noexcept

Iterator **end**() noexcept

ConstIterator **begin**() const noexcept

ConstIterator **end**() const noexcept

ConstIterator **cbegin**() const noexcept

ConstIterator **cend**() const noexcept

ReverseIterator **rbegin**() noexcept

ReverseIterator **rend**() noexcept

ConstReverseIterator **rbegin**() const noexcept

ConstReverseIterator **rend**() const noexcept

ConstReverseIterator **crbegin**() const noexcept

ConstReverseIterator **crend**() const noexcept

template<typename **ShapeType**>
auto **defaultShape**() -> ShapeType

Public Static Functions

template<typename **ShapeType**>
static ShapeType **defaultShape**()

Public Static Attributes

static constexpr SizeType **Size** = product<Size_...>()

Private Members

std::array<Scalar, Size> **m_data**

namespace **detail**

Functions

template<typename **T**>
void **safeDeallocate**(T *ptr, size_t size)

Safely deallocate memory for `size` elements, using an std::allocator `alloc`. If the object cannot be trivially destroyed, the destructor will be called on each element of the data, ensuring that it is safe to free the allocated memory.

Template Parameters **A** – The allocator type

Parameters

- **alloc** – The allocator object
- **ptr** – The pointer to free
- **size** – The number of elements of type `in` the memory block

template<typename **T**>
std::shared_ptr<T> **safeAllocate**(size_t size)

Safely allocate memory for `size` elements using the allocator `alloc`. If the data can be trivially default constructed, then the constructor is not called and no data is initialized. Otherwise, the correct default constructor will be called for each element in the data, making sure the returned pointer is safe to use.

See also:

safeDeallocate

Template Parameters **A** – The allocator type to use

Parameters

- **alloc** – The allocator object to use
- **size** – Number of elements to allocate

Returns Pointer to the first element

template<typename **T**>
std::shared_ptr<T> **safePointerCopy**(T *ptr, size_t size, bool ownsData)

Safely copy a pointer to a shared pointer. If `ownsData` is true, then the shared pointer will be initialized with a custom deleter that will call safeDeallocate on the pointer. Otherwise, the shared pointer will be initialized with a no-op deleter.

Template Parameters **T** – Type of the pointer

Parameters

- **ptr** – Raw pointer to copy
- **ownsData** – Whether the shared pointer should own the data

Returns Shared pointer to the data

template<typename **T**>
std::shared_ptr<T> **safePointerCopy**(const std::shared_ptr<T> &ptr, size_t size, bool ownsData = true)

namespace **typetraits**

Functions

LIBRAPID_DEFINE_AS_TYPE(typename Scalar, Storage<Scalar>)

template<typename **Scalar_**>

struct **TypeInfo**<Storage<Scalar_>>

#include <storage.hpp>

Public Types

using **Scalar** = Scalar_

using **Backend** = backend::CPU

Public Static Attributes

static constexpr bool **isLibRapidType** = true

template<typename **Scalar_**, size_t... **Dims**>

struct **TypeInfo**<FixedStorage<Scalar_, Dims...>>

#include <storage.hpp>

Public Types

using **Scalar** = Scalar_

using **Backend** = backend::CPU

Public Static Attributes

static constexpr bool **isLibRapidType** = true

template<typename **T**>

struct **IsStorage** : public std::false_type

#include <storage.hpp>

template<typename **Scalar**>

struct **IsStorage**<Storage<Scalar>> : public std::true_type

#include <storage.hpp>

template<typename **T**>

struct **IsFixedStorage** : public std::false_type

#include <storage.hpp>

template<typename **Scalar**, size_t... **Size**>

struct **IsFixedStorage**<FixedStorage<Scalar, Size...>> : public std::true_type

#include <storage.hpp>

1.3.2.10 OpenCL Storage

1.3.2.11 CUDA Storage

Defines

CUDA_REF_OPERATOR(OP)

CUDA_REF_OPERATOR_NO_ASSIGN(OP)

namespace **librapid**

template<typename **Scalar_**>

class **CudaStorage**

#include <cudaStorage.hpp>

Public Types

using **Scalar** = Scalar_

using **Pointer** = std::shared_ptr<Scalar>

using **ConstPointer** = const std::shared_ptr<Scalar>

using **Reference** = Scalar&

using **ConstReference** = const Scalar&

using **DifferenceType** = std::ptrdiff_t

using **SizeType** = std::size_t

Public Functions

CudaStorage() = default

Default constructor — initializes with nullptr.

explicit **CudaStorage**(SizeType size)

Create a *CudaStorage* object with `elements`. The data is not initialized.

Parameters **size** – Number of elements

CudaStorage(SizeType size, ConstReference value)

Create a *CudaStorage* object with `elements`. The data is initialized to `value`.

Parameters

- **size** – Number of elements
- **value** – Value to fill with

CudaStorage(Scalar *begin, SizeType size, bool independent)

CudaStorage(const CudaStorage &other)

Create a new *CudaStorage* object from an existing one.

Parameters **other** – The *CudaStorage* to copy

CudaStorage(CudaStorage &&other) noexcept

Create a new *CudaStorage* object from a temporary one, moving the data

Parameters **other** – The array to move

CudaStorage(const std::initializer_list<Scalar> &list)

Create a *CudaStorage* object from an std::initializer_list

Parameters **list** – Initializer list of elements

explicit **CudaStorage**(const std::vector<Scalar> &vec)

Create a *CudaStorage* object from an std::vector of values

Parameters **vec** – The vector to fill with

CudaStorage &**operator=**(const CudaStorage &other)

Assignment operator for a *CudaStorage* object

Parameters **other** – *CudaStorage* object to copy

Returns *this

CudaStorage &**operator=**(CudaStorage &&other) noexcept

Move assignment operator for a *CudaStorage* object

Parameters **other** – *CudaStorage* object to move

Returns *this

~CudaStorage()

Free a *CudaStorage* object.

void **set**(const CudaStorage &other)

Set this *CudaStorage* object to reference the same data as `other`.

Parameters **other** – *CudaStorage* object to reference

CudaStorage **copy**() const

Create a deep copy of this *CudaStorage* object.

Returns Deep copy of this *CudaStorage* object

void **resize**(SizeType newSize)

Resize a *CudaStorage* object to `size` elements. Existing elements are preserved where possible.

See also:

resize(SizeType, int)

Parameters **size** – Number of elements

void **resize**(SizeType newSize, int)

Resize a *CudaStorage* object to `size` elements. Existing elements are not preserved. This method of resizing is faster and more efficient than the version which preserves the original data, but of course, this has the drawback that data will be lost.

Parameters **size** – Number of elements

SizeType **size**() const noexcept

Return the number of elements in the *CudaStorage* object.

Returns The number of elements

detail::CudaRef<Scalar> **operator[]**(SizeType index) const

detail::CudaRef<Scalar> **operator[]**(SizeType index)

Pointer **data**() const noexcept

Return the underlying pointer to the data

Returns The underlying pointer to the data

Pointer **begin**() const noexcept

Returns the pointer to the first element of the *CudaStorage* object

Returns Pointer to the first element of the *CudaStorage* object

Pointer **end**() const noexcept

Returns the pointer to the last element of the *CudaStorage* object

Returns A pointer to the last element of the *CudaStorage*

template<typename **V**>

auto **fromData**(const std::initializer_list<V> &list) -> CudaStorage

template<typename **V**>
auto **fromData**(const std::vector<V> &vec) -> CudaStorage

Public Static Functions

template<typename **ShapeType**>
static ShapeType **defaultShape**()

template<typename **V**>
static CudaStorage **fromData**(const std::initializer_list<V> &vec)

template<typename **V**>
static CudaStorage **fromData**(const std::vector<V> &vec)

Private Functions

template<typename **P**>
void **initData**(*P* begin, *P* end)

Template Parameters `P` – Pointer type

Parameters

- **begin** – Beginning of data to copy
- **end** – End of data to copy

void **resizeImpl**(SizeType newSize, int)

Resize the *Storage* Object to `newSize` elements, retaining existing data.

Parameters `newSize` – New size of the *Storage* object

void **resizeImpl**(SizeType newSize)

Resize the *Storage* object to `newSize` elements. Note this does not initialize the new elements or maintain existing data.

Parameters `newSize` – New size of the *Storage* object

Private Members

Pointer **m_begin** = nullptr

size_t **m_size**

bool **m_ownsData** = true

namespace **detail**

Functions

template<typename T> T *__restrict cudaSafeAllocate (size_t size)

Safely allocate memory for `size` elements of type on the GPU using CUDA.

See also:

safeAllocate

Template Parameters `T` – Scalar type
Parameters `size` – Number of elements to allocate
Returns GPU pointer

template<typename T> void cudaSafeDeallocate (T *__restrict data)

Safely free memory for `size` elements of type on the GPU using CUDA.

See also:

safeAllocate

Template Parameters `T` – Scalar type
Parameters `data` – The data to deallocate
Returns GPU pointer

template<typename **T**>
std::shared_ptr<T> **cudaSharedPtrAllocate**(size_t size)

template<typename **LHS**, typename **RHS**>
auto **operator+**(const CudaRef<LHS> &lhs, const RHS &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator+**(const LHS &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator+**(const CudaRef<LHS> &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator+=**(CudaRef<LHS> &lhs, const RHS &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator+=**(CudaRef<LHS> &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator-**(const CudaRef<LHS> &lhs, const RHS &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator-**(const LHS &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator-**(const CudaRef<LHS> &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator-=**(CudaRef<LHS> &lhs, const RHS &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator-=**(CudaRef<LHS> &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>

auto **operator*** (const CudaRef<LHS> &lhs, const RHS &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator*** (const LHS &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator*** (const CudaRef<LHS> &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator*=** (CudaRef<LHS> &lhs, const RHS &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator*=** (CudaRef<LHS> &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator/** (const CudaRef<LHS> &lhs, const RHS &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator/** (const LHS &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator/** (const CudaRef<LHS> &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator/=** (CudaRef<LHS> &lhs, const RHS &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator/=** (CudaRef<LHS> &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator%** (const CudaRef<LHS> &lhs, const RHS &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator%** (const LHS &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator%** (const CudaRef<LHS> &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator%=** (CudaRef<LHS> &lhs, const RHS &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator%=** (CudaRef<LHS> &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator^** (const CudaRef<LHS> &lhs, const RHS &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator^** (const LHS &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator^** (const CudaRef<LHS> &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator^=** (CudaRef<LHS> &lhs, const RHS &rhs)

template<typename **LHS**, typename **RHS**>

auto **operator^=**(CudaRef<LHS> &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator&**(const CudaRef<LHS> &lhs, const RHS &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator&**(const LHS &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator&**(const CudaRef<LHS> &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator&=**(CudaRef<LHS> &lhs, const RHS &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator&=**(CudaRef<LHS> &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator|**(const CudaRef<LHS> &lhs, const RHS &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator|**(const LHS &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator|**(const CudaRef<LHS> &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator|=**(CudaRef<LHS> &lhs, const RHS &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator|=**(CudaRef<LHS> &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator<<**(const CudaRef<LHS> &lhs, const RHS &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator<<**(const LHS &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator<<**(const CudaRef<LHS> &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator<<=**(CudaRef<LHS> &lhs, const RHS &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator<<=**(CudaRef<LHS> &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator>>**(const CudaRef<LHS> &lhs, const RHS &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator>>**(const LHS &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator>>**(const CudaRef<LHS> &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>

auto **operator>>=**(CudaRef<LHS> &lhs, const RHS &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator>>=**(CudaRef<LHS> &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator==**(const CudaRef<LHS> &lhs, const RHS &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator==**(const LHS &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator==**(const CudaRef<LHS> &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator!=**(const CudaRef<LHS> &lhs, const RHS &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator!=**(const LHS &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator!=**(const CudaRef<LHS> &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator<**(const CudaRef<LHS> &lhs, const RHS &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator<**(const LHS &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator<**(const CudaRef<LHS> &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator>**(const CudaRef<LHS> &lhs, const RHS &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator>**(const LHS &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator>**(const CudaRef<LHS> &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator<=**(const CudaRef<LHS> &lhs, const RHS &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator<=**(const LHS &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator<=**(const CudaRef<LHS> &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator>=**(const CudaRef<LHS> &lhs, const RHS &rhs)

template<typename **LHS**, typename **RHS**>
auto **operator>=**(const LHS &lhs, const CudaRef<RHS> &rhs)

template<typename **LHS**, typename **RHS**>

auto **operator>=**(const CudaRef<LHS> &lhs, const CudaRef<RHS> &rhs)

template<typename **T**>
std::shared_ptr<T> **safePointerCopyCuda**(T *ptr, bool ownsData = true)

template<typename **T**>
std::shared_ptr<T> **safePointerCopyCuda**(std::shared_ptr<T> ptr, bool ownsData = true)

template<typename **T**>

class **CudaRef**

#include <cudaStorage.hpp>

Public Types

using **PtrType** = std::shared_ptr<T>

Public Functions

inline **CudaRef**(const PtrType &ptr, size_t offset)

inline CudaRef &**operator=**(const T &val)

inline T **get**() const

template<typename **CAST**>
inline **operator CAST**() const

inline std::string **str**(const std::string &format = "{}") const

Private Members

std::shared_ptr<T> **m_ptr**

size_t **m_offset**

namespace **typetraits**

Functions

LIBRAPID_DEFINE_AS_TYPE(typename Scalar_, CudaStorage<Scalar_>)

template<typename **Scalar_**>

struct **TypeInfo**<CudaStorage<Scalar_>>

#include <cudaStorage.hpp>

Public Types

using **Scalar** = Scalar_

using **Backend** = backend::CUDA

Public Static Attributes

static constexpr bool **isLibRapidType** = true

template<typename **T**>

struct **IsCudaStorage** : public std::false_type

#include <cudaStorage.hpp>

template<typename **Scalar**>

struct **IsCudaStorage**<CudaStorage<Scalar>> : public std::true_type

#include <cudaStorage.hpp>

1.3.3 Vectors

LibRapid provides a highly optimised fixed-size vector library which supports all primitive types as well as user-defined ones (assuming they implement the required operations).

1.3.3.1 Vector Listing

> **Warning:** doxygenclass: Cannot find class "librapid::GenericVector" in doxygen xml output for project "librapid" from directory: ../xml

1.3.4 Complex Numbers

Documentation View the API and documentation for complex numbers.

Examples See some examples of LibRapid's complex number library in action

Implementation Details Learn about the implementation of complex numbers in LibRapid

1.3.4.1 Complex Number Listing

namespace **librapid**

Functions

template<typename **T**>
auto **operator-**(const Complex<*T*> &other) -> Complex<*T*>

Negate a complex number.

Template Parameters **T** – Scalar type of the complex number

Parameters **other** – *Complex* number to negate

Returns Negated complex number

template<typename **L**, typename **R**>
auto **operator+**(const Complex<*L*> &left, const Complex<*R*> &right)

Add two complex numbers.

Add two complex numbers together, returning the result

Template Parameters

- **L** – Scalar type of LHS
- **R** – Scalar type of RHS

Parameters

- **left** – LHS complex number
- **right** – RHS complex number

Returns Sum of LHS and RHS

template<typename **T**, typename **R**>
auto **operator+**(const Complex<*T*> &left, const *R* &right)

Add a complex number and a scalar.

Add a real number to the real component of a complex number, returning the result

Template Parameters

- **T** – Scalar type of the complex number
- **R** – Type of the real number

Parameters

- **left** – LHS complex number
- **right** – RHS scalar

Returns Sum of LHS and RHS

template<typename **R**, typename **T**>
auto **operator+**(const *R* &left, const Complex<*T*> &right)

Add a scalar to a complex number.

Add a real number to the real component of a complex number, returning the result

Template Parameters

- **R** – Type of the real number
- **T** – Scalar type of the complex number

Parameters

- **left** – LHS scalar
- **right** – RHS complex number

Returns Sum of LHS and RHS

template<typename **L**, typename **R**>
auto **operator-**(const Complex<*L*> &left, const Complex<*R*> &right)

Subtract a complex number from another complex number.

Subtract the real and imaginary components of the RHS complex number from the corresponding components of the LHS complex number, returning the result

Template Parameters

- **L** – Scalar type of the LHS complex number
- **R** – Scalar type of the RHS complex number

Parameters

- **left** – LHS complex number
- **right** – RHS complex number

Returns Difference of LHS and RHS

template<typename **T**, typename **R**>
auto **operator-**(const Complex<*T*> &left, const *R* &right)

Subtract a scalar from a complex number.

Subtract a real number from the real component of a complex number, returning the result

Template Parameters

- **T** – Scalar type of the complex number
- **R** – Type of the real number

Parameters

- **left** – LHS complex number
- **right** – RHS scalar

Returns Difference of LHS and RHS

template<typename **T**, typename **R**>
auto **operator-**(const *R* &left, const Complex<*T*> &right)

Subtract a complex number from a scalar.

Subtract the real and imaginary components of the RHS complex number from a real number, returning the result

Template Parameters

- **T** – Scalar type of the complex number
- **R** – Type of the real number

Parameters

- **left** – LHS scalar
- **right** – RHS complex number

Returns Difference of LHS and RHS

template<typename **L**, typename **R**>
auto **operator***(const Complex<*L*> &left, const Complex<*R*> &right)

Multiply two complex numbers.

Multiply the LHS and RHS complex numbers, returning the result

Template Parameters

- **L** – Scalar type of the LHS complex number
- **R** – Scalar type of the RHS complex number

Parameters

- **left** – LHS complex number
- **right** – RHS complex number

Returns Product of LHS and RHS

template<typename **T**, typename **R**>
auto **operator***(const Complex<*T*> &left, const *R* &right)

Multiply a complex number by a scalar.

Multiply the real and imaginary components of a complex number by a real number, returning the result

Template Parameters

- **T** – Scalar type of the complex number
- **R** – Type of the real number

Parameters

- **left** – LHS complex number
- **right** – RHS scalar

Returns Product of LHS and RHS

template<typename **T**, typename **R**>
auto **operator***(const *R* &left, const Complex<*T*> &right)

Multiply a scalar by a complex number.

Multiply a real number by the real and imaginary components of a complex number, returning the result

Template Parameters

- **T** – Scalar type of the complex number
- **R** – Type of the real number

Parameters

- **left** – LHS scalar
- **right** – RHS complex number

Returns Product of LHS and RHS

template<typename **L**, typename **R**>

auto **operator/**(const Complex<*L*> &left, const Complex<*R*> &right)

Divide two complex numbers.

Divide the LHS complex number by the RHS complex number, returning the result

Template Parameters

- **L** – Scalar type of the LHS complex number
- **R** – Scalar type of the RHS complex number

Parameters

- **left** – LHS complex number
- **right** – RHS complex number

Returns Quotient of LHS and RHS

template<typename **T**, typename **R**>
auto **operator/**(const Complex<*T*> &left, const *R* &right)

Divide a complex number by a scalar.

Divide the real and imaginary components of a complex number by a real number, returning the result

Template Parameters

- **T** – Scalar type of the complex number
- **R** – Type of the real number

Parameters

- **left** – LHS complex number
- **right** – RHS scalar

Returns Quotient of LHS and RHS

template<typename **T**, typename **R**>
auto **operator/**(const *R* &left, const Complex<*T*> &right)

Divide a scalar by a complex number.

Divide a real number by the real and imaginary components of a complex number, returning the result

Template Parameters

- **T** – Scalar type of the complex number
- **R** – Type of the real number

Parameters

- **left** – LHS scalar
- **right** – RHS complex number

Returns Quotient of LHS and RHS

template<typename **L**, typename **R**>
constexpr bool **operator==**(const Complex<L> &left, const Complex<R> &right)

Equality comparison of two complex numbers.

Template Parameters

- **L** – Scalar type of LHS complex number
- **R** – Scalar type of RHS complex number

Parameters

- **left** – LHS complex number
- **right** – RHS complex number

Returns true if equal, false otherwise

template<typename **T**>
constexpr bool **operator==**(const Complex<T> &left, T &right)

Equality comparison of complex number and scalar.

Compares the real component of the complex number to the scalar, and the imaginary component to zero. Returns true if and only if both comparisons are true.

Template Parameters **T** – Scalar type of complex number

Parameters

- **left** – LHS complex number
- **right** – RHS scalar

Returns true if equal, false otherwise

template<typename **T**>
constexpr bool **operator==**(const T &left, const Complex<T> &right)

Equality comparison of scalar and complex number.

Compares the real component of the complex number to the scalar, and the imaginary component to zero. Returns true if and only if both comparisons are true.

Template Parameters **T** – Scalar type of complex number

Parameters

- **left** – LHS scalar
- **right** – RHS complex number

Returns true if equal, false otherwise

template<typename **T**>
constexpr bool **operator!=**(const Complex<T> &left, const Complex<T> &right)

Inequality comparison of two complex numbers.

Template Parameters **T** – Scalar type of complex number

Parameters

- **left** – LHS complex number
- **right** – RHS complex number

Returns true if equal, false otherwise

template<typename **T**>
constexpr bool **operator!=**(const Complex<T> &left, T &right)

Inequality comparison of complex number and scalar.

See also:

operator==(const Complex<T> &, T &)

Template Parameters **T** – Scalar type of complex number

Parameters

- **left** – LHS complex number
- **right** – RHS scalar

Returns true if equal, false otherwise

template<typename **T**>
constexpr bool **operator!=**(const T &left, const Complex<T> &right)

Inequality comparison of scalar and complex number.

See also:

operator==(const T &, const Complex<T> &)

Template Parameters T – Scalar type of complex number

Parameters

- **left** – LHS scalar
- **right** – RHS complex number

Returns true if equal, false otherwise

template<typename **T**>
T **real**(const Complex<T> &val)

Return $\mathrm{Re}(z)$.

Template Parameters T – Scalar type of the complex number

Parameters val – *Complex* number

Returns Real component of the complex number

template<typename **T**>
T **imag**(const Complex<T> &val)

Return $\mathrm{Im}(z)$.

Template Parameters T – Scalar type of the complex number

Parameters val – *Complex* number

Returns Imaginary component of the complex number

template<typename **T**>
Complex<T> **sqrt**(const Complex<T> &val)

Return $\sqrt{z}$.

Template Parameters T – Scalar type of the complex number

Parameters val – *Complex* number

Returns Square root of the complex number

template<typename **T**>
T **abs**(const Complex<T> &val)

Return $\sqrt{\mathrm{Re}(z)^2 + \mathrm{Im}(z)^2}$.

Template Parameters T – Scalar type of the complex number

Parameters val – *Complex* number

Returns Absolute value of the complex number

template<typename **T**>
Complex<T> **conj**(const Complex<T> &val)

Returns z^*.

Template Parameters **T** – Scalar type of the complex number

Parameters **val** – *Complex* number

Returns *Complex* conjugate of the complex number

template<typename **T**>
Complex<T> **acos**(const Complex<T> &other)

Compute the complex arc cosine of a complex number.

This function computes the complex arc cosine of the input complex number, $z = \text{acos}(z)$

The algorithm handles NaN and infinity values, and avoids overflow.

Template Parameters **T** – Scalar type of the complex number

Parameters **other** – Input complex number

Returns *Complex* arc cosine of the input complex number

template<typename **T**>
Complex<T> **acosh**(const Complex<T> &other)

Compute the complex hyperbolic arc cosine of a complex number.

This function computes the complex area hyperbolic cosine of the input complex number, $z = \text{acosh}(z)$

The algorithm handles NaN and infinity values, and avoids overflow.

Template Parameters **T** – Scalar type of the complex number

Parameters **other** – Input complex number

Returns *Complex* area hyperbolic cosine of the input complex number

template<typename **T**>
Complex<T> **asinh**(const Complex<T> &other)

Compute the complex arc hyperbolic sine of a complex number.

This function computes the complex arc hyperbolic sine of the input complex number, $z = \text{asinh}(z)$

The algorithm handles NaN and infinity values, and avoids overflow.

Template Parameters **T** – Scalar type of the complex number

Parameters **other** – Input complex number

Returns *Complex* arc hyperbolic sine of the input complex number

template<typename **T**>
Complex<T> **asin**(const Complex<T> &other)

Compute the complex arc sine of a complex number.

This function computes the complex arc sine of the input complex number, $z = \text{asin}(z)$

It calculates the complex arc sine by using the complex hyperbolic sine function.

See also:

asinh

Template Parameters **T** – Scalar type of the complex number

Parameters **other** – Input complex number

Returns *Complex* arc sine of the input complex number

template<typename **T**>
Complex<T> **atanh**(const Complex<T> &other)

Compute the complex arc hyperbolic tangent of a complex number.

This function computes the complex arc hyperbolic tangent of the input complex number, $z = \text{atanh}(z)$

This function performs error checking and supports NaNs and Infs.

Template Parameters **T** – Scalar type of the complex number

Parameters **other** – Input complex number

Returns *Complex* arc hyperbolic tangent of the input complex number

template<typename **T**>
Complex<T> **atan**(const Complex<T> &other)

Compute the complex arc tangent of a complex number.

This function computes the complex arc tangent of the input complex number, $z = \text{atan}(z)$

The algorithm handles NaN and infinity values, and avoids overflow.

Template Parameters **T** – Scalar type of the complex number

Parameters **other** – Input complex number

Returns *Complex* arc tangent of the input complex number

template<typename **T**>
Complex<T> **cosh**(const Complex<T> &other)

Compute the complex hyperbolic cosine of a complex number.

This function computes the complex hyperbolic cosine of the input complex number, $z = \cosh(z)$

Template Parameters **T** – Scalar type of the complex number

Parameters **other** – Input complex number

Returns *Complex* hyperbolic cosine of the input complex number

template<typename **T**>
Complex<T> **polarPositiveNanInfZeroRho**(const T &rho, const T &theta)

template<typename **T**>
Complex<T> **exp**(const Complex<T> &other)

Compute the complex exponential of a complex number.

This function computes the complex exponential of the input complex number, $z = e^z$

The algorithm handles NaN and infinity values.

Template Parameters **T** – Scalar type of the complex number

Parameters **other** – Input complex number

Returns *Complex* exponential of the input complex number

template<typename **T**>

Complex<T> **exp2**(const Complex<T> &other)

Compute the complex exponential base 2 of a complex number.

See also:

exp

Template Parameters **T** – Scalar type of the complex number

Parameters **other** – Input complex number

Returns *Complex* exponential base 2 of the input complex number

template<typename **T**>
Complex<T> **exp10**(const Complex<T> &other)

Compute the complex exponential base 10 of a complex number.

See also:

exp

Template Parameters **T** – Scalar type of the complex number

Parameters **other** – Input complex number

Returns *Complex* exponential base 10 of the input complex number

template<typename **T**>
T **_fabs**(const Complex<T> &other, int64_t *exp)

template<typename **T**>
T **_logAbs**(const Complex<T> &other) noexcept

template<>
mpfr **_logAbs**(const Complex<mpfr> &other) noexcept

template<>
float **_logAbs**(const Complex<float> &other) noexcept

template<typename **T**>
Complex<T> **log**(const Complex<T> &other)

Calculates the natural logarithm of a complex number.

Template Parameters **T** – Scalar type

Parameters **other** – *Complex* number

Returns Natural logarithm of the complex number

template<typename **T**, typename **B**>
Complex<T> **log**(const Complex<T> &other, const Complex<T> &base)

Calculates the logarithm of a complex number with a complex base.

$\log_{\text{base}}(z) = \log(z)/\log(\text{base})$

See also:

log

Template Parameters

- **T** – Scalar type
- **B** – Base type

Parameters

- **other** – *Complex* number
- **base** – Base of the logarithm

Returns Logarithm of the complex number with the given base

template<typename **T**, typename **B**>
Complex<T> **log**(const Complex<T> &other, const B &base)

Calculates the logarithm of a complex number with a real base.

$\log_{\text{base}}(z) = \log(z)/\log(\text{base})$

See also:

log

Template Parameters

- **T** – Scalar type of the complex number
- **B** – Scalar type of the base

Parameters

- **other** – *Complex* number
- **base** – Base of the logarithm (real)

Returns Logarithm of the complex number with the given base

template<typename **T**>
Complex<T> **_pow**(const T &left, const T &right)

template<typename **T**, typename **V**, typename std::enable_if_t<*typetraits*::TypeInfo<V>::type == detail::LibRapidType::Scalar, int> = 0>
Complex<T> **pow**(const Complex<T> &left, const V &right)

Calculate $\text{left}^{\text{right}}$ for a complex-valued left-hand side.

Template Parameters

- **T** – Value type for the left-hand side
- **V** – Value type for the right-hand side

Parameters

- **left** – *Complex* base
- **right** – Real exponent

Returns $\text{left}^{\text{right}}$

template<typename **T**, typename **V**, typename std::enable_if_t<*typetraits*::TypeInfo<V>::type == detail::LibRapidType::Scalar, int> = 0>

Complex<T> **pow**(const V &left, const Complex<T> &right)

Calculate $\text{left}^{\text{right}}$ for a complex-valued right-hand side.

Template Parameters

- **T** – Value type for the left-hand side
- **V** – Value type for the right-hand side

Parameters

- **left** – Real base
- **right** – *Complex* exponent

Returns $\text{left}^{\text{right}}$

template<typename **T**>
Complex<T> **pow**(const Complex<T> &left, const Complex<T> &right)

Calculate $\text{left}^{\text{right}}$ for complex numbers.

Template Parameters **T** – *Complex* number component type

Parameters

- **left** – *Complex* base
- **right** – *Complex* exponent

Returns $\text{left}^{\text{right}}$

template<typename **T**>
Complex<T> **sinh**(const Complex<T> &other)

Calculate the hyperbolic sine of a complex number.

Template Parameters **T** – Scalar type

Parameters **other** – *Complex* number

Returns $\sinh(z)$

template<typename **T**>
Complex<T> **tanh**(const Complex<T> &other)

Calculate the hyperbolic tangent of a complex number.

This function supports propagation of NaNs and Infs.

Template Parameters **T** – Scalar type

Parameters **other** – *Complex* number

Returns $\tanh(z)$

template<typename **T**>
T **arg**(const Complex<T> &other)

Return the phase angle of a complex value as a real.

This function calls $\text{atan2}(\text{imag}(z), \text{real}(z))$.

See also:

atan2

Template Parameters **T** – Scalar type

Parameters **other** – *Complex* number

Returns $\arg(z)$

template<typename **T**>
Complex<T> **proj**(const Complex<T> &other)

Project a complex number onto the Riemann sphere.

Template Parameters **T** – Scalar type

Parameters **other** – *Complex* number

Returns $\text{proj}(z)$

template<typename **T**>
Complex<T> **cos**(const Complex<T> &other)

Calculate the cosine of a complex number.

Template Parameters **T** – Scalar type

Parameters **other** – *Complex* number

Returns $\cos(z)$

template<typename **T**>
Complex<T> **csc**(const Complex<T> &other)

Calculate the cosecant of a complex number.

Template Parameters **T** – Scalar type

Parameters **other** – *Complex* number

Returns $\csc(z)$

template<typename **T**>
Complex<T> **sec**(const Complex<T> &other)

Calculate the secant of a complex number.

Template Parameters **T** – Scalar type

Parameters **other** – *Complex* number

Returns $\sec(z)$

template<typename **T**>
Complex<T> **cot**(const Complex<T> &other)

Calculate the cotangent of a complex number.

Template Parameters **T** – Scalar type

Parameters **other** – *Complex* number

Returns $\cot(z)$

template<typename **T**>
Complex<T> **acsc**(const Complex<T> &other)

Calculate the arc cosecant of a complex number.

Template Parameters **T** – Scalar type

Parameters **other** – *Complex* number

Returns $\text{arccsc}(z)$

template<typename **T**>

Complex<T> **asec**(const Complex<T> &other)

Calculate the arc secant of a complex number.

Template Parameters **T** – Scalar type

Parameters **other** – *Complex* number

Returns $\mathrm{arcsec}(z)$

template<typename **T**>
Complex<T> **acot**(const Complex<T> &other)

Calculate the arc cotangent of a complex number.

Template Parameters **T** – Scalar type

Parameters **other** – *Complex* number

Returns $\mathrm{arccot}(z)$

template<typename **T**>
Complex<T> **log2**(const Complex<T> &other)

Calculate the logarithm base 2 of a complex number.

Template Parameters **T** – Scalar type

Parameters **other** – *Complex* number

Returns $\log_2(z)$

template<typename **T**>
Complex<T> **log10**(const Complex<T> &other)

Calculate the logarithm base 10 of a complex number.

Template Parameters **T** – Scalar type

Parameters **other** – *Complex* number

Returns $\log_{10}(z)$

template<typename **T**>
T **norm**(const Complex<T> &other)

Calculate the magnitude squared of a complex number.

Template Parameters **T** – Scalar type

Parameters **other** – *Complex* number

Returns $|z|^2$

template<typename **T**>
Complex<T> **polar**(const T &rho, const T &theta)

Return a complex number from polar coordinates.

Given a radius, `rho`, and an angle, `theta`, this function returns the complex number $\rho e^{i\theta}$.

The function returns NaN, infinity or zero based on the input values of rho.

Template Parameters **T** – Scalar type of the complex number

Parameters

- **rho** – Radius of the polar coordinate system
- **theta** – Angle of the polar coordinate system

Returns *Complex* number in polar form.

template<typename **T**>
Complex<T> **sin**(const Complex<T> &other)

Compute the sine of a complex number.

Template Parameters **T** – Scalar type

Parameters **other** – *Complex* number

Returns $\sin(z)$

template<typename **T**>
Complex<T> **tan**(const Complex<T> &other)

Compute the tangent of a complex number.

Template Parameters **T** – Scalar type

Parameters **other** – *Complex* number

Returns $\tan(z)$

template<typename **T**>
Complex<T> **floor**(const Complex<T> &other)

Round the real and imaginary parts of a complex number towards $-\infty$.

Template Parameters **T** – Scalar type

Parameters **other** – *Complex* number

Returns $(\lfloor \mathrm{real}(z) \rfloor, \lfloor \mathrm{imag}(z) \rfloor)$

template<typename **T**>
Complex<T> **ceil**(const Complex<T> &other)

Round the real and imaginary parts of a complex number towards $+\infty$.

Template Parameters **T** – Scalar type

Parameters **other** – *Complex* number

Returns $(\lceil \mathrm{real}(z) \rceil, \lceil \mathrm{imag}(z) \rceil)$

template<typename **T**>
auto **random**(const Complex<T> &min, const Complex<T> &max, uint64_t seed = -1) -> Complex<T>

Generate a random complex number between two given complex numbers.

This function generates a random complex number in the range [min, max], where min and max are given as input. The function uses a default seed if none is provided.

Template Parameters **T** – Scalar type of the complex number

Parameters

- **min** – Minimum complex number
- **max** – Maximum complex number
- **seed** – Seed for the random number generator

Returns Random complex number between min and max

template<typename **T** = double>

class **Complex**

#include <complex.hpp> A class representing a complex number of the form $a + bi$, where a and b are real numbers.

This class represents a complex number of the form $a + bi$, where a and b are real numbers. The class is templated, allowing the user to specify the type of the real and imaginary components. The default type is `double`.

Template Parameters **T** – The type of the real and imaginary components

Public Types

using **Scalar** = typename *typetraits*::TypeInfo<T>::Scalar

Public Functions

inline **Complex**()

Default constructor.

Create a new complex number. Both the real and imaginary components are set to zero

template<typename **R**>
inline explicit **Complex**(const R &realVal)

Construct a complex number from a real number.

Create a complex number, setting only the real component. The imaginary component is initialized to zero

Template Parameters **R** – The type of the real component
Parameters **realVal** – The real component

template<typename **R**, typename **I**>
inline **Complex**(const R &realVal, const I &imagVal)

Construct a complex number from real and imaginary components.

Create a new complex number where both the real and imaginary parts are set from the passed parameters

Template Parameters
- **R** – The type of the real component
- **I** – The type of the imaginary component

Parameters
- **realVal** – The real component
- **imagVal** – The imaginary component

inline **Complex**(const Complex<T> &other)

Complex number copy constructor.

Parameters **other** – The complex number to copy

inline **Complex**(Complex<T> &&other) noexcept

Complex number move constructor.

Parameters **other** – The complex number to move

template<typename **Other**>
inline **Complex**(const Complex<Other> &other)

Construct a complex number from another complex number with a different type.

Template Parameters **Other** – Type of the components of the other complex number
Parameters **other** – The complex number to copy

inline explicit **Complex**(const std::complex<T> &other)

Construct a complex number from a std::complex.

Parameters **other** – The std::complex value to copy

inline auto **operator=**(const Complex<T> &other) -> Complex<T>&

Complex number assignment operator.

Parameters **other** – The value to assign

Returns *this

template<typename **P**>
inline void **store**(P *ptr) const

template<typename **P**>
inline void **load**(const P *ptr)

inline void **real**(const T &val)

Assign to the real component.

Set the real component of this complex number to `val`

Parameters **val** – The value to assign

inline void **imag**(const T &val)

Assign to the imaginary component.

Set the imaginary component of this complex number to `val`

Parameters **val** – The value to assign

inline auto **real**() const -> const T&

Access the real component.

Returns a const reference to the real component of this complex number

Returns Real component

inline auto **imag**() const -> const T&

Access the imaginary component.

Returns a const reference to the imaginary component of this complex number

Returns Imaginary component

inline auto **real**() -> T&

Access the real component.

Returns a reference to the real component of this complex number. Since this is a reference type, it can be assigned to

Returns Real component

inline auto **imag**() -> T&

Access the imaginary component.

Returns a reference to the imaginary component of this complex number. Since this is a reference type, it can be assigned to

Returns imaginary component

inline auto **operator=**(const T &other) -> Complex&

Complex number assigment operator.

Set the real component of this complex number to `other`, and the imaginary component to 0

Parameters **other** –

Returns *this

template<typename **Other**>

inline auto **operator=**(const Complex<Other> &other) -> Complex&

Complex number assigment operator.

Assign another complex number to this one, copying the real and imaginary components

Template Parameters **Other** – The type of the other complex number

Parameters **other** – *Complex* number to assign

Returns *this

inline auto **operator+=**(const T &other) -> Complex&

Inplace addition.

Add a scalar value to the real component of this imaginary number

Parameters **other** – Scalar value to add

Returns *this

inline auto **operator-=**(const T &other) -> Complex&

Inplace subtraction.

Subtract a scalar value from the real component of this imaginary number

Parameters **other** – Scalar value to subtract

Returns *this

inline auto **operator*=**(const T &other) -> Complex&

Inplace multiplication.

Multiply both the real and imaginary components of this complex number by a scalar

Parameters **other** – Scalar value to multiply by

Returns *this

inline auto **operator/=**(const T &other) -> Complex&

Inplace division.

Divide both the real and imaginary components of this complex number by a scalar

Parameters **other** – Scalar value to divide by

Returns *this

inline auto **operator+=**(const Complex &other) -> Complex&

Inplace addition.

Add a complex number to this one

Parameters **other** – *Complex* number to add

Returns *this

inline auto **operator-=**(const Complex &other) -> Complex&

Inplace subtraction.

Subtract a complex number from this one

Parameters **other** – *Complex* number to subtract

Returns *this

inline auto **operator*=**(const Complex &other) -> Complex&

Inplace multiplication.

Multiply this complex number by another one

Parameters **other** – *Complex* number to multiply by

Returns *this

inline auto **operator/=**(const Complex &other) -> Complex&

Inplace division.

Divide this complex number by another one

Parameters **other** – *Complex* number to divide by
Returns *this

template<typename **To**>
inline explicit **operator To**() const

Cast to scalar types.

Cast this complex number to a scalar type. This will extract only the real component.
Template Parameters **To** – Type to cast to
Returns Scalar

template<typename **To**>
inline explicit **operator Complex<To>**() const

Cast to a complex number with a different scalar type.

Cast the real and imaginary components of this complex number to a different type and return the result as a new complex number
Template Parameters **To** – Scalar type to cast to
Returns *Complex* number

inline auto **str**(const std::string &format = "{}") const -> std::string

Complex number to string.

Create a std::string representation of a complex number, formatting each component with the format string
Parameters **format** – Format string
Returns std::string

Public Static Functions

static inline constexpr auto **size**() -> size_t

Protected Functions

template<typename **Other**>
inline void **_add**(const Complex<Other> &other)

Add a complex number to this one.
Template Parameters **Other** – Scalar type of the other complex number
Parameters **other** – Other complex number

template<typename **Other**>
inline void **_sub**(const Complex<Other> &other)

Subtract a complex number from this one.
Template Parameters **Other** – Scalar type of the other complex number
Parameters **other** – Other complex number

template<typename **Other**>
inline void **_mul**(const Complex<Other> &other)

Multiply this complex number by another one.
Template Parameters **Other** – Scalar type of the other complex number
Parameters **other** – Other complex number

template<typename **Other**>

inline void **_div**(const Complex<Other> &other)

Divide this complex number by another one.

Template Parameters **Other** – Scalar type of the other complex number

Parameters **other** – Other complex number

Private Members

T **m_val**[2]

Private Static Attributes

static constexpr size_t **RE** = 0

static constexpr size_t **IM** = 1

namespace **detail**

namespace **algorithm**

Functions

template<typename **T**>
auto **normMinusOne**(const T x, const T y) noexcept -> T

Calculates $x^2 + y^2 - 1$ for $|x| \geq |y|$ and $0.5 \leq |x| < 2^{12}$.

Template Parameters **T** – Template type

Parameters

- **x** – First value
- **y** – Second value

Returns x * x + y * y - 1

template<bool **safe** = true, typename **T**>
auto **logP1**(const T x) -> T

Calculates $\log(1 + x)$.

May be inaccurate for small inputs

Template Parameters

- **safe** – If true, will check for NaNs and overflow
- **T** – Template type

Parameters **x** – Input value

Returns $\log(1 + x)$

template<bool **safe** = true, typename **T**>
auto **logHypot**(const T x, const T y) noexcept -> T

Calculates $\log(\sqrt{x^2 + y^2})$.

Template Parameters

- **safe** – If true, will check for NaNs and overflow
- **T** – Template type

Parameters

- **x** – Horizontal component

- **y** – Vertical component

Returns $\log(\sqrt{x^2 + y^2})$

template<typename **T**>
auto **expMul**(T *pleft, T right, short exponent) -> short

Compute $e^{\text{pleft}} \times \text{right} \times 2^{\text{exponent}}$.

Template Parameters **T** – Template type

Parameters

- **pleft** – Pointer to the value to be exponentiated
- **right** – Multiplier for the exponentiated value
- **exponent** – Exponent for the power of 2 multiplication

Returns 1 if the result is NaN or Inf, -1 otherwise

Variables

template<typename **T**>

static T **HypotLegHuge** = HypotLegHugeHelper<T>::val

template<typename **T**>

static T **HypotLegTiny** = HypotLegTinyHelper<T>::val

template<typename **T**>

struct **HypotLegHugeHelper**

#include <complex.hpp>

Public Static Attributes

```
static T val  =(std::is_integral_v<T>)?
(::librapid::sqrt(typetraits::TypeInfo<T>::max()) / T(2)): (T(0.
5) * ::librapid::sqrt(typetraits::TypeInfo<T>::max()))
```

template<>

struct **HypotLegHugeHelper**<double>

#include <complex.hpp>

Public Static Attributes

static constexpr double **val** = 6.703903964971298e+153

template<>

struct **HypotLegHugeHelper**<float>

#include <complex.hpp>

Public Static Attributes

static constexpr double **val** = 9.2233715e+18f

template<typename **T**>

struct **HypotLegTinyHelper**

#include <complex.hpp>

Public Static Attributes

static T **val** = ::librapid::sqrt(T(2) * *typetraits*::TypeInfo<T>::min() / *typetraits*::TypeInfo<T>::epsilon())

template<>

struct **HypotLegTinyHelper**<double>

#include <complex.hpp>

Public Static Attributes

static constexpr double **val** = 1.4156865331029228e-146

template<>

struct **HypotLegTinyHelper**<float>

#include <complex.hpp>

Public Static Attributes

static constexpr double **val** = 4.440892e-16f

namespace **multiprec**

Functions

template<typename **T**>
constexpr auto **addX2**(const T &x, const T &y) noexcept -> Fmp<T>

Summarizes two 1x precision values combined into a 2x precision result.

This function is exact when:

I. The result doesn't overflow
II. Either underflow is gradual, or no internal underflow occurs
III. Intermediate precision is either the same as T, or greater than twice the precision of T
IV. Parameters and local variables do not retain extra intermediate precision
V. Rounding mode is rounding to nearest.

Violation of condition 3 or 5 could lead to relative error on the order of epsilon^2.

Violation of other conditions could lead to worse results

Template Parameters `T` – Template type

Parameters

- **x** – First value
- **y** – Second value

Returns Sum of x and y

template<typename **T**>
constexpr auto **addSmallX2**(const T x, const T y) noexcept -> Fmp<T>

Combines two 1x precision values into a 2x precision result with the requirement of specific exponent relationship.

Requires: exponent(x) + countr_zero(significand(x)) >= exponent(y) or x == 0

The result is exact when:

I. The requirement above is satisfied
II. No internal overflow occurs
III. Either underflow is gradual, or no internal underflow occurs
IV. Intermediate precision is either the same as T, or greater than twice the precision of T
V. Parameters and local variables do not retain extra intermediate precision
VI. Rounding mode is rounding to nearest

Violation of condition 3 or 5 could lead to relative error on the order of epsilon^2.

Violation of other conditions could lead to worse results

Template Parameters `T` – Template type

Parameters

- **x** – First value
- **y** – Second value

Returns Sum of x and y

template<typename **T**>
constexpr auto **addSmallX2**(const T &x, const Fmp<T> &y) noexcept -> Fmp<T>

Combines a 1x precision value with a 2x precision value.

Requires: exponent(x) + countr_zero(significand(x)) >= exponent(y.val0) or x == 0

Template Parameters `T` – Template type

Parameters

- **x** – First value
- **y** – Second value

Returns Sum of x and y

template<typename **T**>
constexpr auto **addX1**(const Fmp<T> &x, const Fmp<T> &y) noexcept -> T

Combines two 2x precision values into a 1x precision result.

Template Parameters `T` – Template type

Parameters

- **x** – First value
- **y** – Second value

Returns Sum of x and y

constexpr auto **highHalf**(const double x) noexcept -> double

Rounds a 2x precision value to 26 significant bits.

Parameters **x** – Value to round

Returns Rounded value

constexpr double **sqrError**(const double x, const double prod0) noexcept

Fallback method for *sqrError(const double, const double)* when SIMD is not available.

template<typename **T**>

auto **sqrError**(const T x, const T prod0) noexcept -> T

Type-agnostic version of *sqrError(const double, const double)*

Template Parameters T – Template type

Parameters

- **x** – Input value
- **prod0** – Faithfully rounded product of x^2

auto **sqrX2**(const double x) noexcept -> Fmp<double>

Calculates the square of a 1x precision value and returns a 2x precision result.

The result is exact when no internal overflow or underflow occurs.

Parameters x – Input value

Returns 2x precision square of x

template<typename **T**>
auto **sqrX2**(const T x) noexcept -> Fmp<T>

Type-agnostic version of *sqrX2(const double)*

Template Parameters T – Template type

Parameters x – Input value

Returns 2x precision square of x

template<typename **Scalar**>

struct **Fmp**

#include <complex.hpp>

Public Members

Scalar **val0**

Scalar **val1**

namespace **typetraits**

template<typename **T**>

struct **TypeInfo**<Complex<T>>

#include <complex.hpp>

Public Types

using **Scalar** = Complex<T>

using **Packet** = typename std::conditional_t<(TypeInfo<T>::packetWidth > 1), Complex<typename TypeInfo<T>::Packet>, std::false_type>

Public Functions

inline **LIMIT_IMPL**(min)

inline **LIMIT_IMPL**(max)

inline **LIMIT_IMPL**(epsilon)

inline **LIMIT_IMPL**(roundError)

inline **LIMIT_IMPL**(denormMin)

inline **LIMIT_IMPL**(infinity)

inline **LIMIT_IMPL**(quietNaN)

inline **LIMIT_IMPL**(signalingNaN)

Public Static Attributes

static constexpr detail::LibRapidType **type** = detail::LibRapidType::Scalar

static constexpr int64_t **packetWidth** = TypeInfo<typename TypeInfo<T>::Scalar>::packetWidth

static constexpr char **name**[] = "Complex"

static constexpr bool **supportsArithmetic** = true

static constexpr bool **supportsLogical** = true

static constexpr bool **supportsBinary** = false

static constexpr bool **allowVectorisation** = false

static constexpr cudaDataType_t **CudaType** = cudaDataType_t::CUDA_C_64F

static constexpr bool **canAlign** = TypeInfo<T>::canAlign

static constexpr bool **canMemcpy** = TypeInfo<T>::canMemcpy

1.3.4.2 Complex Number Examples

To do

1.3.4.3 Complex Number Implementation Details

To do

1.3.5 Mathematics

1.3.6 Multi-Precision Arithmetic

LibRapid has support for MPIR and MPFR, which support arbitrary-precision integers, floating points and rationals.

We provide a simple wrapper around these libraries, enabling all mathematical operations to be performed on these data types – you don't even need to use a different function name!

1.3.6.1 Multi-Precision Listing

Warning: doxygenclass: Cannot find class "librapid::mpz" in doxygen xml output for project "librapid" from directory: ../xml

---

Warning: doxygenclass: Cannot find class "librapid::mpq" in doxygen xml output for project "librapid" from directory: ../xml

---

Warning: doxygenclass: Cannot find class "librapid::mpf" in doxygen xml output for project "librapid" from directory: ../xml

---

Warning: doxygenclass: Cannot find class "librapid::mpfr" in doxygen xml output for project "librapid" from directory: ../xml

1.4 Tutorials

1.5 Performance and Benchmarks

LibRapid is high-performance library and is fast by default, but there are still ways to make your code even faster.

1.5.1 Lazy Evaluation

Operations performed on Arrays are evaluated only when needed, meaning functions can be chained together and evaluated in one go. In many cases, the compiler can optimise these chained calls into a single loop, resulting in much faster code.

Look at the example below:

```
lrc::Array<float> A, B, C, D:
A = lrc::fromData({{1, 2}, {3, 4}});
B = lrc::fromData({{5, 6}, {7, 8}});
C = lrc::fromData({{9, 10}, {11, 12}});
D = A + B * C;
```

Without lazy-evaluation, the operation A+B*C must be performed in multiple stages:

```
auto tmp1 = B * C;    // First operation and temporary object
auto tmp2 = A + tmp1; // Second operation and ANOTHER temporary object
D = tmp2;             // Unnecessary copy
```

This is clearly suboptimal.

With lazy-evaluation, however, the compiler can generate a loop similar to the pseudocode below:

```
FOR index IN A.size DO
    D[i] = A[i] + B[i] * C[i]
ENDFOR
```

This has no unnecessary copies, no temporary variables, no additional memory allocation, etc. and is substantially quicker.

1.5.1.1 Making Use of LibRapid's Lazy Evaluation

To make use of LibRapid's lazy evaluation, try to avoid creating temporary objects and always assign results directly to an existing array object, instead of creating a new one. This means no heap allocations are performed, which is a very costly operation.

> **Warning:** Be very careful not to reference invalid memory. This is, unfortunately, an unavoidable side effect of returning lazy-objects. See *Caution* for more information.

Note that, sometimes, it is faster to evaluate intermediate results than to use the combined operation. To do this, you can call `eval()` on the result of any operation to generate an Array object directly from it.

1.5.2 Linear Algebra

Linear algebra methods in LibRapid also return temporary objects, meaning they are not evaluated fully until they are needed. One implication of this is that expressions involving ***more than one operation*** will be evaluated ***very slowly***.

> **Danger:** Be careful when calling `eval` on the result of a linear algebra operation. Sometimes, LibRapid will be able to combine multiple operations into a single function call, which can lead to much better performance. Check the documentation for that specific function to see what further optimisations it supports.

1.5.2.1 Solution

To get around this issue, it'll often be quicker to simply evaluate (myExpression.eval()) the result of any linear algebra operations inside the larger expression.

```
auto slowExpression = a + b * c.dot(d);
auto fastExpression = a + b * c.dot(d).eval();
```

1.5.2.2 Explanation

Since c.dot(d) is a lazy object, the lazy evaluator will calculate each element of the resulting array independently as and when it is required by the rest of the expression. This means it is not possible to make use of the extremely fast BLAS and LAPACK functions.

By forcing the result to be evaluated independently of the rest of the expression, LibRapid can call gemm, for example, making the program significantly faster.

1.6 Caution

Warning: LibRapid developers had to make certain decisions regarding the underlying data layout used by the library. We made these decisions with the best interests of the library in mind, and while they may improve performance or usability, they may also incur adverse side effects.

While the developers of LibRapid may not be aware of all the side effects of their design choices, we have done our best to identify and justify those we know of.

1.6.1 Array Referencing Issues

LibRapid uses lazy evaluation to reduce the number of intermediate variables and copies required for any given operation, significantly improving performance. A side effect of this is that combined operations store references to Array objects.

As a result, if any of the referenced Array instances go out of scope before the lazy object is evaluated, an invalid memory location will be accessed, incurring a segmentation fault.

The easiest fix for this is to make sure you evaluate temporary results in time, though this is easier said than done. LibRapid aims to identify when a lazy object is using an invalid value and notify the user, but this will not work in all cases.

The code below will cause a segmentation fault since testArray will go out of scope upon returning from the function while the returned object contains two references to the array.

```
/* References invalid memory
vvvv */
auto doesThisBreak() {
    lrc::Array<float> testArray(lrc::Shape({3, 3}));
    testArray << 1, 2, 3, 4, 5, 6, 7, 8, 9;
    return testArray + testArray;
}
```

```
/*    Changed
-------vvv------- */
lrc::Array<float> doesThisBreak() {
    lrc::Array<float> testArray(lrc::Shape({3, 3}));
    testArray << 1, 2, 3, 4, 5, 6, 7, 8, 9;
    return testArray + testArray;
}
```

CHAPTER

TWO

WHY USE LIBRAPID?

LibRapid aims to provide a cohesive ecosystem of functions that interoperate with each other, allowing for faster development and faster code execution.

For example, LibRapid implements a wide range of mathematical functions which can operate on primitive types, multi-precision types, vectors, and arrays. Due to the way these functions are implemented, a single function call can be used to operate on all of these types, reducing code duplication.

2.1 A Small Example

To prove the point made above, let's take a look at a simple example. Here, we have a function that maps a value from one range to another:

```
// Standard "double" implementation
double map(double val, double start1, double stop1, double start2, double stop2) {
    return start2 + (stop2 - start2) * ((val - start1) / (stop1 - start1));
}

// map(0.5, 0, 1, 0, 10) = 5
// map(10, 0, 100, 0, 1) = 0.1
// map(5, 0, 10, 0, 100) = 50
```

This function will accept integers, floats and doubles, but nothing else can be used, limiting its functionality.

Of course, this could be templated to accept other types, but if you passed a `std::vector<double>` to this function, for example, you'd have to create an edge case to support it. **This is where LibRapid comes in.**

Look at the function below:

```
// An extremely versatile mapping function (used within LibRapid!)
template<typename V, typename B1, typename E1, typename B2, typename E2>
V map(V val, B1 start1, E1 stop1, B2 start2, E2 stop2) {
    return start2 + (stop2 - start2) * ((val - start1) / (stop1 - start1));
}
```

This may look excessively complicated with that many template parameters, but you don't actually need all of those! This just gives the greatest flexibility. This function can be called with **almost any LibRapid type!**.

```
map(0.5, 0, 1, 0, 100); //  . . . . . . . . . . . . . . . . . | 50
map(lrc::Vec2d(0.2, 0.8), 0, 1, 0, 100); // . . . . . . . . . | (20, 80)
map(0.5, 0, 1, 0, lrc::Vec2d(100, 200)); // . . . . . . . . . | (50, 100)
map(lrc::Vec2d(-1, -2), 1, 0, lrc::Vec2d(100, 300)); // . | (75, 250)
```

(continues on next page)

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```cpp

// -----------------------------------------------------------------------

using namespace lrc::literals; // To use "_f" suffix
                               // (also requires multiprecision to be enabled)
// "0.5"_f in this case creates a multiprecision float :)
map("0.5"_f, "0"_f, "1"_f, "0"_f, "100"_f); //  . . . . . . | 50.000000000000000

// -----------------------------------------------------------------------

auto val    = lrc::fromData<float>({{1, 2}, {3, 4}});
auto start1 = lrc::fromData<float>({{0, 0}, {0, 0}});
auto end1   = lrc::fromData<float>({{10, 10}, {10, 10}});
auto start2 = lrc::fromData<float>({{0, 0}, {0, 0}});
auto end2   = lrc::fromData<float>({{100, 100}, {100, 100}});

fmt::print("{}\n", lrc::map(val, start1, end1, start2, end2));
// [[10 20]
//  [30 40]]
```

Note: LibRapid's built-in `map` function has even more functionality! See the Map Function details.

This is just one example of how LibRapid's functions can be used to make your code more concise and more efficient, and hopefully it's clear to see how powerful this could be when working with more complex functions and types.

CHAPTER

THREE

CURRENT DEVELOPMENT STAGE

At the current point in time, LibRapid C++ is under rapid development by me (Pencilcaseman).

I am currently doing my A-Levels and do not have time to work on the library as much as I would like, so if you or someone you know might be willing to support the development of the library, feel free to create a pull request or chat to us on Discord. Any help is greatly appreciated!

CHAPTER

FOUR

ROADMAP

The Roadmap is a rough outline of what I want to get implemented in the library and by what point, but **please don't count on features being implemented quickly** – I can't promise I'll have the time to implement everything as soon as I'd like… (I'll try my best though!)

If you have any feature requests or suggestions, feel free to create an issue describing it. I'll try to get it working as soon as possible. If you really need something implemented quickly, a small donation would be appreciated, and would allow me to bump it to the top of my list of features.

CHAPTER

FIVE

LICENCING

LibRapid is produced under the MIT License, so you are free to use the library how you like for personal and commercial purposes, though this is subject to some conditions, which can be found in full here: LibRapid License

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