

Quantum++
v0.1

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Sat Dec 20 2014 19:31:33

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Chapter 1

Quantum++

Quantum++ is a C++11 general purpose quantum computing library, composed solely of template header files. It uses the [Eigen 3](http://eigen.tuxfamily.org/dox/) linear algebra library and, if available, the [OpenMP](#) multi-processing library. For additional [Eigen 3](http://eigen.tuxfamily.org/dox/) documentation see <http://eigen.tuxfamily.org/dox/>. For a simple [Eigen 3](http://eigen.tuxfamily.org/dox/AsciiQuickReference.txt) quick ASCII reference see <http://eigen.tuxfamily.org/dox/AsciiQuickReference.txt>.

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If you are interesting in contributing, please let me know. There is still work left to be done, and I can provide you with more details about what I have in mind. To contribute, you need to have a decent knowledge of C++ (preferably C++11), including templates and the standard library, a basic knowledge of quantum computing and linear algebra, and some working experience with [Eigen 3](#).

The ultimate goal of this project is to build a universal quantum simulator, applicable to a vast majority of problems in quantum information/computation. The simulator should be fast but nevertheless user-friendly for anyone with a basic knowledge of C/C++.

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Building instructions

Configuration:

- Compiler: [g++](#) version 4.8 or later (for good C++11 support)
- [Eigen 3](#) library located in `$HOME/eigen`
- Quantum++ library located in `$HOME/qpp`
- [MATLAB](#) compiler include header files: `/Applications/MATLAB_R2014b.app/extern/include`
- [MATLAB](#) compiler shared library files: `/Applications/MATLAB_R2014b.app/bin/maci64`

Building without a build system

- Example file: `$HOME/qpp/examples/example.cpp`
- Output executable: `$HOME/qpp/examples/example`

- Must run the commands below from inside the directory `$HOME/qpp/examples`

Release version (without **MATLAB** support):

```
g++ -pedantic -std=c++11 -Wall -Wextra -Weffc++ -fopenmp \
    -O3 -DNDEBUG -DEIGEN_NO_DEBUG \
    -isystem $HOME/eigen -I $HOME/qpp/include \
    example.cpp -o example
```

Debug version (without **MATLAB** support):

```
g++ -pedantic -std=c++11 -Wall -Wextra -Weffc++ -fopenmp \
    -g3 -DDEBUG \
    -isystem $HOME/eigen -I $HOME/qpp/include \
    example.cpp -o example
```

Release version (with **MATLAB** support):

```
g++ -pedantic -std=c++11 -Wall -Wextra -Weffc++ -fopenmp \
    -O3 -DNDEBUG -DEIGEN_NO_DEBUG \
    -isystem $HOME/eigen -I $HOME/qpp/include \
    -I/Applications/MATLAB_R2014b.app/extern/include \
    -L/Applications/MATLAB_R2014b.app/bin/maci64 \
    -lmx -lmat example.cpp -o example
```

Debug version (with **MATLAB** support):

```
g++ -pedantic -std=c++11 -Wall -Wextra -Weffc++ -fopenmp \
    -g3 -DDEBUG \
    -isystem $HOME/eigen -I $HOME/qpp/include \
    -I /Applications/MATLAB_R2014b.app/extern/include \
    -L /Applications/MATLAB_R2014b.app/bin/maci64 \
    -lmx -lmat example.cpp -o example
```

Building using **cmake**

The current version of the repository has a `CMakeLists.txt` configuration file for building examples using **cmake**. To build an example using **cmake**, I recommend an out-of-source build, i.e., from the root of the project (where `./include` is located), type

```
mkdir ./build
cd ./build
cmake ..
make
```

The above commands build the release version (default) executable `qpp`, from the source file `./examples/example.cpp`, without **MATLAB** support (default), inside the directory `./build`. To build a different configuration, e.g. debug version with **MATLAB** support, type from the root of the project

```
cd ./build
rm -rf *
cmake -DCMAKE_BUILD_TYPE=Debug -DWITH_MATLAB=ON ..
make
```

Or, to disable **OpenMP** support (enabled by default), type

```
cd ./build
rm -rf *
cmake -DWITH_OPENMP=OFF ..
make
```

To change the name of the example file, the location of the **Eigen 3** library or the location of **MATLAB** installation, edit the `CMakeLists.txt` file. See also `CMakeLists.txt` for additional options. Do not forget to remove everything from the `./build` directory before a fresh build!

Additional remarks

- The C++ compiler must be C++11 compliant.
- If your compiler does not support **OpenMP** (as it is the case e.g with **clang++**), disable **OpenMP** in your build, as otherwise the linker may not find the **gomp** library.
- If you run the program on **OS X** with **MATLAB** support, make sure that the environment variable `DYLD_LIBRARY_PATH` is set to point to the **MATLAB** compiler library location, see the `run_OSX_MATLAB` script. Otherwise, you will get a runtime error like `dyld: Library not loaded: @rpath/libmat.dylib`.

```
* I recommend running via a script, as otherwise setting the
'DYLD_LIBRARY_PATH' globally may interfere with
[macports](https://www.macports.org/) [cmake](http://www.cmake.org/)
installation (in case you use [cmake](http://www.cmake.org/) from
[macports](https://www.macports.org/)). If you use a script,
then the environment variable is local to the script and
does not interfere with the rest of the system.
```

```
* Example of running script, run from inside the directory where
the executable 'qpp' is located:
```

```
#!/bin/sh # Run Quantum++ under OS X with MATLAB support

export DYLD_LIBRARY_PATH=$DYLD_LIBRARY_PATH:"/Applications/MATLAB_R2014b.app/bin/maci64"
./qpp
```

- If you build a debug version with **g++** under **OS X** and use **gdb** to step inside template functions you may want to add `-fno-weak` compiler flag. See <http://stackoverflow.com/questions/23330641/gnu-gdb-can-not-step-into-template-functions-os-x-mavericks> for more details about this problem.

Chapter 2

Namespace Index

2.1 Namespace List

Here is a list of all namespaces with brief descriptions:

| | | |
|-----------------------------------|---|----|
| qpp | Quantum++ main namespace | 13 |
| qpp::experimental | Experimental/test functions/classes, do not use or modify | 69 |
| qpp::internal | Internal utility functions, do not use/modify | 69 |

Chapter 3

Hierarchical Index

3.1 Class Hierarchy

This inheritance list is sorted roughly, but not completely, alphabetically:

| | |
|--|----|
| std::exception | |
| qpp::Exception | 75 |
| qpp::internal::IOManipEigen | 86 |
| qpp::internal::IOManipPointer< PointerType > | 87 |
| qpp::internal::IOManipRange< InputIterator > | 89 |
| qpp::internal::Singleton< T > | 92 |
| qpp::internal::Singleton< const Codes > | 92 |
| qpp::Codes | 73 |
| qpp::internal::Singleton< const Gates > | 92 |
| qpp::Gates | 79 |
| qpp::internal::Singleton< const Init > | 92 |
| qpp::Init | 85 |
| qpp::internal::Singleton< const States > | 92 |
| qpp::States | 93 |
| qpp::internal::Singleton< RandomDevices > | 92 |
| qpp::RandomDevices | 90 |
| qpp::Timer | 97 |

Chapter 4

Class Index

4.1 Class List

Here are the classes, structs, unions and interfaces with brief descriptions:

| | | |
|--|--|----|
| qpp::Codes | Const Singleton class that defines quantum error correcting codes | 73 |
| qpp::Exception | Generates custom exceptions, used when validating function parameters | 75 |
| qpp::Gates | Const Singleton class that implements most commonly used gates | 79 |
| qpp::Init | Const Singleton class that performs additional initializations/cleanups | 85 |
| qpp::internal::IOManipEigen | | 86 |
| qpp::internal::IOManipPointer< PointerType > | | 87 |
| qpp::internal::IOManipRange< InputIterator > | | 89 |
| qpp::RandomDevices | Singleton class that manages the source of randomness in the library | 90 |
| qpp::internal::Singleton< T > | Singleton policy class, used internally to implement the singleton pattern via CRTP (Curiously recurring template pattern) | 92 |
| qpp::States | Const Singleton class that implements most commonly used states | 93 |
| qpp::Timer | Measures time | 97 |

Chapter 5

File Index

5.1 File List

Here is a list of all files with brief descriptions:

| | |
|--|-----|
| constants.h | |
| Constants | 106 |
| entanglement.h | |
| Entanglement functions | 107 |
| entropies.h | |
| Entropy functions | 108 |
| functions.h | |
| Generic quantum computing functions | 109 |
| input_output.h | |
| Input/output functions | 113 |
| instruments.h | |
| Measurement functions | 114 |
| number_theory.h | |
| Number theory functions | 120 |
| operations.h | |
| Quantum operation functions | 121 |
| qpp.h | |
| Quantum++ main header file, includes all other necessary headers | 123 |
| random.h | |
| Randomness-related functions | 124 |
| types.h | |
| Type aliases | 126 |
| classes/ codes.h | |
| Quantum error correcting codes | 101 |
| classes/ exception.h | |
| Exceptions | 101 |
| classes/ gates.h | |
| Quantum gates | 102 |
| classes/ init.h | |
| Initialization | 103 |
| classes/ random_devices.h | |
| Random devices | 104 |
| classes/ states.h | |
| Quantum states | 104 |
| classes/ timer.h | |
| Timing | 105 |
| experimental/ test.h | |
| Experimental/test functions/classes | 109 |

| | |
|--|-----|
| internal/ util.h | |
| Internal utility functions | 117 |
| internal/classes/ iomanip.h | |
| Input/output manipulators | 116 |
| internal/classes/ singleton.h | |
| Singleton pattern via CRTP | 117 |
| MATLAB/ matlab.h | |
| Input/output interfacing with MATLAB | 119 |

Chapter 6

Namespace Documentation

6.1 qpp Namespace Reference

Quantum++ main namespace.

Namespaces

- [experimental](#)
Experimental/test functions/classes, do not use or modify.
- [internal](#)
Internal utility functions, do not use/modify.

Classes

- class [Codes](#)
const Singleton class that defines quantum error correcting codes
- class [Exception](#)
Generates custom exceptions, used when validating function parameters.
- class [Gates](#)
const Singleton class that implements most commonly used gates
- class [Init](#)
const Singleton class that performs additional initializations/cleanups
- class [RandomDevices](#)
Singleton class that manages the source of randomness in the library.
- class [States](#)
const Singleton class that implements most commonly used states
- class [Timer](#)
Measures time.

Typedefs

- using [idx](#) = std::size_t
Non-negative integer index.
- using [cplx](#) = std::complex< double >
Complex number in double precision.
- using [ket](#) = Eigen::VectorXcd

- *Complex (double precision) dynamic Eigen column vector.*
- using `bra` = `Eigen::RowVectorXcd`
- *Complex (double precision) dynamic Eigen row vector.*
- using `cmat` = `Eigen::MatrixXcd`
- *Complex (double precision) dynamic Eigen matrix.*
- using `dmat` = `Eigen::MatrixXd`
- *Real (double precision) dynamic Eigen matrix.*
- template<typename Scalar >
using `dyn_mat` = `Eigen::Matrix< Scalar, Eigen::Dynamic, Eigen::Dynamic >`
Dynamic Eigen matrix over the field specified by Scalar.
- template<typename Scalar >
using `dyn_col_vect` = `Eigen::Matrix< Scalar, Eigen::Dynamic, 1 >`
Dynamic Eigen column vector over the field specified by Scalar.
- template<typename Scalar >
using `dyn_row_vect` = `Eigen::Matrix< Scalar, 1, Eigen::Dynamic >`
Dynamic Eigen row vector over the field specified by Scalar.

Functions

- constexpr `cplx operator""_i` (unsigned long long int x)
User-defined literal for complex $i = \sqrt{-1}$ (integer overload)
- constexpr `cplx operator""_i` (long double x)
User-defined literal for complex $i = \sqrt{-1}$ (real overload)
- `cplx omega` (idx D)
D-th root of unity.
- template<typename Derived >
`dyn_col_vect< double > schmidtcoeffs` (const `Eigen::MatrixBase< Derived >` &A, const `std::vector< idx >` &dims)
Schmidt coefficients of the bi-partite pure state A.
- template<typename Derived >
`cmat schmidtA` (const `Eigen::MatrixBase< Derived >` &A, const `std::vector< idx >` &dims)
Schmidt basis on Alice side.
- template<typename Derived >
`cmat schmidtB` (const `Eigen::MatrixBase< Derived >` &A, const `std::vector< idx >` &dims)
Schmidt basis on Bob side.
- template<typename Derived >
`std::vector< double > schmidtprobs` (const `Eigen::MatrixBase< Derived >` &A, const `std::vector< idx >` &dims)
Schmidt probabilities of the bi-partite pure state A.
- template<typename Derived >
`double entanglement` (const `Eigen::MatrixBase< Derived >` &A, const `std::vector< idx >` &dims)
Entanglement of the bi-partite pure state A.
- template<typename Derived >
`double gconcurrence` (const `Eigen::MatrixBase< Derived >` &A)
G-concurrence of the bi-partite pure state A.
- template<typename Derived >
`double negativity` (const `Eigen::MatrixBase< Derived >` &A, const `std::vector< idx >` &dims)
Negativity of the bi-partite mixed state A.
- template<typename Derived >
`double lognegativity` (const `Eigen::MatrixBase< Derived >` &A, const `std::vector< idx >` &dims)
Logarithmic negativity of the bi-partite mixed state A.

- `template<typename Derived >`
`double concurrence (const Eigen::MatrixBase< Derived > &A)`
Wootters concurrence of the bi-partite qubit mixed state A.
- `template<typename Derived >`
`double entropy (const Eigen::MatrixBase< Derived > &A)`
von-Neumann entropy of the density matrix A
- `double entropy (const std::vector< double > &prob)`
Shannon entropy of the probability distribution prob.
- `template<typename Derived >`
`double renyi (const Eigen::MatrixBase< Derived > &A, double alpha)`
Renyi- α entropy of the density matrix A, for $\alpha \geq 0$.
- `double renyi (const std::vector< double > &prob, double alpha)`
Renyi- α entropy of the probability distribution prob, for $\alpha \geq 0$.
- `template<typename Derived >`
`double tsallis (const Eigen::MatrixBase< Derived > &A, double q)`
Tsallis- q entropy of the density matrix A, for $q \geq 0$.
- `double tsallis (const std::vector< double > &prob, double q)`
Tsallis- q entropy of the probability distribution prob, for $q \geq 0$.
- `template<typename Derived >`
`double qmutualinfo (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &subsA, const std::vector< idx > &subsB, const std::vector< idx > &dims)`
Quantum mutual information between 2 subsystems of a composite system.
- `template<typename Derived >`
`double qmutualinfo (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &subsA, const std::vector< idx > &subsB, idx d=2)`
Quantum mutual information between 2 subsystems of a composite system.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > transpose (const Eigen::MatrixBase< Derived > &A)`
Transpose.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > conjugate (const Eigen::MatrixBase< Derived > &A)`
Complex conjugate.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > adjoint (const Eigen::MatrixBase< Derived > &A)`
Adjoint.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > inverse (const Eigen::MatrixBase< Derived > &A)`
Inverse.
- `template<typename Derived >`
`Derived::Scalar trace (const Eigen::MatrixBase< Derived > &A)`
Trace.
- `template<typename Derived >`
`Derived::Scalar det (const Eigen::MatrixBase< Derived > &A)`
Determinant.
- `template<typename Derived >`
`Derived::Scalar logdet (const Eigen::MatrixBase< Derived > &A)`
Logarithm of the determinant.
- `template<typename Derived >`
`Derived::Scalar sum (const Eigen::MatrixBase< Derived > &A)`
Element-wise sum of A.
- `template<typename Derived >`
`Derived::Scalar prod (const Eigen::MatrixBase< Derived > &A)`
Element-wise product of A.

- `template<typename Derived >`
`double norm (const Eigen::MatrixBase< Derived > &A)`
Frobenius norm.
- `template<typename Derived >`
`std::pair< dyn_col_vect< cplx >`
`, cmat > eig (const Eigen::MatrixBase< Derived > &A)`
Full eigen decomposition.
- `template<typename Derived >`
`dyn_col_vect< cplx > evals (const Eigen::MatrixBase< Derived > &A)`
Eigenvalues.
- `template<typename Derived >`
`cmat evecs (const Eigen::MatrixBase< Derived > &A)`
Eigenvectors.
- `template<typename Derived >`
`std::pair< dyn_col_vect`
`< double >, cmat > heig (const Eigen::MatrixBase< Derived > &A)`
Full eigen decomposition of Hermitian expression.
- `template<typename Derived >`
`dyn_col_vect< double > hevals (const Eigen::MatrixBase< Derived > &A)`
Hermitian eigenvalues.
- `template<typename Derived >`
`cmat hevecs (const Eigen::MatrixBase< Derived > &A)`
Hermitian eigenvectors.
- `template<typename Derived >`
`std::tuple< cmat, dyn_col_vect`
`< double >, cmat > svd (const Eigen::MatrixBase< Derived > &A)`
Full singular value decomposition.
- `template<typename Derived >`
`dyn_col_vect< double > svals (const Eigen::MatrixBase< Derived > &A)`
Singular values.
- `template<typename Derived >`
`cmat svdU (const Eigen::MatrixBase< Derived > &A)`
Left singular vectors.
- `template<typename Derived >`
`cmat svdV (const Eigen::MatrixBase< Derived > &A)`
Right singular vectors.
- `template<typename Derived >`
`cmat funm (const Eigen::MatrixBase< Derived > &A, cplx(*f)(const cplx &))`
Functional calculus $f(A)$
- `template<typename Derived >`
`cmat sqrtm (const Eigen::MatrixBase< Derived > &A)`
Matrix square root.
- `template<typename Derived >`
`cmat absm (const Eigen::MatrixBase< Derived > &A)`
Matrix absolut value.
- `template<typename Derived >`
`cmat expm (const Eigen::MatrixBase< Derived > &A)`
Matrix exponential.
- `template<typename Derived >`
`cmat logm (const Eigen::MatrixBase< Derived > &A)`
Matrix logarithm.
- `template<typename Derived >`
`cmat sinm (const Eigen::MatrixBase< Derived > &A)`

Matrix sin.

- template<typename Derived >
`cmat cosm` (const Eigen::MatrixBase< Derived > &A)

Matrix cos.

- template<typename Derived >
`cmat spectralpowm` (const Eigen::MatrixBase< Derived > &A, const `cplx` z)

Matrix power.

- template<typename Derived >
`dyn_mat`< typename Derived::Scalar > `powm` (const Eigen::MatrixBase< Derived > &A, `idx` n)

Matrix power.

- template<typename Derived >
double `schatten` (const Eigen::MatrixBase< Derived > &A, `idx` p)

Schatten norm.

- template<typename OutputScalar , typename Derived >
`dyn_mat`< OutputScalar > `cwise` (const Eigen::MatrixBase< Derived > &A, OutputScalar(*f)(const type-
name Derived::Scalar &))

Functor.

- template<typename T >
`dyn_mat`< typename T::Scalar > `kron` (const T &head)

Kronecker product.

- template<typename T , typename... Args>
`dyn_mat`< typename T::Scalar > `kron` (const T &head, const Args &...tail)

Kronecker product.

- template<typename Derived >
`dyn_mat`< typename Derived::Scalar > `kron` (const std::vector< Derived > &As)

Kronecker product.

- template<typename Derived >
`dyn_mat`< typename Derived::Scalar > `kron` (const std::initializer_list< Derived > &As)

Kronecker product.

- template<typename Derived >
`dyn_mat`< typename Derived::Scalar > `kronpow` (const Eigen::MatrixBase< Derived > &A, `idx` n)

Kronecker power.

- template<typename T >
`dyn_mat`< typename T::Scalar > `dirsum` (const T &head)

Direct sum.

- template<typename T , typename... Args>
`dyn_mat`< typename T::Scalar > `dirsum` (const T &head, const Args &...tail)

Direct sum.

- template<typename Derived >
`dyn_mat`< typename Derived::Scalar > `dirsum` (const std::vector< Derived > &As)

Direct sum.

- template<typename Derived >
`dyn_mat`< typename Derived::Scalar > `dirsum` (const std::initializer_list< Derived > &As)

Direct sum.

- template<typename Derived >
`dyn_mat`< typename Derived::Scalar > `dirsumpow` (const Eigen::MatrixBase< Derived > &A, `idx` n)

Direct sum power.

- template<typename Derived >
`dyn_mat`< typename Derived::Scalar > `reshape` (const Eigen::MatrixBase< Derived > &A, `idx` rows, `idx` cols)

Reshape.

- `template<typename Derived1 , typename Derived2 >`
`dyn_mat< typename`
`Derived1::Scalar > comm` (`const Eigen::MatrixBase< Derived1 > &A`, `const Eigen::MatrixBase< Derived2 > &B`)
Commutator.
- `template<typename Derived1 , typename Derived2 >`
`dyn_mat< typename`
`Derived1::Scalar > anticomm` (`const Eigen::MatrixBase< Derived1 > &A`, `const Eigen::MatrixBase< Derived2 > &B`)
Anti-commutator.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > prj` (`const Eigen::MatrixBase< Derived > &V`)
Projector.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > grams` (`const std::vector< Derived > &Vs`)
Gram-Schmidt orthogonalization.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > grams` (`const std::initializer_list< Derived > &Vs`)
Gram-Schmidt orthogonalization.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > grams` (`const Eigen::MatrixBase< Derived > &A`)
Gram-Schmidt orthogonalization.
- `std::vector< idx > n2multiidx` (`idx n`, `const std::vector< idx > &dims`)
Non-negative integer index to multi-index.
- `idx multiidx2n` (`const std::vector< idx > &midx`, `const std::vector< idx > &dims`)
Multi-index to non-negative integer index.
- `ket mket` (`const std::vector< idx > &mask`, `const std::vector< idx > &dims`)
Multi-partite qudit ket.
- `ket mket` (`const std::vector< idx > &mask`, `idx d=2`)
Multi-partite qudit ket.
- `cmat mprj` (`const std::vector< idx > &mask`, `const std::vector< idx > &dims`)
Projector onto multi-partite qudit ket.
- `cmat mprj` (`const std::vector< idx > &mask`, `idx d=2`)
Projector onto multi-partite qudit ket.
- `template<typename InputIterator >`
`std::vector< double > abssq` (`InputIterator first`, `InputIterator last`)
Computes the absolut values squared of a range of complex numbers.
- `template<typename Derived >`
`std::vector< double > abssq` (`const Eigen::MatrixBase< Derived > &V`)
Computes the absolut values squared of a column vector.
- `template<typename InputIterator >`
`InputIterator::value_type sum` (`InputIterator first`, `InputIterator last`)
Element-wise sum of a range.
- `template<typename InputIterator >`
`InputIterator::value_type prod` (`InputIterator first`, `InputIterator last`)
Element-wise product of a range.
- `template<typename Derived >`
`dyn_col_vect< typename`
`Derived::Scalar > rho2pure` (`const Eigen::MatrixBase< Derived > &A`)
Finds the pure state representation of a matrix proportional to a projector onto a pure state.
- `template<typename Derived >`
`internal::IOManipEigen disp` (`const Eigen::MatrixBase< Derived > &A`, `double chop=qpp::chop`)
Eigen expression ostream manipulator.

- [internal::IOManipEigen disp](#) (cplx z, double chop=qpp::chop)
Complex number ostream manipulator.
- template<typename InputIterator >
[internal::IOManipRange](#)
< InputIterator > [disp](#) (const InputIterator &first, const InputIterator &last, const std::string &separator, const std::string &start="[" , const std::string &end="]")
Range ostream manipulator.
- template<typename Container >
[internal::IOManipRange](#)
< typename
Container::const_iterator > [disp](#) (const Container &c, const std::string &separator, const std::string &start="[" , const std::string &end="]")
Standard container ostream manipulator. The container must support std::begin(), std::end() and forward iteration.
- template<typename PointerType >
[internal::IOManipPointer](#)
< PointerType > [disp](#) (const PointerType *p, [idx](#) n, const std::string &separator, const std::string &start="[" , const std::string &end="]")
C-style pointer ostream manipulator.
- template<typename Derived >
void [save](#) (const Eigen::MatrixBase< Derived > &A, const std::string &fname)
Saves Eigen expression to a binary file (internal format) in double precision.
- template<typename Derived >
[dyn_mat](#)< typename Derived::Scalar > [load](#) (const std::string &fname)
Loads Eigen matrix from a binary file (internal format) in double precision.
- template<typename Derived >
std::tuple< [idx](#), std::vector
< double >, std::vector< [cmat](#) > > [measure](#) (const Eigen::MatrixBase< Derived > &A, const std::vector<
[cmat](#) > &Ks, const std::vector< [idx](#) > &subsys, const std::vector< [idx](#) > &dims)
Measures the part subsys of the multi-partite state vector or density matrix A using the set of Kraus operators Ks.
- template<typename Derived >
std::tuple< [idx](#), std::vector
< double >, std::vector< [cmat](#) > > [measure](#) (const Eigen::MatrixBase< Derived > &A, const std::vector<
::initializer_list< [cmat](#) > &Ks, const std::vector< [idx](#) > &subsys, const std::vector< [idx](#) > &dims)
Measures the part subsys of the multi-partite state vector or density matrix A using the set of Kraus operators Ks.
- template<typename Derived >
std::tuple< [idx](#), std::vector
< double >, std::vector< [cmat](#) > > [measure](#) (const Eigen::MatrixBase< Derived > &A, const std::vector<
[cmat](#) > &Ks, const std::vector< [idx](#) > &subsys, const [idx](#) d=2)
Measures the part subsys of the multi-partite state vector or density matrix A using the set of Kraus operators Ks.
- template<typename Derived >
std::tuple< [idx](#), std::vector
< double >, std::vector< [cmat](#) > > [measure](#) (const Eigen::MatrixBase< Derived > &A, const std::vector<
::initializer_list< [cmat](#) > &Ks, const std::vector< [idx](#) > &subsys, const [idx](#) d=2)
Measures the part subsys of the multi-partite state vector or density matrix A using the set of Kraus operators Ks.
- template<typename Derived >
std::tuple< [idx](#), std::vector
< double >, std::vector< [cmat](#) > > [measure](#) (const Eigen::MatrixBase< Derived > &A, const [cmat](#) &U,
const std::vector< [idx](#) > &subsys, const std::vector< [idx](#) > &dims)
Measures the part subsys of the multi-partite state A in the orthonormal basis specified by the unitary matrix U.
- template<typename Derived >
std::tuple< [idx](#), std::vector
< double >, std::vector< [cmat](#) > > [measure](#) (const Eigen::MatrixBase< Derived > &A, const [cmat](#) &U,
const std::vector< [idx](#) > &subsys, const [idx](#) d=2)
Measures the part subsys of the multi-partite state A in the orthonormal basis specified by the unitary matrix U.

- `template<typename Derived >`
`std::tuple< idx, std::vector`
`< double >, std::vector< cmat > > measure (const Eigen::MatrixBase< Derived > &A, const std::vector<`
`cmat > &Ks)`
Measures the state A using the set of Kraus operators Ks.
- `template<typename Derived >`
`std::tuple< idx, std::vector`
`< double >, std::vector< cmat > > measure (const Eigen::MatrixBase< Derived > &A, const std::vector<`
`::initializer_list< cmat > &Ks)`
Measures the state A using the set of Kraus operators Ks.
- `template<typename Derived >`
`std::tuple< idx, std::vector`
`< double >, std::vector< cmat > > measure (const Eigen::MatrixBase< Derived > &A, const cmat &U)`
Measures the state A in the orthonormal basis specified by the unitary matrix U.
- `template<typename Derived >`
`Derived loadMATLABmatrix (const std::string &mat_file, const std::string &var_name)`
Loads an Eigen dynamic matrix from a MATLAB .mat file, generic version.
- `template<>`
`dmat loadMATLABmatrix (const std::string &mat_file, const std::string &var_name)`
Loads an Eigen dynamic matrix from a MATLAB .mat file, specialization for double matrices ([qpp::dmat](#))
- `template<>`
`cmat loadMATLABmatrix (const std::string &mat_file, const std::string &var_name)`
Loads an Eigen dynamic matrix from a MATLAB .mat file, specialization for complex matrices ([qpp::cmat](#))
- `template<typename Derived >`
`void saveMATLABmatrix (const Eigen::MatrixBase< Derived > &A, const std::string &mat_file, const std::string &var_name, const std::string &mode)`
Saves an Eigen dynamic matrix to a MATLAB .mat file, generic version.
- `template<>`
`void saveMATLABmatrix (const Eigen::MatrixBase< dmat > &A, const std::string &mat_file, const std::string &var_name, const std::string &mode)`
Saves an Eigen dynamic matrix to a MATLAB .mat file, specialization for double matrices ([qpp::dmat](#))
- `template<>`
`void saveMATLABmatrix (const Eigen::MatrixBase< cmat > &A, const std::string &mat_file, const std::string &var_name, const std::string &mode)`
Saves an Eigen dynamic matrix to a MATLAB .mat file, specialization for complex matrices ([qpp::cmat](#))
- `std::vector< long long int > x2contfrac (double x, idx n, idx cut=1e5)`
Simple continued fraction expansion.
- `double contfrac2x (const std::vector< int > &cf, idx n)`
Real representation of a simple continued fraction.
- `double contfrac2x (const std::vector< int > &cf)`
Real representation of a simple continued fraction.
- `idx gcd (idx m, idx n)`
Greatest common divisor of two non-negative integers.
- `idx gcd (const std::vector< idx > &ns)`
Greatest common divisor of a list of non-negative integers.
- `idx lcm (idx m, idx n)`
Least common multiple of two positive integers.
- `idx lcm (const std::vector< idx > &ns)`
Least common multiple of a list of positive integers.
- `std::vector< idx > invperm (const std::vector< idx > &perm)`
Inverse permutation.
- `std::vector< idx > compperm (const std::vector< idx > &perm, const std::vector< idx > &sigma)`
Compose permutations.

- `template<typename Derived1 , typename Derived2 >`
`dyn_mat< typename`
`Derived1::Scalar > applyCTRL` (const Eigen::MatrixBase< Derived1 > &state, const Eigen::MatrixBase< Derived2 > &A, const std::vector< `idx` > &ctrl, const std::vector< `idx` > &subsys, const std::vector< `idx` > &dims)
Applies the controlled-gate A to the part subsys of the multi-partite state vector or density matrix state.
- `template<typename Derived1 , typename Derived2 >`
`dyn_mat< typename`
`Derived1::Scalar > applyCTRL` (const Eigen::MatrixBase< Derived1 > &state, const Eigen::MatrixBase< Derived2 > &A, const std::vector< `idx` > &ctrl, const std::vector< `idx` > &subsys, `idx` d=2)
Applies the controlled-gate A to the part subsys of the multi-partite state vector or density matrix state.
- `template<typename Derived1 , typename Derived2 >`
`dyn_mat< typename`
`Derived1::Scalar > apply` (const Eigen::MatrixBase< Derived1 > &state, const Eigen::MatrixBase< Derived2 > &A, const std::vector< `idx` > &subsys, const std::vector< `idx` > &dims)
Applies the gate A to the part subsys of the multi-partite state vector or density matrix state.
- `template<typename Derived1 , typename Derived2 >`
`dyn_mat< typename`
`Derived1::Scalar > apply` (const Eigen::MatrixBase< Derived1 > &state, const Eigen::MatrixBase< Derived2 > &A, const std::vector< `idx` > &subsys, `idx` d=2)
Applies the gate A to the part subsys of the multi-partite state vector or density matrix state.
- `template<typename Derived >`
`cmat apply` (const Eigen::MatrixBase< Derived > &rho, const std::vector< `cmat` > &Ks)
Applies the channel specified by the set of Kraus operators Ks to the density matrix rho.
- `template<typename Derived >`
`cmat apply` (const Eigen::MatrixBase< Derived > &rho, const std::vector< `cmat` > &Ks, const std::vector< `idx` > &subsys, const std::vector< `idx` > &dims)
Applies the channel specified by the set of Kraus operators Ks to the part subsys of the multi-partite density matrix rho.
- `template<typename Derived >`
`cmat apply` (const Eigen::MatrixBase< Derived > &rho, const std::vector< `cmat` > &Ks, const std::vector< `idx` > &subsys, `idx` d=2)
Applies the channel specified by the set of Kraus operators Ks to the part subsys of the multi-partite density matrix rho.
- `cmat kraus2super` (const std::vector< `cmat` > &Ks)
Superoperator matrix.
- `cmat kraus2choi` (const std::vector< `cmat` > &Ks)
Choi matrix.
- `std::vector< cmat > choi2kraus` (const `cmat` &A)
Orthogonal Kraus operators from Choi matrix.
- `cmat choi2super` (const `cmat` &A)
Converts Choi matrix to superoperator matrix.
- `cmat super2choi` (const `cmat` &A)
Converts superoperator matrix to Choi matrix.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > ptrace1` (const Eigen::MatrixBase< Derived > &A, const std::vector< `idx` > &dims)
Partial trace.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > ptrace2` (const Eigen::MatrixBase< Derived > &A, const std::vector< `idx` > &dims)
Partial trace.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > ptrace` (const Eigen::MatrixBase< Derived > &A, const std::vector< `idx` > &subsys, const std::vector< `idx` > &dims)

Partial trace.

- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > ptrace` (const Eigen::MatrixBase< Derived > &A, const std::vector< `idx` > &subsys, `idx` d=2)

Partial trace.

- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > ptranspose` (const Eigen::MatrixBase< Derived > &A, const std::vector< `idx` > &subsys, const std::vector< `idx` > &dims)

Partial transpose.

- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > ptranspose` (const Eigen::MatrixBase< Derived > &A, const std::vector< `idx` > &subsys, `idx` d=2)

Partial transpose.

- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > syspermute` (const Eigen::MatrixBase< Derived > &A, const std::vector< `idx` > &perm, const std::vector< `idx` > &dims)

Subsystem permutation.

- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > syspermute` (const Eigen::MatrixBase< Derived > &A, const std::vector< `idx` > &perm, `idx` d=2)

Subsystem permutation.

- `template<typename Derived >`
`Derived rand` (`idx` rows, `idx` cols, double a=0, double b=1)

Generates a random matrix with entries uniformly distributed in the interval [a, b]

- `template<>`
`dmat rand` (`idx` rows, `idx` cols, double a, double b)

Generates a random real matrix with entries uniformly distributed in the interval [a, b], specialization for double matrices (`qpp::dmat`)

- `template<>`
`cmat rand` (`idx` rows, `idx` cols, double a, double b)

Generates a random complex matrix with entries (both real and imaginary) uniformly distributed in the interval [a, b], specialization for complex matrices (`qpp::cmat`)

- `double rand` (double a=0, double b=1)

Generates a random real number uniformly distributed in the interval [a, b]

- `idx randidx` (`idx` a=std::numeric_limits< `idx` >::min(), `idx` b=std::numeric_limits< `idx` >::max())

Generates a random index (idx) uniformly distributed in the interval [a, b].

- `template<typename Derived >`
`Derived randn` (`idx` rows, `idx` cols, double mean=0, double sigma=1)

Generates a random matrix with entries normally distributed in N(mean, sigma)

- `template<>`
`dmat randn` (`idx` rows, `idx` cols, double mean, double sigma)

Generates a random real matrix with entries normally distributed in N(mean, sigma), specialization for double matrices (`qpp::dmat`)

- `template<>`
`cmat randn` (`idx` rows, `idx` cols, double mean, double sigma)

Generates a random complex matrix with entries (both real and imaginary) normally distributed in N(mean, sigma), specialization for complex matrices (`qpp::cmat`)

- `double randn` (double mean=0, double sigma=1)

Generates a random real number (double) normally distributed in N(mean, sigma)

- `cmat randU` (`idx` D)

Generates a random unitary matrix.

- `cmat randV` (`idx` Din, `idx` Dout)

Generates a random isometry matrix.

- `std::vector< cmat > randkraus` (`idx` N, `idx` D)

- *Generates a set of random Kraus operators.*
- `cmat randH (idx D)`
Generates a random Hermitian matrix.
- `ket randket (idx D)`
Generates a random normalized ket (pure state vector)
- `cmat randrho (idx D)`
Generates a random density matrix.
- `std::vector< idx > randperm (idx n)`
Generates a random uniformly distributed permutation.

Variables

- `constexpr double chop = 1e-10`
Used in `qpp::disp()` for setting to zero numbers that have their absolute value smaller than `qpp::chop`.
- `constexpr double eps = 1e-12`
Used to decide whether a number or expression in double precision is zero or not.
- `constexpr idx maxn = 64`
Maximum number of allowed qu(d)its (subsystems)
- `constexpr double pi = 3.141592653589793238462643383279502884`
 π
- `constexpr double ee = 2.718281828459045235360287471352662497`
Base of natural logarithm, e .
- `constexpr double infy = std::numeric_limits<double>::infinity()`
Used to denote infinity in double precision.
- `const Init & init = Init::get_instance()`
`qpp::Init` const Singleton
- `const Codes & codes = Codes::get_instance()`
`qpp::Codes` const Singleton
- `const Gates & gt = Gates::get_instance()`
`qpp::Gates` const Singleton
- `const States & st = States::get_instance()`
`qpp::States` const Singleton
- `RandomDevices & rdevs = RandomDevices::get_instance()`
`qpp::RandomDevices` Singleton

6.1.1 Detailed Description

Quantum++ main namespace.

6.1.2 Typedef Documentation

6.1.2.1 using qpp::bra = typedef Eigen::RowVectorXcd

Complex (double precision) dynamic Eigen row vector.

6.1.2.2 using qpp::cmat = typedef Eigen::MatrixXcd

Complex (double precision) dynamic Eigen matrix.

6.1.2.3 using qpp::cplx = typedef std::complex<double>

Complex number in double precision.

6.1.2.4 using qpp::dmat = typedef Eigen::MatrixXd

Real (double precision) dynamic Eigen matrix.

6.1.2.5 template<typename Scalar > using qpp::dyn_col_vect = typedef Eigen::Matrix<Scalar, Eigen::Dynamic, 1>

Dynamic Eigen column vector over the field specified by *Scalar*.

Example:

```
// type of colvect is Eigen::Matrix<float, Eigen::Dynamic, 1>
auto colvect = dyn_col_vect<float>(2);
```

6.1.2.6 template<typename Scalar > using qpp::dyn_mat = typedef Eigen::Matrix<Scalar, Eigen::Dynamic, Eigen::Dynamic>

Dynamic Eigen matrix over the field specified by *Scalar*.

Example:

```
// type of mat is Eigen::Matrix<float, Eigen::Dynamic, Eigen::Dynamic>
auto mat = dyn_mat<float>(2,3);
```

6.1.2.7 template<typename Scalar > using qpp::dyn_row_vect = typedef Eigen::Matrix<Scalar, 1, Eigen::Dynamic>

Dynamic Eigen row vector over the field specified by *Scalar*.

Example:

```
// type of rowvect is Eigen::Matrix<float, 1, Eigen::Dynamic>
auto rowvect = dyn_row_vect<float>(3);
```

6.1.2.8 using qpp::idx = typedef std::size_t

Non-negative integer index.

6.1.2.9 using qpp::ket = typedef Eigen::VectorXcd

Complex (double precision) dynamic Eigen column vector.

6.1.3 Function Documentation

6.1.3.1 template<typename Derived > cmat qpp::absm (const Eigen::MatrixBase< Derived > & A)

Matrix absolut value.

Parameters

| | |
|-----|------------------|
| A | Eigen expression |
|-----|------------------|

Returns

Matrix absolut value of A

6.1.3.2 `template<typename InputIterator > std::vector<double> qpp::abssq (InputIterator first, InputIterator last)`

Computes the absolut values squared of a range of complex numbers.

Parameters

| | |
|--------------|--|
| <i>first</i> | Iterator to the first element of the range |
| <i>last</i> | Iterator to the last element of the range |

Returns

Real vector consisting of the range absolut values squared

6.1.3.3 `template<typename Derived > std::vector<double> qpp::abssq (const Eigen::MatrixBase< Derived > & V)`

Computes the absolut values squared of a column vector.

Parameters

| | |
|-----|------------------|
| V | Eigen expression |
|-----|------------------|

Returns

Real vector consisting of the absolut values squared

6.1.3.4 `template<typename Derived > dyn_mat<typename Derived::Scalar> qpp::adjoint (const Eigen::MatrixBase< Derived > & A)`

Adjoint.

Parameters

| | |
|-----|------------------|
| A | Eigen expression |
|-----|------------------|

Returns

Adjoint (Hermitian conjugate) of A , as a dynamic matrix over the same scalar field as A

6.1.3.5 `template<typename Derived1 , typename Derived2 > dyn_mat<typename Derived1::Scalar> qpp::anticomm (const Eigen::MatrixBase< Derived1 > & A , const Eigen::MatrixBase< Derived2 > & B)`

Anti-commutator.

See also

[qpp::comm\(\)](#)

Anti-commutator $\{A, B\} = AB + BA$. Both A and B must be Eigen expressions over the same scalar field.

Parameters

| | |
|-----|------------------|
| A | Eigen expression |
| B | Eigen expression |

Returns

Anti-commutator $AB + BA$, as a dynamic matrix over the same scalar field as A

6.1.3.6 `template<typename Derived1 , typename Derived2 > dyn_mat<typename Derived1::Scalar> qpp::apply (const Eigen::MatrixBase< Derived1 > & state, const Eigen::MatrixBase< Derived2 > & A, const std::vector< idx > & subsys, const std::vector< idx > & dims)`

Applies the gate A to the part $subsys$ of the multi-partite state vector or density matrix $state$.

Note

The dimension of the gate A must match the dimension of $subsys$

Parameters

| | |
|----------|---|
| $state$ | Eigen expression |
| A | Eigen expression |
| $subsys$ | Subsystem indexes where the gate A is applied |
| $dims$ | Dimensions of the multi-partite system |

Returns

Gate A applied to the part $subsys$ of $state$

6.1.3.7 `template<typename Derived1 , typename Derived2 > dyn_mat<typename Derived1::Scalar> qpp::apply (const Eigen::MatrixBase< Derived1 > & state, const Eigen::MatrixBase< Derived2 > & A, const std::vector< idx > & subsys, idx d = 2)`

Applies the gate A to the part $subsys$ of the multi-partite state vector or density matrix $state$.

Note

The dimension of the gate A must match the dimension of $subsys$

Parameters

| | |
|----------|---|
| $state$ | Eigen expression |
| A | Eigen expression |
| $subsys$ | Subsystem indexes where the gate A is applied |
| d | Subsystem dimensions |

Returns

Gate A applied to the part $subsys$ of $state$

6.1.3.8 `template<typename Derived > cmat qpp::apply (const Eigen::MatrixBase< Derived > & rho, const std::vector< cmat > & Ks)`

Applies the channel specified by the set of Kraus operators Ks to the density matrix rho .

Parameters

| | |
|------------|------------------------|
| <i>rho</i> | Eigen expression |
| <i>Ks</i> | Set of Kraus operators |

Returns

Output density matrix after the action of the channel

6.1.3.9 `template<typename Derived > cmat qpp::apply (const Eigen::MatrixBase< Derived > & rho, const std::vector< cmat > & Ks, const std::vector< idx > & subsys, const std::vector< idx > & dims)`

Applies the channel specified by the set of Kraus operators *Ks* to the part *subsys* of the multi-partite density matrix *rho*.

Parameters

| | |
|---------------|---|
| <i>rho</i> | Eigen expression |
| <i>Ks</i> | Set of Kraus operators |
| <i>subsys</i> | Subsystem indexes where the Kraus operators <i>Ks</i> are applied |
| <i>dims</i> | Dimensions of the multi-partite system |

Returns

Output density matrix after the action of the channel

6.1.3.10 `template<typename Derived > cmat qpp::apply (const Eigen::MatrixBase< Derived > & rho, const std::vector< cmat > & Ks, const std::vector< idx > & subsys, idx d = 2)`

Applies the channel specified by the set of Kraus operators *Ks* to the part *subsys* of the multi-partite density matrix *rho*.

Parameters

| | |
|---------------|---|
| <i>rho</i> | Eigen expression |
| <i>Ks</i> | Set of Kraus operators |
| <i>subsys</i> | Subsystem indexes where the Kraus operators <i>Ks</i> are applied |
| <i>d</i> | Subsystem dimensions |

Returns

Output density matrix after the action of the channel

6.1.3.11 `template<typename Derived1 , typename Derived2 > dyn_mat<typename Derived1::Scalar> qpp::applyCTRL (const Eigen::MatrixBase< Derived1 > & state, const Eigen::MatrixBase< Derived2 > & A, const std::vector< idx > & ctrl, const std::vector< idx > & subsys, const std::vector< idx > & dims)`

Applies the controlled-gate *A* to the part *subsys* of the multi-partite state vector or density matrix *state*.

See also

[qpp::Gates::CTRL\(\)](#)

Note

The dimension of the gate *A* must match the dimension of *subsys*. Also, all control subsystems in *ctrl* must have the same dimension.

Parameters

| | |
|---------------|--|
| <i>state</i> | Eigen expression |
| <i>A</i> | Eigen expression |
| <i>ctrl</i> | Control subsystem indexes |
| <i>subsys</i> | Subsystem indexes where the gate <i>A</i> is applied |
| <i>dims</i> | Dimensions of the multi-partite system |

Returns

CTRL-A gate applied to the part *subsys* of *state*

6.1.3.12 `template<typename Derived1 , typename Derived2 > dyn_mat<typename Derived1::Scalar> qpp::applyCTRL (const Eigen::MatrixBase< Derived1 > & state, const Eigen::MatrixBase< Derived2 > & A, const std::vector< idx > & ctrl, const std::vector< idx > & subsys, idx d = 2)`

Applies the controlled-gate *A* to the part *subsys* of the multi-partite state vector or density matrix *state*.

See also

[qpp::Gates::CTRL\(\)](#)

Note

The dimension of the gate *A* must match the dimension of *subsys*

Parameters

| | |
|---------------|--|
| <i>state</i> | Eigen expression |
| <i>A</i> | Eigen expression |
| <i>ctrl</i> | Control subsystem indexes |
| <i>subsys</i> | Subsystem indexes where the gate <i>A</i> is applied |
| <i>d</i> | Subsystem dimensions |

Returns

CTRL-A gate applied to the part *subsys* of *state*

6.1.3.13 `std::vector< cmat > qpp::choi2kraus (const cmat & A)`

Orthogonal Kraus operators from Choi matrix.

See also

[qpp::kraus2choi\(\)](#)

Extracts a set of orthogonal (under Hilbert-Schmidt operator norm) Kraus operators from the Choi matrix *A*

Note

The Kraus operators satisfy $Tr(K_i^\dagger K_j) = \delta_{ij}$ for all $i \neq j$

Parameters

| | |
|-----|-------------|
| A | Choi matrix |
|-----|-------------|

Returns

Set of orthogonal Kraus operators

6.1.3.14 `cmat qpp::choi2super (const cmat & A)`

Converts Choi matrix to superoperator matrix.

See also

[qpp::super2choi\(\)](#)

Parameters

| | |
|-----|-------------|
| A | Choi matrix |
|-----|-------------|

Returns

Superoperator matrix

6.1.3.15 `template<typename Derived1, typename Derived2> dyn_mat<typename Derived1::Scalar> qpp::comm (const Eigen::MatrixBase< Derived1 > & A, const Eigen::MatrixBase< Derived2 > & B)`

Commutator.

See also

[qpp::anticomm\(\)](#)

Commutator $[A, B] = AB - BA$. Both A and B must be Eigen expressions over the same scalar field.

Parameters

| | |
|-----|------------------|
| A | Eigen expression |
| B | Eigen expression |

Returns

Commutator $AB - BA$, as a dynamic matrix over the same scalar field as A

6.1.3.16 `std::vector<idx> qpp::compperm (const std::vector< idx > & perm, const std::vector< idx > & sigma)`

Compose permutations.

Parameters

| | |
|---------|-------------|
| $perm$ | Permutation |
| $sigma$ | Permutation |

Returns

Composition of the permutations $perm \circ sigma = perm(sigma)$

6.1.3.17 `template<typename Derived > double qpp::concurrence (const Eigen::MatrixBase< Derived > & A)`

Wootters concurrence of the bi-partite qubit mixed state A .

Parameters

| | |
|----------|------------------|
| <i>A</i> | Eigen expression |
|----------|------------------|

Returns

Wootters concurrence

6.1.3.18 `template<typename Derived > dyn_mat<typename Derived::Scalar> qpp::conjugate (const Eigen::MatrixBase<Derived > & A)`

Complex conjugate.

Parameters

| | |
|----------|------------------|
| <i>A</i> | Eigen expression |
|----------|------------------|

Returns

Complex conjugate of *A*, as a dynamic matrix over the same scalar field as *A*

6.1.3.19 `double qpp::contfrac2x (const std::vector< int > & cf, idx n)`

Real representation of a simple continued fraction.

See also

[qpp::x2contfrac\(\)](#)

Parameters

| | |
|-----------|---|
| <i>cf</i> | Integer vector containing the simple continued fraction expansion |
| <i>n</i> | Number of terms considered in the continued fraction expansion. If <i>n</i> is greater than the size of <i>cf</i> , then all terms in <i>cf</i> are considered. |

Returns

Real representation of the simple continued fraction

6.1.3.20 `double qpp::contfrac2x (const std::vector< int > & cf)`

Real representation of a simple continued fraction.

See also

[qpp::x2contfrac\(\)](#)

Parameters

| | |
|-----------|---|
| <i>cf</i> | Integer vector containing the simple continued fraction expansion |
|-----------|---|

Returns

Real representation of the simple continued fraction

6.1.3.21 `template<typename Derived > cmat qpp::cosm (const Eigen::MatrixBase< Derived > & A)`

Matrix cos.

Parameters

| | |
|-----|------------------|
| A | Eigen expression |
|-----|------------------|

Returns

Matrix cosine of A

6.1.3.22 `template<typename OutputScalar , typename Derived > dyn_mat<OutputScalar> qpp::cwise (const Eigen::MatrixBase< Derived > & A, OutputScalar*)(const typename Derived::Scalar &) f)`

Functor.

Parameters

| | |
|-----|--|
| A | Eigen expression |
| f | Pointer-to-function from scalars of A to <i>OutputScalar</i> |

Returns

Component-wise $f(A)$, as a dynamic matrix over the *OutputScalar* scalar field

6.1.3.23 `template<typename Derived > Derived::Scalar qpp::det (const Eigen::MatrixBase< Derived > & A)`

Determinant.

Parameters

| | |
|-----|------------------|
| A | Eigen expression |
|-----|------------------|

Returns

Determinant of A , as a scalar in the same scalar field as A . Returns $\pm\infty$ when the determinant overflows/underflows.

6.1.3.24 `template<typename T > dyn_mat<typename T::Scalar> qpp::dirsum (const T & head)`

Direct sum.

See also

[qpp::dirsumpow\(\)](#)

Used to stop the recursion for the variadic template version of [qpp::dirsum\(\)](#)

Parameters

| | |
|-------------|------------------|
| <i>head</i> | Eigen expression |
|-------------|------------------|

Returns

Its argument *head*

6.1.3.25 `template<typename T, typename... Args> dyn_mat<typename T::Scalar> qpp::dirsum (const T & head, const Args &... tail)`

Direct sum.

See also

[qpp::dirsumpow\(\)](#)

Parameters

| | |
|-------------|---|
| <i>head</i> | Eigen expression |
| <i>tail</i> | Variadic Eigen expression (zero or more parameters) |

Returns

Direct sum of all input parameters, evaluated from left to right, as a dynamic matrix over the same scalar field as its arguments

6.1.3.26 `template<typename Derived > dyn_mat<typename Derived::Scalar> qpp::dirsum (const std::vector< Derived > & As)`

Direct sum.

See also

[qpp::dirsumpow\(\)](#)

Parameters

| | |
|-----------|----------------------------------|
| <i>As</i> | std::vector of Eigen expressions |
|-----------|----------------------------------|

Returns

Direct sum of all elements in *As*, evaluated from left to right, as a dynamic matrix over the same scalar field as its arguments

6.1.3.27 `template<typename Derived > dyn_mat<typename Derived::Scalar> qpp::dirsum (const std::initializer_list< Derived > & As)`

Direct sum.

See also

[qpp::dirsumpow\(\)](#)

Parameters

| | |
|-----------|---|
| <i>As</i> | std::initializer_list of Eigen expressions, such as { <i>A1</i> , <i>A2</i> , ... , <i>Ak</i> } |
|-----------|---|

Returns

Direct sum of all elements in *As*, evaluated from left to right, as a dynamic matrix over the same scalar field as its arguments

6.1.3.28 `template<typename Derived > dyn_mat<typename Derived::Scalar> qpp::dirsumpow (const Eigen::MatrixBase< Derived > & A, idx n)`

Direct sum power.

See also

[qpp::dirsum\(\)](#)

Parameters

| | |
|-----|----------------------|
| A | Eigen expression |
| n | Non-negative integer |

Returns

Direct sum of A with itself n times $A^{\oplus n}$, as a dynamic matrix over the same scalar field as A

6.1.3.29 `template<typename Derived > internal::IOManipEigen qpp::disp (const Eigen::MatrixBase< Derived > & A, double chop = qpp::chop)`

Eigen expression ostream manipulator.

Parameters

| | |
|--------|--|
| A | Eigen expression |
| $chop$ | Set to zero the elements smaller in absolute value than $chop$ |

Returns

Instance of `qpp::internal::internal::IOManipEigen`

6.1.3.30 `internal::IOManipEigen qpp::disp (cplx z, double chop = qpp::chop)`

Complex number ostream manipulator.

Parameters

| | |
|--------|---|
| z | Complex number (or any other type implicitly cast-able to <code>std::complex<double></code>) |
| $chop$ | Set to zero the elements smaller in absolute value than $chop$ |

Returns

Instance of `qpp::internal::internal::IOManipEigen`

6.1.3.31 `template<typename InputIterator > internal::IOManipRange<InputIterator> qpp::disp (const InputIterator & first, const InputIterator & last, const std::string & separator, const std::string & start = " [", const std::string & end = "] ")`

Range ostream manipulator.

Parameters

| | |
|------------------|--|
| <i>first</i> | Iterator to the first element of the range |
| <i>last</i> | Iterator to the last element of the range |
| <i>separator</i> | Separator |
| <i>start</i> | Left marking |
| <i>end</i> | Right marking |

Returns

Instance of `qpp::internal::internal::IOManipRange`

6.1.3.32 `template<typename Container > internal::IOManipRange<typename Container::const_iterator> qpp::disp (const Container & c, const std::string & separator, const std::string & start = " [", const std::string & end = "] ")`

Standard container ostream manipulator. The container must support `std::begin()`, `std::end()` and forward iteration.

Parameters

| | |
|------------------|---------------|
| <i>c</i> | Container |
| <i>separator</i> | Separator |
| <i>start</i> | Left marking |
| <i>end</i> | Right marking |

Returns

Instance of `qpp::internal::internal::IOManipRange`

6.1.3.33 `template<typename PointerType > internal::IOManipPointer<PointerType> qpp::disp (const PointerType * p, idx n, const std::string & separator, const std::string & start = " [", const std::string & end = "] ")`

C-style pointer ostream manipulator.

Parameters

| | |
|------------------|------------------------------------|
| <i>p</i> | Pointer to the first element |
| <i>n</i> | Number of elements to be displayed |
| <i>separator</i> | Separator |
| <i>start</i> | Left marking |
| <i>end</i> | Right marking |

Returns

Instance of `qpp::internal::internal::IOManipPointer`

6.1.3.34 `template<typename Derived > std::pair<dyn_col_vect<cplx>, cmat> qpp::eig (const Eigen::MatrixBase<Derived > & A)`

Full eigen decomposition.

See also

[qpp::heig\(\)](#)

Parameters

| | |
|----------|------------------|
| <i>A</i> | Eigen expression |
|----------|------------------|

Returns

Pair of: 1. Eigenvalues of A , as a complex dynamic column vector, and 2. Eigenvectors of A , as columns of a complex dynamic matrix

6.1.3.35 `template<typename Derived> double qpp::entanglement (const Eigen::MatrixBase< Derived > & A, const std::vector< idx > & dims)`

Entanglement of the bi-partite pure state A .

Defined as the von-Neumann entropy of the reduced density matrix of one of the subsystems

See also

[qpp::entropy\(\)](#)

Parameters

| | |
|-------------|-------------------------------------|
| <i>A</i> | Eigen expression |
| <i>dims</i> | Dimensions of the bi-partite system |

Returns

Entanglement, with the logarithm in base 2

6.1.3.36 `template<typename Derived> double qpp::entropy (const Eigen::MatrixBase< Derived > & A)`

von-Neumann entropy of the density matrix A

Parameters

| | |
|----------|------------------|
| <i>A</i> | Eigen expression |
|----------|------------------|

Returns

von-Neumann entropy, with the logarithm in base 2

6.1.3.37 `double qpp::entropy (const std::vector< double > & prob)`

Shannon entropy of the probability distribution $prob$.

Parameters

| | |
|-------------|-------------------------|
| <i>prob</i> | Real probability vector |
|-------------|-------------------------|

Returns

Shannon entropy, with the logarithm in base 2

6.1.3.38 `template<typename Derived > dyn_col_vect<cplx> qpp::evals (const Eigen::MatrixBase< Derived > & A)`

Eigenvalues.

See also

[qpp::hevals\(\)](#)

Parameters

| | |
|-----|------------------|
| A | Eigen expression |
|-----|------------------|

Returns

Eigenvalues of A , as a complex dynamic column vector

6.1.3.39 `template<typename Derived > cmat qpp::evecs (const Eigen::MatrixBase< Derived > & A)`

Eigenvectors.

See also

[qpp::hevecs\(\)](#)

Parameters

| | |
|-----|------------------|
| A | Eigen expression |
|-----|------------------|

Returns

Eigenvectors of A , as columns of a complex dynamic matrix

6.1.3.40 `template<typename Derived > cmat qpp::expm (const Eigen::MatrixBase< Derived > & A)`

Matrix exponential.

Parameters

| | |
|-----|------------------|
| A | Eigen expression |
|-----|------------------|

Returns

Matrix exponential of A

6.1.3.41 `template<typename Derived > cmat qpp::funm (const Eigen::MatrixBase< Derived > & A, cplx(*) (const cplx &) f)`

Functional calculus $f(A)$

Parameters

| | |
|-----|---|
| A | Eigen expression |
| f | Pointer-to-function from complex to complex |

Returns

$f(A)$

6.1.3.42 `idx qpp::gcd (idx m, idx n)`

Greatest common divisor of two non-negative integers.

See also

[qpp::lcm\(\)](#)

Parameters

| | |
|----------|----------------------|
| <i>m</i> | Non-negative integer |
| <i>n</i> | Non-negative integer |

Returns

Greatest common divisor of *m* and *n*

6.1.3.43 `idx qpp::gcd (const std::vector< idx > & ns)`

Greatest common divisor of a list of non-negative integers.

See also

[qpp::lcm\(\)](#)

Parameters

| | |
|-----------|-------------------------------|
| <i>ns</i> | List of non-negative integers |
|-----------|-------------------------------|

Returns

Greatest common divisor of all numbers in *ns*

6.1.3.44 `template<typename Derived> double qpp::gconcurrence (const Eigen::MatrixBase< Derived > & A)`

G-concurrence of the bi-partite pure state *A*.

Note

Both local dimensions must be equal

Uses [qpp::logdet\(\)](#) to avoid overflows

See also

[qpp::logdet\(\)](#)

Parameters

| | |
|----------|------------------|
| <i>A</i> | Eigen expression |
|----------|------------------|

Returns

G-concurrence

6.1.3.45 `template<typename Derived> dyn_mat<typename Derived::Scalar> qpp::grams (const std::vector< Derived > & Vs)`

Gram-Schmidt orthogonalization.

Parameters

| | |
|-----------|--|
| <i>Vs</i> | std::vector of Eigen expressions as column vectors |
|-----------|--|

Returns

Gram-Schmidt vectors of *Vs* as columns of a dynamic matrix over the same scalar field as its arguments

6.1.3.46 `template<typename Derived > dyn_mat<typename Derived::Scalar> qpp::grams (const std::initializer_list<Derived > & Vs)`

Gram-Schmidt orthogonalization.

Parameters

| | |
|-----------|--|
| <i>Vs</i> | std::initializer_list of Eigen expressions as column vectors |
|-----------|--|

Returns

Gram-Schmidt vectors of *Vs* as columns of a dynamic matrix over the same scalar field as its arguments

6.1.3.47 `template<typename Derived > dyn_mat<typename Derived::Scalar> qpp::grams (const Eigen::MatrixBase<Derived > & A)`

Gram-Schmidt orthogonalization.

Parameters

| | |
|----------|---|
| <i>A</i> | Eigen expression, the input vectors are the columns of <i>A</i> |
|----------|---|

Returns

Gram-Schmidt vectors of the columns of *A*, as columns of a dynamic matrix over the same scalar field as *A*

6.1.3.48 `template<typename Derived > std::pair<dyn_col_vect<double>, cmat> qpp::heig (const Eigen::MatrixBase<Derived > & A)`

Full eigen decomposition of Hermitian expression.

See also

[qpp::eig\(\)](#)

Parameters

| | |
|----------|------------------|
| <i>A</i> | Eigen expression |
|----------|------------------|

Returns

Pair of: 1. Eigenvalues of *A*, as a real dynamic column vector, and 2. Eigenvectors of *A*, as columns of a complex dynamic matrix

6.1.3.49 `template<typename Derived > dyn_col_vect<double> qpp::hevals (const Eigen::MatrixBase< Derived > & A)`

Hermitian eigenvalues.

See also

[qpp::evals\(\)](#)

Parameters

| | |
|----------|------------------|
| <i>A</i> | Eigen expression |
|----------|------------------|

Returns

Eigenvalues of Hermitian *A*, as a real dynamic column vector

6.1.3.50 `template<typename Derived > cmat qpp::hevects (const Eigen::MatrixBase< Derived > & A)`

Hermitian eigenvectors.

See also

[qpp::evects\(\)](#)

Parameters

| | |
|----------|------------------|
| <i>A</i> | Eigen expression |
|----------|------------------|

Returns

Eigenvectors of Hermitian *A*, as columns of a complex matrix

6.1.3.51 `template<typename Derived > dyn_mat<typename Derived::Scalar> qpp::inverse (const Eigen::MatrixBase< Derived > & A)`

Inverse.

Parameters

| | |
|----------|------------------|
| <i>A</i> | Eigen expression |
|----------|------------------|

Returns

Inverse of *A*, as a dynamic matrix over the same scalar field as *A*

6.1.3.52 `std::vector<idx> qpp::invperm (const std::vector< idx > & perm)`

Inverse permutation.

Parameters

| | |
|-------------|-------------|
| <i>perm</i> | Permutation |
|-------------|-------------|

Returns

Inverse of the permutation *perm*

6.1.3.53 `cmat qpp::kraus2choi (const std::vector< cmat > & Ks)`

Choi matrix.

See also

[qpp::choi2kraus\(\)](#)

Constructs the Choi matrix of the channel specified by the set of Kraus operators Ks in the standard operator basis $\{|i\rangle\langle j|\}$ ordered in lexicographical order, i.e. $|0\rangle\langle 0|$, $|0\rangle\langle 1|$ etc.

Note

The superoperator matrix S and the Choi matrix C are related by $S_{ab,mn} = C_{ma,nb}$

Parameters

| | |
|------|------------------------|
| Ks | Set of Kraus operators |
|------|------------------------|

Returns

Choi matrix

6.1.3.54 `cmat qpp::kraus2super (const std::vector< cmat > & Ks)`

Superoperator matrix.

Constructs the superoperator matrix of the channel specified by the set of Kraus operators Ks in the standard operator basis $\{|i\rangle\langle j|\}$ ordered in lexicographical order, i.e. $|0\rangle\langle 0|$, $|0\rangle\langle 1|$ etc.

Parameters

| | |
|------|------------------------|
| Ks | Set of Kraus operators |
|------|------------------------|

Returns

Superoperator matrix

6.1.3.55 `template<typename T> dyn_mat<typename T::Scalar> qpp::kron (const T & head)`

Kronecker product.

See also

[qpp::kronpow\(\)](#)

Used to stop the recursion for the variadic template version of [qpp::kron\(\)](#)

Parameters

| | |
|-------------|------------------|
| <i>head</i> | Eigen expression |
|-------------|------------------|

Returns

Its argument *head*

6.1.3.56 `template<typename T, typename... Args> dyn_mat<typename T::Scalar> qpp::kron (const T & head, const Args &... tail)`

Kronecker product.

See also

[qpp::kronpow\(\)](#)

Parameters

| | |
|-------------|---|
| <i>head</i> | Eigen expression |
| <i>tail</i> | Variadic Eigen expression (zero or more parameters) |

Returns

Kronecker product of all input parameters, evaluated from left to right, as a dynamic matrix over the same scalar field as its arguments

6.1.3.57 `template<typename Derived > dyn_mat<typename Derived::Scalar> qpp::kron (const std::vector< Derived > & As)`

Kronecker product.

See also

[qpp::kronpow\(\)](#)

Parameters

| | |
|-----------|----------------------------------|
| <i>As</i> | std::vector of Eigen expressions |
|-----------|----------------------------------|

Returns

Kronecker product of all elements in *As*, evaluated from left to right, as a dynamic matrix over the same scalar field as its arguments

6.1.3.58 `template<typename Derived > dyn_mat<typename Derived::Scalar> qpp::kron (const std::initializer_list< Derived > & As)`

Kronecker product.

See also

[qpp::kronpow\(\)](#)

Parameters

| | |
|-----------|---|
| <i>As</i> | std::initializer_list of Eigen expressions, such as { <i>A1</i> , <i>A2</i> , ... , <i>Ak</i> } |
|-----------|---|

Returns

Kronecker product of all elements in *As*, evaluated from left to right, as a dynamic matrix over the same scalar field as its arguments

6.1.3.59 `template<typename Derived> dyn_mat<typename Derived::Scalar> qpp::kronpow (const Eigen::MatrixBase<Derived> & A, idx n)`

Kronecker power.

See also

[qpp::kron\(\)](#)

Parameters

| | |
|-----|----------------------|
| A | Eigen expression |
| n | Non-negative integer |

Returns

Kronecker product of A with itself n times $A^{\otimes n}$, as a dynamic matrix over the same scalar field as A

6.1.3.60 `idx qpp::lcm (idx m, idx n)`

Least common multiple of two positive integers.

See also

[qpp::gcd\(\)](#)

Parameters

| | |
|-----|------------------|
| m | Positive integer |
| n | Positive integer |

Returns

Least common multiple of m and n

6.1.3.61 `idx qpp::lcm (const std::vector< idx> & ns)`

Least common multiple of a list of positive integers.

See also

[qpp::gcd\(\)](#)

Parameters

| | |
|------|---------------------------|
| ns | List of positive integers |
|------|---------------------------|

Returns

Least common multiple of all numbers in ns

6.1.3.62 `template<typename Derived> dyn_mat<typename Derived::Scalar> qpp::load (const std::string & fname)`

Loads Eigen matrix from a binary file (internal format) in double precision.

See also

[qpp::save\(\)](#)

The template parameter cannot be automatically deduced and must be explicitly provided, depending on the scalar field of the matrix that is being loaded.

Example:

```
// loads a previously saved Eigen dynamic complex matrix from "input.bin"
auto mat = load<cmat>("input.bin");
```

Parameters

| | |
|--------------|------------------|
| <i>A</i> | Eigen expression |
| <i>fname</i> | Output file name |

6.1.3.63 `template<typename Derived > Derived qpp::loadMATLABmatrix (const std::string & mat_file, const std::string & var_name)`

Loads an Eigen dynamic matrix from a MATLAB .mat file, generic version.

See also

[qpp::saveMATLABmatrix\(\)](#)

This is the generic version that always throws [qpp::Exception::Type::UNDEFINED_TYPE](#). It is specialized only for [qpp::dmat](#) and [qpp::cmat](#) (the only matrix types that can be loaded)

6.1.3.64 `template<> dmat qpp::loadMATLABmatrix (const std::string & mat_file, const std::string & var_name)`
`[inline]`

Loads an Eigen dynamic matrix from a MATLAB .mat file, specialization for double matrices ([qpp::dmat](#))

See also

[qpp::saveMATLABmatrix\(\)](#)

The template parameter cannot be automatically deduced and must be explicitly provided

Example:

```
// loads a previously saved Eigen dynamic double matrix from the
MATLAB file "input.mat"
auto mat = loadMATLABmatrix<dmat>("input.mat");
```

Note

If *var_name* is a complex matrix, only the real part is loaded

Parameters

| | |
|-----------------|---|
| <i>mat_file</i> | MATALB .mat file |
| <i>var_name</i> | Variable name in the .mat file representing the matrix to be loaded |

Returns

Eigen double dynamic matrix ([qpp::dmat](#))

6.1.3.65 `template<> cmat qpp::loadMATLABmatrix (const std::string & mat_file, const std::string & var_name)`
`[inline]`

Loads an Eigen dynamic matrix from a MATLAB .mat file, specialization for complex matrices ([qpp::cmat](#))

See also

[qpp::saveMATLABmatrix\(\)](#)

The template parameter cannot be automatically deduced and must be explicitly provided

Example:

```
// loads a previously saved Eigen dynamic complex matrix from the
MATLAB file "input.mat"
auto mat = loadMATLABmatrix<cmat>("input.mat");
```

Parameters

| | |
|-----------------|---|
| <i>mat_file</i> | MATALB .mat file |
| <i>var_name</i> | Variable name in the .mat file representing the matrix to be loaded |

Returns

Eigen complex dynamic matrix ([qpp::cmat](#))

6.1.3.66 `template<typename Derived > Derived::Scalar qpp::logdet (const Eigen::MatrixBase< Derived > & A)`

Logarithm of the determinant.

Useful when the determinant overflows/underflows

Parameters

| | |
|----------|------------------|
| <i>A</i> | Eigen expression |
|----------|------------------|

Returns

Logarithm of the determinant of *A*, as a scalar in the same scalar field as *A*

6.1.3.67 `template<typename Derived > cmat qpp::logm (const Eigen::MatrixBase< Derived > & A)`

Matrix logarithm.

Parameters

| | |
|----------|------------------|
| <i>A</i> | Eigen expression |
|----------|------------------|

Returns

Matrix logarithm of *A*

6.1.3.68 `template<typename Derived > double qpp::lognegativity (const Eigen::MatrixBase< Derived > & A, const std::vector< idx > & dims)`

Logarithmic negativity of the bi-partite mixed state *A*.

Parameters

| | |
|-------------|-------------------------------------|
| <i>A</i> | Eigen expression |
| <i>dims</i> | Dimensions of the bi-partite system |

Returns

Logarithmic negativity, with the logarithm in base 2

```
6.1.3.69 template<typename Derived > std::tuple<idx, std::vector<double>, std::vector<cmat> > qpp::measure ( const
Eigen::MatrixBase< Derived > & A, const std::vector< cmat > & Ks, const std::vector< idx > & subsys, const
std::vector< idx > & dims )
```

Measures the part *subsys* of the multi-partite state vector or density matrix *A* using the set of Kraus operators *Ks*.

Note

The dimension of all *Ks* must match the dimension of *subsys*.

Parameters

| | |
|---------------|--|
| <i>A</i> | Eigen expression |
| <i>Ks</i> | Set of Kraus operators |
| <i>subsys</i> | Subsystem indexes that are measured |
| <i>dims</i> | Dimensions of the multi-partite system |

Returns

Tuple consisting of 1. Result of the measurement, 2. Vector of outcome probabilities and 3. Vector of post-measurement normalized states

```
6.1.3.70 template<typename Derived > std::tuple<idx, std::vector<double>, std::vector<cmat> > qpp::measure ( const
Eigen::MatrixBase< Derived > & A, const std::initializer_list< cmat > & Ks, const std::vector< idx > & subsys,
const std::vector< idx > & dims )
```

Measures the part *subsys* of the multi-partite state vector or density matrix *A* using the set of Kraus operators *Ks*.

Note

The dimension of all *Ks* must match the dimension of *subsys*.

Parameters

| | |
|---------------|--|
| <i>A</i> | Eigen expression |
| <i>subsys</i> | Subsystem indexes that are measured |
| <i>dims</i> | Dimensions of the multi-partite system |
| <i>Ks</i> | Set of Kraus operators |

Returns

Tuple consisting of 1. Result of the measurement,

1. Vector of outcome probabilities and 3. Vector of post-measurement normalized states

6.1.3.71 `template<typename Derived > std::tuple<idx, std::vector<double>, std::vector<cmat> > qpp::measure (const Eigen::MatrixBase< Derived > & A, const std::vector< cmat > & Ks, const std::vector< idx > & subsys, const idx d = 2)`

Measures the part *subsys* of the multi-partite state vector or density matrix *A* using the set of Kraus operators *Ks*.

Note

The dimension of all *Ks* must match the dimension of *subsys*.

Parameters

| | |
|---------------|-------------------------------------|
| <i>A</i> | Eigen expression |
| <i>subsys</i> | Subsystem indexes that are measured |
| <i>d</i> | Subsystem dimensions |
| <i>Ks</i> | Set of Kraus operators |

Returns

Tuple consisting of 1. Result of the measurement,

1. Vector of outcome probabilities and 3. Vector of post-measurement normalized states

6.1.3.72 `template<typename Derived > std::tuple<idx, std::vector<double>, std::vector<cmat> > qpp::measure (const Eigen::MatrixBase< Derived > & A, const std::initializer_list< cmat > & Ks, const std::vector< idx > & subsys, const idx d = 2)`

Measures the part *subsys* of the multi-partite state vector or density matrix *A* using the set of Kraus operators *Ks*.

Note

The dimension of all *Ks* must match the dimension of *subsys*.

Parameters

| | |
|---------------|-------------------------------------|
| <i>A</i> | Eigen expression |
| <i>subsys</i> | Subsystem indexes that are measured |
| <i>d</i> | Subsystem dimensions |
| <i>Ks</i> | Set of Kraus operators |

Returns

Tuple consisting of 1. Result of the measurement,

1. Vector of outcome probabilities and 3. Vector of post-measurement normalized states

6.1.3.73 `template<typename Derived > std::tuple<idx, std::vector<double>, std::vector<cmat> > qpp::measure (const Eigen::MatrixBase< Derived > & A, const cmat & U, const std::vector< idx > & subsys, const std::vector< idx > & dims)`

Measures the part *subsys* of the multi-partite state *A* in the orthonormal basis specified by the unitary matrix *U*.

Note

The dimension of *U* must match the dimension of *subsys*.

Parameters

| | |
|---------------|--|
| <i>A</i> | Eigen expression |
| <i>subsys</i> | Subsystem indexes that are measured |
| <i>dims</i> | Dimensions of the multi-partite system |
| <i>U</i> | Unitary matrix whose columns represent the measurement basis vectors |

Returns

- Tuple consisting of 1. Result of the measurement,
1. Vector of outcome probabilities and 3. Vector of post-measurement normalized states

6.1.3.74 `template<typename Derived> std::tuple<idx, std::vector<double>, std::vector<cmat>> qpp::measure (const Eigen::MatrixBase< Derived> & A, const cmat & U, const std::vector< idx> & subsys, const idx d = 2)`

Measures the part *subsys* of the multi-partite state *A* in the orthonormal basis specified by the unitary matrix *U*.

Note

The dimension of *U* must match the dimension of *subsys*.

Parameters

| | |
|---------------|--|
| <i>A</i> | Eigen expression |
| <i>subsys</i> | Subsystem indexes that are measured |
| <i>d</i> | Subsystem dimensions |
| <i>U</i> | Unitary matrix whose columns represent the measurement basis vectors |

Returns

- Tuple consisting of 1. Result of the measurement,
1. Vector of outcome probabilities and 3. Vector of post-measurement normalized states

6.1.3.75 `template<typename Derived> std::tuple<idx, std::vector<double>, std::vector<cmat>> qpp::measure (const Eigen::MatrixBase< Derived> & A, const std::vector< cmat> & Ks)`

Measures the state *A* using the set of Kraus operators *Ks*.

Parameters

| | |
|-----------|------------------------|
| <i>A</i> | Eigen expression |
| <i>Ks</i> | Set of Kraus operators |

Returns

- Tuple consisting of 1. Result of the measurement,
1. Vector of outcome probabilities and 3. Vector of post-measurement normalized states

6.1.3.76 `template<typename Derived> std::tuple<idx, std::vector<double>, std::vector<cmat>> qpp::measure (const Eigen::MatrixBase< Derived> & A, const std::initializer_list< cmat> & Ks)`

Measures the state *A* using the set of Kraus operators *Ks*.

Parameters

| | |
|-----------|------------------------|
| <i>A</i> | Eigen expression |
| <i>Ks</i> | Set of Kraus operators |

Returns

Tuple consisting of 1. Result of the measurement,
1. Vector of outcome probabilities and 3. Vector of post-measurement normalized states

6.1.3.77 `template<typename Derived > std::tuple<idx, std::vector<double>, std::vector<cmat> > qpp::measure (const Eigen::MatrixBase< Derived > & A, const cmat & U)`

Measures the state *A* in the orthonormal basis specified by the unitary matrix *U*.

Parameters

| | |
|----------|--|
| <i>A</i> | Eigen expression |
| <i>U</i> | Unitary matrix whose columns represent the measurement basis vectors |

Returns

Tuple consisting of 1. Result of the measurement,
1. Vector of outcome probabilities and 3. Vector of post-measurement normalized states

6.1.3.78 `ket qpp::mket (const std::vector< idx > & mask, const std::vector< idx > & dims)`

Multi-partite qudit ket.

Constructs the multi-partite qudit ket $|\text{mask}\rangle$, where *mask* is a `std::vector` of non-negative integers. Each element in *mask* has to be smaller than the corresponding element in *dims*.

Parameters

| | |
|-------------|---|
| <i>mask</i> | <code>std::vector</code> of non-negative integers |
| <i>dims</i> | Dimensions of the multi-partite system |

Returns

Multi-partite qudit state vector, as a complex dynamic column vector

6.1.3.79 `ket qpp::mket (const std::vector< idx > & mask, idx d = 2)`

Multi-partite qudit ket.

Constructs the multi-partite qudit ket $|\text{mask}\rangle$, all subsystem having equal dimension *d*. *mask* is a `std::vector` of non-negative integers, and each element in *mask* has to be strictly smaller than *d*.

Parameters

| | |
|-------------|---|
| <i>mask</i> | <code>std::vector</code> of non-negative integers |
| <i>d</i> | Subsystem dimensions |

Returns

Multi-partite qudit state vector, as a complex dynamic column vector

6.1.3.80 `cmat qpp::mprj (const std::vector< idx > & mask, const std::vector< idx > & dims)`

Projector onto multi-partite qudit ket.

Constructs the projector onto the multi-partite qudit ket $|\text{mask}\rangle$, where *mask* is a `std::vector` of non-negative integers. Each element in *mask* has to be smaller than the corresponding element in *dims*.

Parameters

| | |
|-------------|---|
| <i>mask</i> | <code>std::vector</code> of non-negative integers |
| <i>dims</i> | Dimensions of the multi-partite system |

Returns

Projector onto multi-partite qudit state vector, as a complex dynamic matrix

6.1.3.81 `cmat qpp::mprj (const std::vector< idx > & mask, idx d = 2)`

Projector onto multi-partite qudit ket.

Constructs the projector onto the multi-partite qudit ket $|\text{mask}\rangle$, all subsystem having equal dimension *d*. *mask* is a `std::vector` of non-negative integers, and each element in *mask* has to be strictly smaller than *d*.

Parameters

| | |
|-------------|---|
| <i>mask</i> | <code>std::vector</code> of non-negative integers |
| <i>d</i> | Subsystem dimensions |

Returns

Projector onto multi-partite qudit state vector, as a complex dynamic matrix

6.1.3.82 `idx qpp::multiidx2n (const std::vector< idx > & midx, const std::vector< idx > & dims)`

Multi-index to non-negative integer index.

See also

[qpp::n2multiidx\(\)](#)

Uses standard lexicographical order, i.e. 00...0, 00...1 etc.

Parameters

| | |
|-------------|--|
| <i>midx</i> | Multi-index |
| <i>dims</i> | Dimensions of the multi-partite system |

Returns

Non-negative integer index

6.1.3.83 `std::vector<idx> qpp::n2multiidx (idx n, const std::vector< idx > & dims)`

Non-negative integer index to multi-index.

See also

[qpp::multiidx2n\(\)](#)

Uses standard lexicographical order, i.e. 00...0, 00...1 etc.

Parameters

| | |
|--------|--|
| n | Non-negative integer index |
| $dims$ | Dimensions of the multi-partite system |

Returns

Multi-index of the same size as $dims$

6.1.3.84 `template<typename Derived> double qpp::negativity (const Eigen::MatrixBase< Derived> & A, const std::vector< idx> & dims)`

Negativity of the bi-partite mixed state A .

Parameters

| | |
|--------|-------------------------------------|
| A | Eigen expression |
| $dims$ | Dimensions of the bi-partite system |

Returns

Negativity

6.1.3.85 `template<typename Derived> double qpp::norm (const Eigen::MatrixBase< Derived> & A)`

Frobenius norm.

Parameters

| | |
|-----|------------------|
| A | Eigen expression |
|-----|------------------|

Returns

Frobenius norm of A , as a real number

6.1.3.86 `cplx qpp::omega (idx D) [inline]`

D -th root of unity.

Parameters

| | |
|-----|----------------------|
| D | Non-negative integer |
|-----|----------------------|

Returns

D -th root of unity $\exp(2\pi i/D)$

6.1.3.87 `constexpr cplx qpp::operator""_i (unsigned long long int x)`

User-defined literal for complex $i = \sqrt{-1}$ (integer overload)

Example:

```
auto z = 4_i; // type of z is std::complex<double>
```

6.1.3.88 `constexpr cplx qpp::operator""_i (long double x)`

User-defined literal for complex $i = \sqrt{-1}$ (real overload)

Example:

```
auto z = 4.5_i; // type of z is std::complex<double>
```

6.1.3.89 `template<typename Derived > dyn_mat<typename Derived::Scalar> qpp::powm (const Eigen::MatrixBase< Derived > & A, idx n)`

Matrix power.

See also

[qpp::spectralpowm\(\)](#)

Explicitly multiplies the matrix A with itself n times. By convention $A^0 = I$.

Parameters

| | |
|-----|----------------------|
| A | Eigen expression |
| n | Non-negative integer |

Returns

Matrix power A^n , as a dynamic matrix over the same scalar field as A

6.1.3.90 `template<typename Derived > dyn_mat<typename Derived::Scalar> qpp::prj (const Eigen::MatrixBase< Derived > & V)`

Projector.

Normalized projector onto state vector

Parameters

| | |
|-----|------------------|
| V | Eigen expression |
|-----|------------------|

Returns

Projector onto the state vector V , or the matrix *Zero* if V has norm zero (i.e. smaller than [qpp::eps](#)), as a dynamic matrix over the same scalar field as A

6.1.3.91 `template<typename Derived > Derived::Scalar qpp::prod (const Eigen::MatrixBase< Derived > & A)`

Element-wise product of A .

Parameters

| | |
|-----|------------------|
| A | Eigen expression |
|-----|------------------|

Returns

Element-wise product of A , as a scalar in the same scalar field as A

6.1.3.92 `template<typename InputIterator > InputIterator::value_type qpp::prod (InputIterator first, InputIterator last)`

Element-wise product of a range.

Parameters

| | |
|--------------|--|
| <i>first</i> | Iterator to the first element of the range |
| <i>last</i> | Iterator to the last element of the range |

Returns

Element-wise product of the range, as a scalar in the same scalar field as the range

6.1.3.93 `template<typename Derived > dyn_mat<typename Derived::Scalar> qpp::ptrace (const Eigen::MatrixBase<Derived > & A, const std::vector< idx > & subsys, const std::vector< idx > & dims)`

Partial trace.

See also

[qpp::ptrace1\(\)](#), [qpp::ptrace2\(\)](#)

Partial trace of the multi-partite density matrix over a list of subsystems

Parameters

| | |
|---------------|--|
| <i>A</i> | Eigen expression |
| <i>subsys</i> | Subsystem indexes |
| <i>dims</i> | Dimensions of the multi-partite system |

Returns

Partial trace $Tr_{subsys}(\cdot)$ over the subsystems *subsys* in a multi-partite system, as a dynamic matrix over the same scalar field as *A*

6.1.3.94 `template<typename Derived > dyn_mat<typename Derived::Scalar> qpp::ptrace (const Eigen::MatrixBase<Derived > & A, const std::vector< idx > & subsys, idx d = 2)`

Partial trace.

See also

[qpp::ptrace1\(\)](#), [qpp::ptrace2\(\)](#)

Partial trace of the multi-partite density matrix over a list of subsystems

Parameters

| | |
|---------------|----------------------|
| <i>A</i> | Eigen expression |
| <i>subsys</i> | Subsystem indexes |
| <i>d</i> | Subsystem dimensions |

Returns

Partial trace $Tr_{subsys}(\cdot)$ over the subsystems *subsys* in a multi-partite system, as a dynamic matrix over the same scalar field as *A*

6.1.3.95 `template<typename Derived > dyn_mat<typename Derived::Scalar> qpp::ptrace1 (const Eigen::MatrixBase<Derived > & A, const std::vector< idx > & dims)`

Partial trace.

See also

[qpp::ptrace2\(\)](#)

Partial trace of density matrix over the first subsystem in a bi-partite system

Parameters

| | |
|--------|--|
| A | Eigen expression |
| $dims$ | Dimensions of the bi-partite system (must be a <code>std::vector</code> with 2 elements) |

Returns

Partial trace $Tr_A(\cdot)$ over the first subsystem A in a bi-partite system $A \otimes B$, as a dynamic matrix over the same scalar field as A

6.1.3.96 `template<typename Derived> dyn_mat<typename Derived::Scalar> qpp::ptrace2 (const Eigen::MatrixBase<Derived> & A, const std::vector< idx > & dims)`

Partial trace.

See also

[qpp::ptrace1\(\)](#)

Parameters

| | |
|--------|--|
| A | Eigen expression |
| $dims$ | Dimensions of the bi-partite system (must be a <code>std::vector</code> with 2 elements) |

Returns

Partial trace $Tr_B(\cdot)$ over the second subsystem B in a bi-partite system $A \otimes B$, as a dynamic matrix over the same scalar field as A

6.1.3.97 `template<typename Derived> dyn_mat<typename Derived::Scalar> qpp::ptrtranspose (const Eigen::MatrixBase<Derived> & A, const std::vector< idx > & subsys, const std::vector< idx > & dims)`

Partial transpose.

Partial transpose of the multi-partite density matrix over a list of subsystems

Parameters

| | |
|----------|--|
| A | Eigen expression |
| $subsys$ | Subsystem indexes |
| $dims$ | Dimensions of the multi-partite system |

Returns

Partial transpose $(\cdot)^{T_{subsys}}$ over the subsystems $subsys$ in a multi-partite system, as a dynamic matrix over the same scalar field as A

6.1.3.98 `template<typename Derived> dyn_mat<typename Derived::Scalar> qpp::ptrtranspose (const Eigen::MatrixBase<Derived> & A, const std::vector< idx > & subsys, idx d = 2)`

Partial transpose.

Partial transpose of the multi-partite density matrix over a list of subsystems

Parameters

| | |
|----------|----------------------|
| A | Eigen expression |
| $subsys$ | Subsystem indexes |
| d | Subsystem dimensions |

Returns

Partial transpose $(\cdot)^{T_{subsys}}$ over the subsystems $subsys$ in a multi-partite system, as a dynamic matrix over the same scalar field as A

6.1.3.99 `template<typename Derived> double qpp::qmutualinfo (const Eigen::MatrixBase< Derived> & A, const std::vector< idx> & subsysA, const std::vector< idx> & subsysB, const std::vector< idx> & dims)`

Quantum mutual information between 2 subsystems of a composite system.

Parameters

| | |
|-----------|--|
| A | Eigen expression |
| $subsysA$ | Indexes of the first subsystem |
| $subsysB$ | Indexes of the second subsystem |
| $dims$ | Dimensions of the multi-partite system |

Returns

Mutual information between the 2 subsystems

6.1.3.100 `template<typename Derived> double qpp::qmutualinfo (const Eigen::MatrixBase< Derived> & A, const std::vector< idx> & subsysA, const std::vector< idx> & subsysB, idx d = 2)`

Quantum mutual information between 2 subsystems of a composite system.

Parameters

| | |
|-----------|---------------------------------|
| A | Eigen expression |
| $subsysA$ | Indexes of the first subsystem |
| $subsysB$ | Indexes of the second subsystem |
| d | Subsystem dimensions |

Returns

Mutual information between the 2 subsystems

6.1.3.101 `template<typename Derived> Derived qpp::rand (idx rows, idx cols, double a = 0, double b = 1)`

Generates a random matrix with entries uniformly distributed in the interval [a, b)

If complex, then both real and imaginary parts are uniformly distributed in [a, b)

This is the generic version that always throws `qpp::Exception::Type::UNDEFINED_TYPE`. It is specialized only for `qpp::dmat` and `qpp::cmat`

6.1.3.102 `template<> dmat qpp::rand (idx rows, idx cols, double a, double b) [inline]`

Generates a random real matrix with entries uniformly distributed in the interval [a, b), specialization for double matrices (`qpp::dmat`)

The template parameter cannot be automatically deduced and must be explicitly provided

Example:

```
// generates a 3 x 3 random Eigen::MatrixXd,
// with entries uniformly distributed in [-1,1)
auto mat = rand<dmat>(3, 3, -1, 1);
```

Parameters

| | |
|-------------|--|
| <i>rows</i> | Number of rows of the random generated matrix |
| <i>cols</i> | Number of columns of the random generated matrix |
| <i>a</i> | Beginning of the interval, belongs to it |
| <i>b</i> | End of the interval, does not belong to it |

Returns

Random real matrix

6.1.3.103 `template<> cmat qpp::rand (idx rows, idx cols, double a, double b)` `[inline]`

Generates a random complex matrix with entries (both real and imaginary) uniformly distributed in the interval [a, b), specialization for complex matrices ([qpp::cmat](#))

The template parameter cannot be automatically deduced and must be explicitly provided

Example:

```
// generates a 3 x 3 random Eigen::MatrixXcd,
// with entries (both real and imaginary) uniformly distributed in [-1,1)
auto mat = rand<cmat>(3, 3, -1, 1);
```

Parameters

| | |
|-------------|--|
| <i>rows</i> | Number of rows of the random generated matrix |
| <i>cols</i> | Number of columns of the random generated matrix |
| <i>a</i> | Beginning of the interval, belongs to it |
| <i>b</i> | End of the interval, does not belong to it |

Returns

Random complex matrix

6.1.3.104 `double qpp::rand (double a = 0, double b = 1)`

Generates a random real number uniformly distributed in the interval [a, b)

Parameters

| | |
|----------|--|
| <i>a</i> | Beginning of the interval, belongs to it |
| <i>b</i> | End of the interval, does not belong to it |

Returns

Random real number (double) uniformly distributed in the interval [a, b)

6.1.3.105 `cmat qpp::randH (idx D)`

Generates a random Hermitian matrix.

Parameters

| | |
|-----|--------------------------------|
| D | Dimension of the Hilbert space |
|-----|--------------------------------|

Returns

Random Hermitian matrix

6.1.3.106 `idx qpp::randidx (idx a = std::numeric_limits<idx>::min(), idx b = std::numeric_limits<idx>::max())`

Generates a random index (idx) uniformly distributed in the interval [a, b].

Parameters

| | |
|-----|--|
| a | Beginning of the interval, belongs to it |
| b | End of the interval, belongs to it |

Returns

Random index (idx) uniformly distributed in the interval [a, b]

6.1.3.107 `ket qpp::randket (idx D)`

Generates a random normalized ket (pure state vector)

Parameters

| | |
|-----|--------------------------------|
| D | Dimension of the Hilbert space |
|-----|--------------------------------|

Returns

Random normalized ket

6.1.3.108 `std::vector<cmat> qpp::randkraus (idx N , idx D)`

Generates a set of random Kraus operators.

Note

The set of Kraus operators satisfy the closure condition $\sum_i K_i^\dagger K_i = I$

Parameters

| | |
|-----|--------------------------------|
| N | Number of Kraus operators |
| D | Dimension of the Hilbert space |

Returns

Set of N Kraus operators satisfying the closure condition

6.1.3.109 `template<typename Derived > Derived qpp::randn (idx $rows$, idx $cols$, double $mean = 0$, double $sigma = 1$)`

Generates a random matrix with entries normally distributed in $N(mean, sigma)$

If complex, then both real and imaginary parts are normally distributed in $N(mean, sigma)$

This is the generic version that always throws `qpp::Exception::Type::UNDEFINED_TYPE`. It is specialized only for `qpp::dmat` and `qpp::cmat`

6.1.3.110 `template<> dmat qpp::randn (idx rows, idx cols, double mean, double sigma) [inline]`

Generates a random real matrix with entries normally distributed in $N(\text{mean}, \text{sigma})$, specialization for double matrices ([qpp::dmat](#))

The template parameter cannot be automatically deduced and must be explicitly provided

Example:

```
// generates a 3 x 3 random Eigen::MatrixXd,
// with entries normally distributed in N(0,2)
auto mat = randn<dmat>(3, 3, 0, 2);
```

Parameters

| | |
|--------------|--|
| <i>rows</i> | Number of rows of the random generated matrix |
| <i>cols</i> | Number of columns of the random generated matrix |
| <i>mean</i> | Mean |
| <i>sigma</i> | Standard deviation |

Returns

Random real matrix

6.1.3.111 `template<> cmat qpp::randn (idx rows, idx cols, double mean, double sigma) [inline]`

Generates a random complex matrix with entries (both real and imaginary) normally distributed in $N(\text{mean}, \text{sigma})$, specialization for complex matrices ([qpp::cmat](#))

The template parameter cannot be automatically deduced and must be explicitly provided

Example:

```
// generates a 3 x 3 random Eigen::MatrixXcd,
// with entries (both real and imaginary) normally distributed in N(0,2)
auto mat = randn<cmat>(3, 3, 0, 2);
```

Parameters

| | |
|--------------|--|
| <i>rows</i> | Number of rows of the random generated matrix |
| <i>cols</i> | Number of columns of the random generated matrix |
| <i>mean</i> | Mean |
| <i>sigma</i> | Standard deviation |

Returns

Random complex matrix

6.1.3.112 `double qpp::randn (double mean = 0, double sigma = 1)`

Generates a random real number (double) normally distributed in $N(\text{mean}, \text{sigma})$

Parameters

| | |
|-------------|------|
| <i>mean</i> | Mean |
|-------------|------|

| | |
|--------------|--------------------|
| <i>sigma</i> | Standard deviation |
|--------------|--------------------|

Returns

Random real number normally distributed in $N(\text{mean}, \text{sigma})$

6.1.3.113 `std::vector<idx> qpp::randperm (idx n)`

Generates a random uniformly distributed permutation.

Uses Knuth shuffle method (as implemented by `std::shuffle`), so that all permutations are equally probable

Parameters

| | |
|----------|-------------------------|
| <i>n</i> | Size of the permutation |
|----------|-------------------------|

Returns

Random permutation of size *n*

6.1.3.114 `cmat qpp::randrho (idx D)`

Generates a random density matrix.

Parameters

| | |
|----------|--------------------------------|
| <i>D</i> | Dimension of the Hilbert space |
|----------|--------------------------------|

Returns

Random density matrix

6.1.3.115 `cmat qpp::randU (idx D)`

Generates a random unitary matrix.

Parameters

| | |
|----------|--------------------------------|
| <i>D</i> | Dimension of the Hilbert space |
|----------|--------------------------------|

Returns

Random unitary

6.1.3.116 `cmat qpp::randV (idx Din, idx Dout)`

Generates a random isometry matrix.

Parameters

| | |
|------------|---------------------------------|
| <i>Din</i> | Size of the input Hilbert space |
|------------|---------------------------------|

| | |
|-------------|----------------------------------|
| <i>Dout</i> | Size of the output Hilbert space |
|-------------|----------------------------------|

Returns

Random isometry matrix

6.1.3.117 `template<typename Derived > double qpp::renyi (const Eigen::MatrixBase< Derived > & A, double alpha)`

Renyi- α entropy of the density matrix A , for $\alpha \geq 0$.

Note

When $\alpha \rightarrow 1$ the Renyi entropy converges to the von-Neumann entropy, with the logarithm in base 2

Parameters

| | |
|--------------|--|
| <i>A</i> | Eigen expression |
| <i>alpha</i> | Non-negative real number, use qpp::infty for $\alpha = \infty$ |

Returns

Renyi- α entropy, with the logarithm in base 2

6.1.3.118 `double qpp::renyi (const std::vector< double > & prob, double alpha)`

Renyi- α entropy of the probability distribution $prob$, for $\alpha \geq 0$.

Note

When $\alpha \rightarrow 1$ the Renyi entropy converges to the Shannon entropy, with the logarithm in base 2

Parameters

| | |
|--------------|--|
| <i>prob</i> | Real probability vector |
| <i>alpha</i> | Non-negative real number, use qpp::infty for $\alpha = \infty$ |

Returns

Renyi- α entropy, with the logarithm in base 2

6.1.3.119 `template<typename Derived > dyn_mat<typename Derived::Scalar> qpp::reshape (const Eigen::MatrixBase< Derived > & A, idx rows, idx cols)`

Reshape.

Uses column-major order when reshaping (same as MATLAB)

Parameters

| | |
|-------------|---------------------------------------|
| <i>A</i> | Eigen expression |
| <i>rows</i> | Number of rows of the reshaped matrix |

| | |
|-------------|--|
| <i>cols</i> | Number of columns of the reshaped matrix |
|-------------|--|

Returns

Reshaped matrix with *rows* rows and *cols* columns, as a dynamic matrix over the same scalar field as *A*

6.1.3.120 `template<typename Derived > dyn_col_vect<typename Derived::Scalar> qpp::rho2pure (const Eigen::MatrixBase< Derived > & A)`

Finds the pure state representation of a matrix proportional to a projector onto a pure state.

Note

No purity check is done, the input state *A* must have rank one, otherwise the function returns the first non-zero eigenvector of *A*

Parameters

| | |
|----------|--|
| <i>A</i> | Eigen expression, assumed to be proportional to a projector onto a pure state, i.e. <i>A</i> is assumed to have rank one |
|----------|--|

Returns

The unique non-zero eigenvector of *A*, as a dynamic column vector over the same scalar field as *A*

6.1.3.121 `template<typename Derived > void qpp::save (const Eigen::MatrixBase< Derived > & A, const std::string & fname)`

Saves Eigen expression to a binary file (internal format) in double precision.

See also

[qpp::load\(\)](#)

Parameters

| | |
|--------------|------------------|
| <i>A</i> | Eigen expression |
| <i>fname</i> | Output file name |

6.1.3.122 `template<typename Derived > void qpp::saveMATLABmatrix (const Eigen::MatrixBase< Derived > & A, const std::string & mat_file, const std::string & var_name, const std::string & mode)`

Saves an Eigen dynamic matrix to a MATLAB .mat file, generic version.

See also

[qpp::loadMATLABmatrix\(\)](#)

This is the generic version that always throws `qpp::Exception::Type::UNDEFINED_TYPE`. It is specialized only for `qpp::dmat` and `qpp::cmat` (the only matrix types that can be saved)

6.1.3.123 `template<> void qpp::saveMATLABmatrix (const Eigen::MatrixBase< dmat > & A, const std::string & mat_file, const std::string & var_name, const std::string & mode) [inline]`

Saves an Eigen dynamic matrix to a MATLAB .mat file, specialization for double matrices ([qpp::dmat](#))

See also

[qpp::loadMATLABmatrix\(\)](#)

Parameters

| | |
|-----------------|---|
| <i>A</i> | Eigen expression over the complex field |
| <i>mat_file</i> | MATALB .mat file |
| <i>var_name</i> | Variable name in the .mat file representing the matrix to be saved |
| <i>mode</i> | Saving mode (append, overwrite etc.), see MATLAB <i>matOpen()</i> documentation for details |

6.1.3.124 `template<> void qpp::saveMATLABmatrix (const Eigen::MatrixBase< cmat > & A, const std::string & mat_file, const std::string & var_name, const std::string & mode) [inline]`

Saves an Eigen dynamic matrix to a MATLAB .mat file, specialization for complex matrices ([qpp::cmat](#))

See also

[qpp::loadMATLABmatrix\(\)](#)

Parameters

| | |
|-----------------|---|
| <i>A</i> | Eigen expression over the complex field |
| <i>mat_file</i> | MATALB .mat file |
| <i>var_name</i> | Variable name in the .mat file representing the matrix to be saved |
| <i>mode</i> | Saving mode (append, overwrite etc.), see MATLAB <i>matOpen()</i> documentation for details |

6.1.3.125 `template<typename Derived > double qpp::schatten (const Eigen::MatrixBase< Derived > & A, idx p)`

Schatten norm.

Parameters

| | |
|----------|--------------------------------|
| <i>A</i> | Eigen expression |
| <i>p</i> | Integer, greater or equal to 1 |

Returns

Schatten-*p* norm of *A*, as a real number

6.1.3.126 `template<typename Derived > cmat qpp::schmidtA (const Eigen::MatrixBase< Derived > & A, const std::vector< idx > & dims)`

Schmidt basis on Alice side.

Parameters

| | |
|-------------|-------------------------------------|
| <i>A</i> | Eigen expression |
| <i>dims</i> | Dimensions of the bi-partite system |

Returns

Unitary matrix U whose columns represent the Schmidt basis vectors on Alice side.

6.1.3.127 `template<typename Derived > cmat qpp::schmidtB (const Eigen::MatrixBase< Derived > & A, const std::vector< idx > & dims)`

Schmidt basis on Bob side.

Parameters

| | |
|-------------|-------------------------------------|
| <i>A</i> | Eigen expression |
| <i>dims</i> | Dimensions of the bi-partite system |

Returns

Unitary matrix V whose columns represent the Schmidt basis vectors on Bob side.

6.1.3.128 `template<typename Derived > dyn_col_vect<double> qpp::schmidtcoeffs (const Eigen::MatrixBase< Derived > & A, const std::vector< idx > & dims)`

Schmidt coefficients of the bi-partite pure state A .

Note

The sum of the squares of the Schmidt coefficients equals 1

See also

[qpp::schmidtprobs\(\)](#)

Parameters

| | |
|-------------|-------------------------------------|
| <i>A</i> | Eigen expression |
| <i>dims</i> | Dimensions of the bi-partite system |

Returns

Schmidt coefficients of A , as a real dynamic column vector

6.1.3.129 `template<typename Derived > std::vector<double> qpp::schmidtprobs (const Eigen::MatrixBase< Derived > & A, const std::vector< idx > & dims)`

Schmidt probabilities of the bi-partite pure state A .

Defined as the squares of the Schmidt coefficients. The sum of the Schmidt probabilities equals 1.

See also

[qpp::schmidtcoeffs\(\)](#)

Parameters

| | |
|--------|-------------------------------------|
| A | Eigen expression |
| $dims$ | Dimensions of the bi-partite system |

Returns

Real vector consisting of the Schmidt probabilities of A

6.1.3.130 `template<typename Derived> cmat qpp::sinm (const Eigen::MatrixBase< Derived> & A)`

Matrix sin.

Parameters

| | |
|-----|------------------|
| A | Eigen expression |
|-----|------------------|

Returns

Matrix sine of A

6.1.3.131 `template<typename Derived> cmat qpp::spectralpowm (const Eigen::MatrixBase< Derived> & A, const cplx z)`

Matrix power.

See also

[qpp::powm\(\)](#)

Uses the spectral decomposition of A to compute the matrix power. By convention $A^0 = I$.

Parameters

| | |
|-----|------------------|
| A | Eigen expression |
| z | Complex number |

Returns

Matrix power A^z

6.1.3.132 `template<typename Derived> cmat qpp::sqrtm (const Eigen::MatrixBase< Derived> & A)`

Matrix square root.

Parameters

| | |
|-----|------------------|
| A | Eigen expression |
|-----|------------------|

Returns

Matrix square root of A

6.1.3.133 `template<typename Derived> Derived::Scalar qpp::sum (const Eigen::MatrixBase< Derived> & A)`

Element-wise sum of A .

Parameters

| | |
|----------|------------------|
| <i>A</i> | Eigen expression |
|----------|------------------|

Returns

Element-wise sum of *A*, as a scalar in the same scalar field as *A*

6.1.3.134 `template<typename InputIterator > InputIterator::value_type qpp::sum (InputIterator first, InputIterator last)`

Element-wise sum of a range.

Parameters

| | |
|--------------|--|
| <i>first</i> | Iterator to the first element of the range |
| <i>last</i> | Iterator to the last element of the range |

Returns

Element-wise sum of the range, as a scalar in the same scalar field as the range

6.1.3.135 `cmat qpp::super2choi (const cmatrix & A)`

Converts superoperator matrix to Choi matrix.

See also

[qpp::choi2super\(\)](#)

Parameters

| | |
|----------|----------------------|
| <i>A</i> | Superoperator matrix |
|----------|----------------------|

Returns

Choi matrix

6.1.3.136 `template<typename Derived > dyn_col_vect<double> qpp::svals (const Eigen::MatrixBase< Derived > & A)`

Singular values.

Parameters

| | |
|----------|------------------|
| <i>A</i> | Eigen expression |
|----------|------------------|

Returns

Singular values of *A*, ordered in decreasing order, as a real dynamic column vector

6.1.3.137 `template<typename Derived > std::tuple<cmatrix, dyn_col_vect<double>, cmatrix> qpp::svd (const Eigen::MatrixBase< Derived > & A)`

Full singular value decomposition.

Parameters

| | |
|-----|------------------|
| A | Eigen expression |
|-----|------------------|

Returns

Tuple of: 1. Left singular vectors of A , as columns of a complex dynamic matrix, 2. Singular values of A , ordered in decreasing order, as a real dynamic column vector, and 3. Right singular vectors of A , as columns of a complex dynamic matrix

6.1.3.138 `template<typename Derived > cmat qpp::svdU (const Eigen::MatrixBase< Derived > & A)`

Left singular vectors.

Parameters

| | |
|-----|------------------|
| A | Eigen expression |
|-----|------------------|

Returns

Complex dynamic matrix, whose columns are the left singular vectors of A

6.1.3.139 `template<typename Derived > cmat qpp::svdV (const Eigen::MatrixBase< Derived > & A)`

Right singular vectors.

Parameters

| | |
|-----|------------------|
| A | Eigen expression |
|-----|------------------|

Returns

Complex dynamic matrix, whose columns are the right singular vectors of A

6.1.3.140 `template<typename Derived > dyn_mat<typename Derived::Scalar> qpp::syspermute (const Eigen::MatrixBase< Derived > & A, const std::vector< idx > & perm, const std::vector< idx > & dims)`

Subsystem permutation.

Permutes the subsystems in a state vector or density matrix. The qubit $perm[i]$ is permuted to the location i .

Parameters

| | |
|--------|--|
| A | Eigen expression |
| $perm$ | Permutation |
| $dims$ | Dimensions of the multi-partite system |

Returns

Permuted system, as a dynamic matrix over the same scalar field as A

6.1.3.141 `template<typename Derived > dyn_mat<typename Derived::Scalar> qpp::syspermute (const Eigen::MatrixBase< Derived > & A, const std::vector< idx > & perm, idx d = 2)`

Subsystem permutation.

Permutes the subsystems in a state vector or density matrix. The qubit $perm[i]$ is permuted to the location i .

Parameters

| | |
|--------|----------------------|
| A | Eigen expression |
| $perm$ | Permutation |
| d | Subsystem dimensions |

Returns

Permuted system, as a dynamic matrix over the same scalar field as A

6.1.3.142 `template<typename Derived > Derived::Scalar qpp::trace (const Eigen::MatrixBase< Derived > & A)`

Trace.

Parameters

| | |
|-----|------------------|
| A | Eigen expression |
|-----|------------------|

Returns

Trace of A , as a scalar in the same scalar field as A

6.1.3.143 `template<typename Derived > dyn_mat<typename Derived::Scalar> qpp::transpose (const Eigen::MatrixBase< Derived > & A)`

Transpose.

Parameters

| | |
|-----|------------------|
| A | Eigen expression |
|-----|------------------|

Returns

Transpose of A , as a dynamic matrix over the same scalar field as A

6.1.3.144 `template<typename Derived > double qpp::tsallis (const Eigen::MatrixBase< Derived > & A, double q)`

Tsallis- q entropy of the density matrix A , for $q \geq 0$.

Note

When $q \rightarrow 1$ the Tsallis entropy converges to the von-Neumann entropy, with the logarithm in base e

Parameters

| | |
|-----|--------------------------|
| A | Eigen expression |
| q | Non-negative real number |

Returns

Tsallis- q entropy

6.1.3.145 `double qpp::tsallis (const std::vector< double > & prob, double q)`

Tsallis- q entropy of the probability distribution $prob$, for $q \geq 0$.

Note

When $q \rightarrow 1$ the Tsallis entropy converges to the Shannon entropy, with the logarithm in base e

Parameters

| | |
|-------------|--------------------------|
| <i>prob</i> | Real probability vector |
| <i>q</i> | Non-negative real number |

Returns

Tsallis- q entropy

6.1.3.146 `std::vector<long long int> qpp::x2contfrac (double x, idx n, idx cut = 1e5)`

Simple continued fraction expansion.

See also

[qpp::contfrac2x\(\)](#)

Parameters

| | |
|------------|--|
| <i>x</i> | Real number |
| <i>n</i> | Number of terms in the expansion |
| <i>cut</i> | Stop the expansion when the next term is greater than <i>cut</i> |

Returns

Integer vector containing the simple continued fraction expansion of x . If there are m less than n terms in the expansion, a shorter vector with m components is returned.

6.1.4 Variable Documentation

6.1.4.1 `constexpr double qpp::chop = 1e-10`

Used in [qpp::disp\(\)](#) for setting to zero numbers that have their absolute value smaller than [qpp::chop](#).

6.1.4.2 `const Codes& qpp::codes = Codes::get_instance()`

[qpp::Codes](#) const Singleton

Initializes the codes, see the class [qpp::Codes](#)

6.1.4.3 `constexpr double qpp::ee = 2.718281828459045235360287471352662497`

Base of natural logarithm, e .

6.1.4.4 `constexpr double qpp::eps = 1e-12`

Used to decide whether a number or expression in double precision is zero or not.

Example:

```
if (std::abs(x) < qpp::eps) // x is zero
```

6.1.4.5 `const Gates& qpp::gt = Gates::get_instance()`

[qpp::Gates](#) const Singleton

Initializes the gates, see the class [qpp::Gates](#)

6.1.4.6 `constexpr double qpp::infy = std::numeric_limits<double>::infinity()`

Used to denote infinity in double precision.

6.1.4.7 `const Init& qpp::init = Init::get_instance()`

[qpp::Init](#) const Singleton

Additional initializations/cleanups, see the class [qpp::Init](#)

6.1.4.8 `constexpr idx qpp::maxn = 64`

Maximum number of allowed qu(d)its (subsystems)

Used internally to allocate arrays on the stack (for speed reasons)

6.1.4.9 `constexpr double qpp::pi = 3.141592653589793238462643383279502884`

π

6.1.4.10 `RandomDevices& qpp::rdevs = RandomDevices::get_instance()`

[qpp::RandomDevices](#) Singleton

Initializes the random devices, see the class [qpp::RandomDevices](#)

6.1.4.11 `const States& qpp::st = States::get_instance()`

[qpp::States](#) const Singleton

Initializes the states, see the class [qpp::States](#)

6.2 qpp::experimental Namespace Reference

Experimental/test functions/classes, do not use or modify.

6.2.1 Detailed Description

Experimental/test functions/classes, do not use or modify.

6.3 qpp::internal Namespace Reference

Internal utility functions, do not use/modify.

Classes

- class [IOManipEigen](#)
- class [IOManipPointer](#)
- class [IOManipRange](#)
- class [Singleton](#)

[Singleton](#) policy class, used internally to implement the singleton pattern via CRTP (Curiously recurring template pattern)

Functions

- void `_n2multiidx` (`idx` n, `idx` numdims, const `idx` *dims, `idx` *result)
- `idx_multiidx2n` (const `idx` *midx, `idx` numdims, const `idx` *dims)
- template<typename Derived >
bool `_check_square_mat` (const Eigen::MatrixBase< Derived > &A)
- template<typename Derived >
bool `_check_vector` (const Eigen::MatrixBase< Derived > &A)
- template<typename Derived >
bool `_check_row_vector` (const Eigen::MatrixBase< Derived > &A)
- template<typename Derived >
bool `_check_col_vector` (const Eigen::MatrixBase< Derived > &A)
- template<typename T >
bool `_check_nonzero_size` (const T &x)
- bool `_check_dims` (const std::vector< `idx` > &dims)
- template<typename Derived >
bool `_check_dims_match_mat` (const std::vector< `idx` > &dims, const Eigen::MatrixBase< Derived > &A)
- template<typename Derived >
bool `_check_dims_match_cvect` (const std::vector< `idx` > &dims, const Eigen::MatrixBase< Derived > &V)
- template<typename Derived >
bool `_check_dims_match_rvect` (const std::vector< `idx` > &dims, const Eigen::MatrixBase< Derived > &V)
- bool `_check_eq_dims` (const std::vector< `idx` > &dims, `idx` dim)
- bool `_check_subsys_match_dims` (const std::vector< `idx` > &subsys, const std::vector< `idx` > &dims)
- bool `_check_perm` (const std::vector< `idx` > &perm)
- template<typename Derived1 , typename Derived2 >
`dyn_mat`< typename
Derived1::Scalar > `_kron2` (const Eigen::MatrixBase< Derived1 > &A, const Eigen::MatrixBase< Derived2
> &B)
- template<typename Derived1 , typename Derived2 >
`dyn_mat`< typename
Derived1::Scalar > `_dirsum2` (const Eigen::MatrixBase< Derived1 > &A, const Eigen::MatrixBase< De-
rived2 > &B)
- template<typename T >
void `variadic_vector_emplace` (std::vector< T > &)
- template<typename T , typename First , typename... Args>
void `variadic_vector_emplace` (std::vector< T > &v, First &&first, Args &&...args)

6.3.1 Detailed Description

Internal utility functions, do not use/modify.

6.3.2 Function Documentation

6.3.2.1 template<typename Derived > bool qpp::internal::_check_col_vector (const Eigen::MatrixBase< Derived > & A)

6.3.2.2 bool qpp::internal::_check_dims (const std::vector< `idx` > & dims)

6.3.2.3 template<typename Derived > bool qpp::internal::_check_dims_match_cvect (const std::vector< `idx` > & dims,
const Eigen::MatrixBase< Derived > & V)

6.3.2.4 template<typename Derived > bool qpp::internal::_check_dims_match_mat (const std::vector< `idx` > & dims, const
Eigen::MatrixBase< Derived > & A)

6.3.2.5 template<typename Derived > bool qpp::internal::_check_dims_match_rvect (const std::vector< `idx` > & dims,
const Eigen::MatrixBase< Derived > & V)

- 6.3.2.6 `bool qpp::internal::_check_eq_dims (const std::vector< idx > & dims, idx dim)`
- 6.3.2.7 `template<typename T > bool qpp::internal::_check_nonzero_size (const T & x)`
- 6.3.2.8 `bool qpp::internal::_check_perm (const std::vector< idx > & perm)`
- 6.3.2.9 `template<typename Derived > bool qpp::internal::_check_row_vector (const Eigen::MatrixBase< Derived > & A)`
- 6.3.2.10 `template<typename Derived > bool qpp::internal::_check_square_mat (const Eigen::MatrixBase< Derived > & A)`
- 6.3.2.11 `bool qpp::internal::_check_subsys_match_dims (const std::vector< idx > & subsys, const std::vector< idx > & dims)`
- 6.3.2.12 `template<typename Derived > bool qpp::internal::_check_vector (const Eigen::MatrixBase< Derived > & A)`
- 6.3.2.13 `template<typename Derived1 , typename Derived2 > dyn_mat<typename Derived1::Scalar>
qpp::internal::_dirsum2 (const Eigen::MatrixBase< Derived1 > & A, const Eigen::MatrixBase< Derived2 > & B)`
- 6.3.2.14 `template<typename Derived1 , typename Derived2 > dyn_mat<typename Derived1::Scalar> qpp::internal::_kron2 (
const Eigen::MatrixBase< Derived1 > & A, const Eigen::MatrixBase< Derived2 > & B)`
- 6.3.2.15 `idx qpp::internal::_multiidx2n (const idx * midx, idx numdims, const idx * dims)` [inline]
- 6.3.2.16 `void qpp::internal::_n2multiidx (idx n, idx numdims, const idx * dims, idx * result)` [inline]
- 6.3.2.17 `template<typename T > void qpp::internal::variadic_vector_emplace (std::vector< T > &)`
- 6.3.2.18 `template<typename T , typename First , typename... Args> void qpp::internal::variadic_vector_emplace (
std::vector< T > & v, First && first, Args &&... args)`

Chapter 7

Class Documentation

7.1 qpp::Codes Class Reference

const Singleton class that defines quantum error correcting codes

```
#include <classes/codes.h>
```

Inheritance diagram for qpp::Codes:



Collaboration diagram for qpp::Codes:



Public Types

- enum `Type` { `Type::FIVE_QUBIT` = 1, `Type::SEVEN_QUBIT_STEANE`, `Type::NINE_QUBIT_SHOR` }
Code types, add more codes here if needed.

Public Member Functions

- `ket codeword` (`Type` type, `idx` i) const
Returns the codeword of the specified code type.

Private Member Functions

- `Codes` ()
Default constructor.

Friends

- class `internal::Singleton< const Codes >`

Additional Inherited Members

7.1.1 Detailed Description

const Singleton class that defines quantum error correcting codes

7.1.2 Member Enumeration Documentation

7.1.2.1 enum `qpp::Codes::Type` [strong]

Code types, add more codes here if needed.

See also

`qpp::Codes::codeword()`

Enumerator

`FIVE_QUBIT` [[5,1,3]] qubit code

`SEVEN_QUBIT_STEANE` [[7,1,3]] Steane qubit code

`NINE_QUBIT_SHOR` [[9,1,3]] Shor qubit code

7.1.3 Constructor & Destructor Documentation

7.1.3.1 `qpp::Codes::Codes` () [inline], [private]

Default constructor.

7.1.4 Member Function Documentation

7.1.4.1 `ket qpp::Codes::codeword (Type type, idx i) const` `[inline]`

Returns the codeword of the specified code type.

See also

[qpp::Codes::Type](#)

Parameters

| | |
|-------------|----------------|
| <i>type</i> | Code type |
| <i>i</i> | Codeword index |

Returns

i-th codeword of the code *type*

7.1.5 Friends And Related Function Documentation

7.1.5.1 `friend class internal::Singleton< const Codes >` `[friend]`

The documentation for this class was generated from the following file:

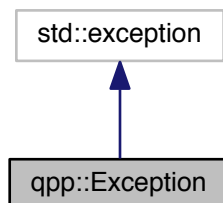
- [classes/codes.h](#)

7.2 qpp::Exception Class Reference

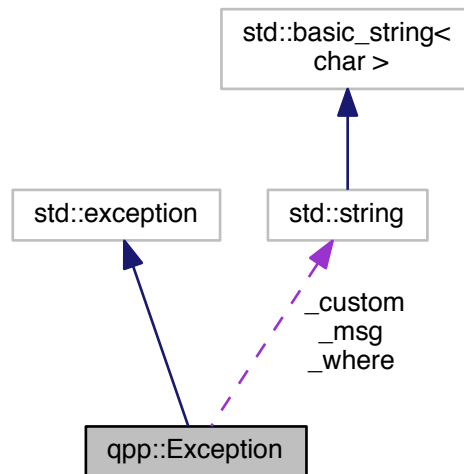
Generates custom exceptions, used when validating function parameters.

```
#include <classes/exception.h>
```

Inheritance diagram for qpp::Exception:



Collaboration diagram for qpp::Exception:



Public Types

- enum `Type` {
`Type::UNKNOWN_EXCEPTION = 1`, `Type::ZERO_SIZE`, `Type::MATRIX_NOT_SQUARE`, `Type::MATRIX_NOT_CVECTOR`,
`Type::MATRIX_NOT_RVECTOR`, `Type::MATRIX_NOT_VECTOR`, `Type::MATRIX_NOT_SQUARE_OR_CVECTOR`, `Type::MATRIX_NOT_SQUARE_OR_RVECTOR`,
`Type::MATRIX_NOT_SQUARE_OR_VECTOR`, `Type::MATRIX_MISMATCH_SUBSYS`, `Type::DIMS_INVALID`, `Type::DIMS_NOT_EQUAL`,
`Type::DIMS_MISMATCH_MATRIX`, `Type::DIMS_MISMATCH_CVECTOR`, `Type::DIMS_MISMATCH_RVECTOR`, `Type::DIMS_MISMATCH_VECTOR`,
`Type::SUBSYS_MISMATCH_DIMS`, `Type::PERM_INVALID`, `Type::PERM_MISMATCH_DIMS`, `Type::NOT_QUBIT_GATE`,
`Type::NOT_QUBIT_SUBSYS`, `Type::NOT_BIPARTITE`, `Type::NO_CODEWORD`, `Type::OUT_OF_RANGE`,
`Type::TYPE_MISMATCH`, `Type::UNDEFINED_TYPE`, `Type::CUSTOM_EXCEPTION` }
Exception types, add more here if needed.

Public Member Functions

- `Exception` (const std::string &where, const `Type` &type)
Constructs an exception.
- `Exception` (const std::string &where, const std::string &custom)
Constructs an exception.
- virtual const char * `what` () const noexcept override
Overrides std::exception::what()

Private Member Functions

- void `_construct_exception_msg` ()
Constructs the exception description from its type.

Private Attributes

- `std::string _where`
- `std::string _msg`
- `Type _type`
- `std::string _custom`

7.2.1 Detailed Description

Generates custom exceptions, used when validating function parameters.

Customize this class if more exceptions are needed

7.2.2 Member Enumeration Documentation

7.2.2.1 `enum qpp::Exception::Type` [strong]

[Exception](#) types, add more here if needed.

See also

[qpp::Exception::_construct_exception_msg\(\)](#)

Enumerator

- UNKNOWN_EXCEPTION** Unknown exception
- ZERO_SIZE** Zero sized object, e.g. empty `Eigen::Matrix` or `std::vector<>` with no elements
- MATRIX_NOT_SQUARE** `Eigen::Matrix` is not square
- MATRIX_NOT_CVECTOR** `Eigen::Matrix` is not a column vector
- MATRIX_NOT_RVECTOR** `Eigen::Matrix` is not a row vector
- MATRIX_NOT_VECTOR** `Eigen::Matrix` is not a row/column vector
- MATRIX_NOT_SQUARE_OR_CVECTOR** `Eigen::Matrix` is not square nor a column vector
- MATRIX_NOT_SQUARE_OR_RVECTOR** `Eigen::Matrix` is not square nor a row vector
- MATRIX_NOT_SQUARE_OR_VECTOR** `Eigen::Matrix` is not square nor a row/column vector
- MATRIX_MISMATCH_SUBSYS** Matrix size mismatch subsystem sizes (e.g. in [qpp::apply\(\)](#))
- DIMS_INVALID** `std::vector<idx>` of dimensions has zero size or contains zeros
- DIMS_NOT_EQUAL** Local/global dimensions are not equal
- DIMS_MISMATCH_MATRIX** Product of the elements of `std::vector<idx>` of dimensions is not equal to the number of rows of `Eigen::Matrix` (assumed to be a square matrix)
- DIMS_MISMATCH_CVECTOR** Product of the elements of `std::vector<idx>` of dimensions is not equal to the number of elements of `Eigen::Matrix` (assumed to be a column vector)
- DIMS_MISMATCH_RVECTOR** Product of the elements of `std::vector<idx>` of dimensions is not equal to the number of elements of `Eigen::Matrix` (assumed to be a row vector)
- DIMS_MISMATCH_VECTOR** Product of the elements of `std::vector<idx>` of dimensions is not equal to the number of elements of `Eigen::Matrix` (assumed to be a row/column vector)
- SUBSYS_MISMATCH_DIMS** `std::vector<idx>` of subsystem labels has duplicates, or has entries that are larger than the size of the `std::vector<idx>` of dimensions
- PERM_INVALID** `std::vector<idx>` does not represent a valid permutation
- PERM_MISMATCH_DIMS** Size of the `std::vector<idx>` representing the permutation is different from the size of the `std::vector<idx>` of dimensions
- NOT_QUBIT_GATE** `Eigen::Matrix` is not 2 x 2

NOT_QUBIT_SUBSYS Subsystems are not 2-dimensional

NOT_BIPARTITE `std::vector<idx>` of dimensions has size different from 2

NO_CODEWORD Codeword does not exist, thrown when calling `qpp::Codes::codeword()` with invalid index *i*

OUT_OF_RANGE Parameter out of range

TYPE_MISMATCH Scalar types do not match

UNDEFINED_TYPE Templated specialization not defined for this type

CUSTOM_EXCEPTION Custom exception, user must provide a custom message

7.2.3 Constructor & Destructor Documentation

7.2.3.1 `qpp::Exception::Exception (const std::string & where, const Type & type)` `[inline]`

Constructs an exception.

Parameters

| | |
|--------------|--|
| <i>where</i> | Text representing where the exception occurred |
| <i>type</i> | Exception type, defined in <code>qpp::Exception::Type</code> |

7.2.3.2 `qpp::Exception::Exception (const std::string & where, const std::string & custom)` `[inline]`

Constructs an exception.

This is an overloaded member function, provided for convenience. It differs from the above function only in what argument(s) it accepts.

Parameters

| | |
|---------------|--|
| <i>where</i> | Text representing where the exception occurred |
| <i>custom</i> | Exception description |

7.2.4 Member Function Documentation

7.2.4.1 `void qpp::Exception::_construct_exception_msg ()` `[inline]`, `[private]`

Constructs the exception description from its type.

See also

[qpp::Exception::Type](#)

Must modify the code of this function if more exceptions are added

7.2.4.2 `virtual const char* qpp::Exception::what () const` `[inline]`, `[override]`, `[virtual]`, `[noexcept]`

Overrides `std::exception::what()`

Returns

[Exception](#) description

7.2.5 Member Data Documentation

7.2.5.1 `std::string qpp::Exception::_custom` [private]

7.2.5.2 `std::string qpp::Exception::_msg` [private]

7.2.5.3 `Type qpp::Exception::_type` [private]

7.2.5.4 `std::string qpp::Exception::_where` [private]

The documentation for this class was generated from the following file:

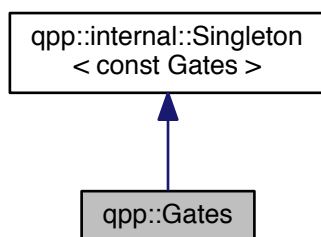
- [classes/exception.h](#)

7.3 qpp::Gates Class Reference

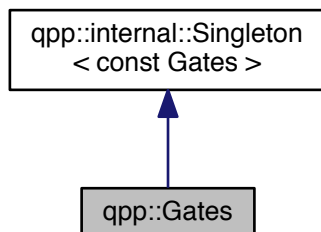
const Singleton class that implements most commonly used gates

```
#include <classes/gates.h>
```

Inheritance diagram for qpp::Gates:



Collaboration diagram for qpp::Gates:



Public Member Functions

- **cmat Rn** (double theta, std::vector< double > n) const
Rotation of theta about the 3-dimensional real unit vector n.
- **cmat Zd** (idx D) const
Generalized Z gate for qudits.
- **cmat Fd** (idx D) const
Fourier transform gate for qudits.
- **cmat Xd** (idx D) const
Generalized X gate for qudits.
- template<typename Derived = Eigen::MatrixXcd>
Derived **Id** (idx D) const
Identity gate.
- template<typename Derived >
dyn_mat< typename Derived::Scalar > **CTRL** (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &ctrl, const std::vector< idx > &subsys, idx n, idx d=2) const
Generates the multi-partite multiple-controlled-A gate in matrix form.
- template<typename Derived >
dyn_mat< typename Derived::Scalar > **expandout** (const Eigen::MatrixBase< Derived > &A, idx pos, const std::vector< idx > &dims) const
Expands out.

Public Attributes

- **cmat Id2** {cmat::Identity(2, 2)}
Identity gate.
- **cmat H** {cmat::Zero(2, 2)}
Hadamard gate.
- **cmat X** {cmat::Zero(2, 2)}
Pauli Sigma-X gate.
- **cmat Y** {cmat::Zero(2, 2)}
Pauli Sigma-Y gate.
- **cmat Z** {cmat::Zero(2, 2)}
Pauli Sigma-Z gate.
- **cmat S** {cmat::Zero(2, 2)}
S gate.
- **cmat T** {cmat::Zero(2, 2)}
T gate.
- **cmat CNOT** {cmat::Identity(4, 4)}
Controlled-NOT control target gate.
- **cmat CZ** {cmat::Identity(4, 4)}
Controlled-Phase gate.
- **cmat CNOTba** {cmat::Zero(4, 4)}
Controlled-NOT target control gate.
- **cmat SWAP** {cmat::Identity(4, 4)}
SWAP gate.
- **cmat TOF** {cmat::Identity(8, 8)}
Toffoli gate.
- **cmat FRED** {cmat::Identity(8, 8)}
Fredkin gate.

Private Member Functions

- [Gates \(\)](#)
Initializes the gates.

Friends

- class [internal::Singleton< const Gates >](#)

Additional Inherited Members

7.3.1 Detailed Description

const Singleton class that implements most commonly used gates

7.3.2 Constructor & Destructor Documentation

7.3.2.1 qpp::Gates::Gates () [inline], [private]

Initializes the gates.

7.3.3 Member Function Documentation

7.3.3.1 template<typename Derived > dyn_mat<typename Derived::Scalar> qpp::Gates::CTRL (const Eigen::MatrixBase< Derived > & A, const std::vector< idx > & ctrl, const std::vector< idx > & subsys, idx n, idx d = 2) const [inline]

Generates the multi-partite multiple-controlled-*A* gate in matrix form.

See also

[qpp::applyCTRL\(\)](#)

Note

The dimension of the gate *A* must match the dimension of *subsys*

Parameters

| | |
|---------------|--|
| <i>A</i> | Eigen expression |
| <i>ctrl</i> | Control subsystem indexes |
| <i>subsys</i> | Subsystem indexes where the gate <i>A</i> is applied |
| <i>n</i> | Total number of subsystems |
| <i>d</i> | Subsystem dimensions |

Returns

CTRL-*A* gate, as a matrix over the same scalar field as *A*

7.3.3.2 `template<typename Derived > dyn_mat<typename Derived::Scalar> qpp::Gates::expandout (const Eigen::MatrixBase< Derived > & A, idx pos, const std::vector< idx > & dims) const [inline]`

Expands out.

See also

[qpp::kron\(\)](#)

Expands out A as a matrix in a multi-partite system. Faster than using [qpp::kron\(I, I, ..., I, A, I, ..., I\)](#).

Parameters

| | |
|--------|--|
| A | Eigen expression |
| pos | Position |
| $dims$ | Dimensions of the multi-partite system |

Returns

Tensor product $I \otimes \cdots \otimes I \otimes A \otimes I \otimes \cdots \otimes I$, with A on position pos , as a dynamic matrix over the same scalar field as A

7.3.3.3 `cmat qpp::Gates::Fd (idx D) const [inline]`

Fourier transform gate for qudits.

Note

Defined as $F = \sum_{jk} \exp(2\pi i jk/D) |j\rangle\langle k|$

Parameters

| | |
|-----|--------------------------------|
| D | Dimension of the Hilbert space |
|-----|--------------------------------|

Returns

Fourier transform gate for qudits

7.3.3.4 `template<typename Derived = Eigen::MatrixXcd> Derived qpp::Gates::Id (idx D) const [inline]`

Identity gate.

Note

Can change the return type from complex matrix (default) by explicitly specifying the template parameter

Parameters

| | |
|-----|--------------------------------|
| D | Dimension of the Hilbert space |
|-----|--------------------------------|

Returns

Identity gate

7.3.3.5 `cmat qpp::Gates::Rn (double theta, std::vector< double > n) const [inline]`

Rotation of $theta$ about the 3-dimensional real unit vector n .

Parameters

| | |
|--------------|--------------------------------|
| <i>theta</i> | Rotation angle |
| <i>n</i> | 3-dimensional real unit vector |

Returns

Rotation gate

7.3.3.6 `cmat qpp::Gates::Xd (idx D) const [inline]`

Generalized X gate for qudits.

Note

Defined as $X = \sum_j |j \oplus 1\rangle \langle j|$

Parameters

| | |
|----------|--------------------------------|
| <i>D</i> | Dimension of the Hilbert space |
|----------|--------------------------------|

Returns

Generalized X gate for qudits

7.3.3.7 `cmat qpp::Gates::Zd (idx D) const [inline]`

Generalized Z gate for qudits.

Note

Defined as $Z = \sum_j \exp(2\pi i j / D) |j\rangle \langle j|$

Parameters

| | |
|----------|--------------------------------|
| <i>D</i> | Dimension of the Hilbert space |
|----------|--------------------------------|

Returns

Generalized Z gate for qudits

7.3.4 Friends And Related Function Documentation

7.3.4.1 `friend class internal::Singleton< const Gates > [friend]`

7.3.5 Member Data Documentation

7.3.5.1 `cmat qpp::Gates::CNOT {cmat::Identity(4, 4)}`

Controlled-NOT control target gate.

7.3.5.2 `cmat qpp::Gates::CNOTba {cmat::Zero(4, 4)}`

Controlled-NOT target control gate.

7.3.5.3 `cmat qpp::Gates::CZ {cmat::Identity(4, 4)}`

Controlled-Phase gate.

7.3.5.4 `cmat qpp::Gates::FRED {cmat::Identity(8, 8)}`

Fredkin gate.

7.3.5.5 `cmat qpp::Gates::H {cmat::Zero(2, 2)}`

Hadamard gate.

7.3.5.6 `cmat qpp::Gates::Id2 {cmat::Identity(2, 2)}`

Identity gate.

7.3.5.7 `cmat qpp::Gates::S {cmat::Zero(2, 2)}`

S gate.

7.3.5.8 `cmat qpp::Gates::SWAP {cmat::Identity(4, 4)}`

SWAP gate.

7.3.5.9 `cmat qpp::Gates::T {cmat::Zero(2, 2)}`

T gate.

7.3.5.10 `cmat qpp::Gates::TOF {cmat::Identity(8, 8)}`

Toffoli gate.

7.3.5.11 `cmat qpp::Gates::X {cmat::Zero(2, 2)}`

Pauli Sigma-X gate.

7.3.5.12 `cmat qpp::Gates::Y {cmat::Zero(2, 2)}`

Pauli Sigma-Y gate.

7.3.5.13 `cmat qpp::Gates::Z {cmat::Zero(2, 2)}`

Pauli Sigma-Z gate.

The documentation for this class was generated from the following file:

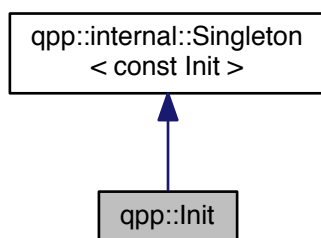
- [classes/gates.h](#)

7.4 qpp::Init Class Reference

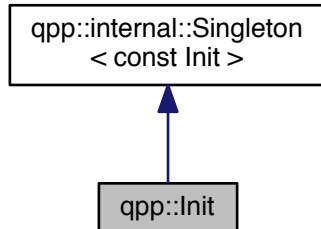
const Singleton class that performs additional initializations/cleanups

```
#include <classes/init.h>
```

Inheritance diagram for qpp::Init:



Collaboration diagram for qpp::Init:



Public Member Functions

- [Init \(\)](#)
Additional initializations.

Private Member Functions

- [~Init \(\)](#)
Cleanups.

Friends

- class [internal::Singleton< const Init >](#)

Additional Inherited Members

7.4.1 Detailed Description

const Singleton class that performs additional initializations/cleanups

7.4.2 Constructor & Destructor Documentation

7.4.2.1 `qpp::Init::Init()` `[inline]`

Additional initializations.

7.4.2.2 `qpp::Init::~~Init()` `[inline]`, `[private]`

Cleanups.

7.4.3 Friends And Related Function Documentation

7.4.3.1 `friend class internal::Singleton< const Init >` `[friend]`

The documentation for this class was generated from the following file:

- [classes/init.h](#)

7.5 `qpp::internal::IOManipEigen` Class Reference

```
#include <internal/classes/iomanip.h>
```

Public Member Functions

- `template<typename Derived >`
`IOManipEigen` (`const Eigen::MatrixBase< Derived > &A`, `double chop=qpp::chop`)
- `IOManipEigen` (`const cplx z`, `double chop=qpp::chop`)

Private Attributes

- `cmat_A`
- `double _chop`

Friends

- `template<typename charT , typename traits >`
`std::basic_ostream< charT,`
`traits > &operator<< (std::basic_ostream< charT, traits > &os, const IOManipEigen &rhs)`

7.5.1 Constructor & Destructor Documentation

7.5.1.1 `template<typename Derived > qpp::internal::IOManipEigen::IOManipEigen (const Eigen::MatrixBase< Derived > &A, double chop = qpp::chop)` `[inline]`, `[explicit]`

7.5.1.2 `qpp::internal::IOManipEigen::IOManipEigen (const cplx z, double chop = qpp::chop) [inline], [explicit]`

7.5.2 Friends And Related Function Documentation

7.5.2.1 `template<typename charT , typename traits > std::basic_ostream<charT, traits>& operator<< (std::basic_ostream< charT, traits > & os, const IOManipEigen & rhs) [friend]`

7.5.3 Member Data Documentation

7.5.3.1 `cmat qpp::internal::IOManipEigen::_A [private]`

7.5.3.2 `double qpp::internal::IOManipEigen::_chop [private]`

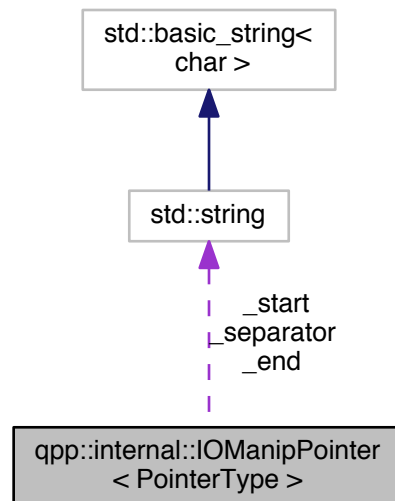
The documentation for this class was generated from the following file:

- [internal/classes/iomanip.h](#)

7.6 qpp::internal::IOManipPointer< PointerType > Class Template Reference

```
#include <internal/classes/iomanip.h>
```

Collaboration diagram for `qpp::internal::IOManipPointer< PointerType >`:



Public Member Functions

- [IOManipPointer](#) (const PointerType *p, const [idx](#) n, const std::string &separator, const std::string &start="[, const std::string &end="]")
- [IOManipPointer](#) (const [IOManipPointer](#) &)=default
- [IOManipPointer](#) & [operator=](#) (const [IOManipPointer](#) &)=default

Private Attributes

- `const PointerType * _p`
- `idx _n`
- `std::string _separator`
- `std::string _start`
- `std::string _end`

Friends

- `template<typename charT , typename traits >
std::basic_ostream< charT,
traits > & operator<< (std::basic_ostream< charT, traits > &os, const IManipPointer &rhs)`

7.6.1 Constructor & Destructor Documentation

- 7.6.1.1 `template<typename PointerType> qpp::internal::IManipPointer< PointerType >::IManipPointer (const PointerType * p, const idx n, const std::string & separator, const std::string & start = " [", const std::string & end = "]") [inline],[explicit]`
- 7.6.1.2 `template<typename PointerType> qpp::internal::IManipPointer< PointerType >::IManipPointer (const IManipPointer< PointerType > &) [default]`

7.6.2 Member Function Documentation

- 7.6.2.1 `template<typename PointerType> IManipPointer& qpp::internal::IManipPointer< PointerType >::operator= (const IManipPointer< PointerType > &) [default]`

7.6.3 Friends And Related Function Documentation

- 7.6.3.1 `template<typename PointerType> template<typename charT , typename traits > std::basic_ostream<charT, traits>& operator<< (std::basic_ostream< charT, traits > & os, const IManipPointer< PointerType > & rhs) [friend]`

7.6.4 Member Data Documentation

- 7.6.4.1 `template<typename PointerType> std::string qpp::internal::IManipPointer< PointerType >::_end [private]`
- 7.6.4.2 `template<typename PointerType> idx qpp::internal::IManipPointer< PointerType >::_n [private]`
- 7.6.4.3 `template<typename PointerType> const PointerType* qpp::internal::IManipPointer< PointerType >::_p [private]`
- 7.6.4.4 `template<typename PointerType> std::string qpp::internal::IManipPointer< PointerType >::_separator [private]`
- 7.6.4.5 `template<typename PointerType> std::string qpp::internal::IManipPointer< PointerType >::_start [private]`

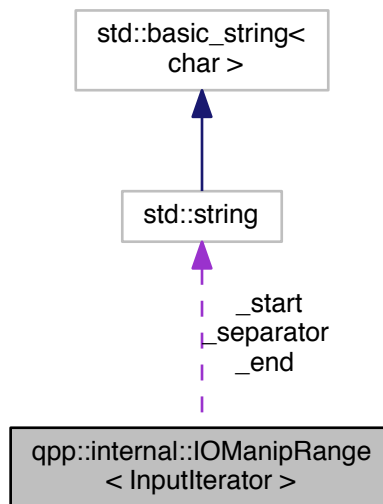
The documentation for this class was generated from the following file:

- `internal/classes/iomanip.h`

7.7 qpp::internal::IOManipRange< InputIterator > Class Template Reference

```
#include <internal/classes/iomanip.h>
```

Collaboration diagram for qpp::internal::IOManipRange< InputIterator >:



Public Member Functions

- [IOManipRange](#) (InputIterator first, InputIterator last, const std::string &separator, const std::string &start="[,", const std::string &end="]")

Private Attributes

- InputIterator [_first](#)
- InputIterator [_last](#)
- std::string [_separator](#)
- std::string [_start](#)
- std::string [_end](#)

Friends

- template<typename charT, typename traits>
std::basic_ostream< charT,
traits > & [operator<<](#) (std::basic_ostream< charT, traits > &os, const [IOManipRange](#) &rhs)

7.7.1 Constructor & Destructor Documentation

7.7.1.1 template<typename InputIterator> qpp::internal::IOManipRange< InputIterator >::IOManipRange (InputIterator *first*, InputIterator *last*, const std::string & *separator*, const std::string & *start* = "[", const std::string & *end* = "]") [inline], [explicit]

7.7.2 Friends And Related Function Documentation

7.7.2.1 `template<typename InputIterator > template<typename charT , typename traits > std::basic_ostream<charT, traits>& operator<< (std::basic_ostream< charT, traits > & os, const IOManipRange< InputIterator > & rhs)`
[friend]

7.7.3 Member Data Documentation

7.7.3.1 `template<typename InputIterator > std::string qpp::internal::IOManipRange< InputIterator >::_end`
[private]

7.7.3.2 `template<typename InputIterator > InputIterator qpp::internal::IOManipRange< InputIterator >::_first`
[private]

7.7.3.3 `template<typename InputIterator > InputIterator qpp::internal::IOManipRange< InputIterator >::_last`
[private]

7.7.3.4 `template<typename InputIterator > std::string qpp::internal::IOManipRange< InputIterator >::_separator`
[private]

7.7.3.5 `template<typename InputIterator > std::string qpp::internal::IOManipRange< InputIterator >::_start`
[private]

The documentation for this class was generated from the following file:

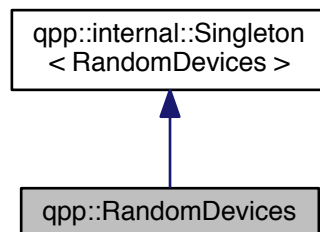
- [internal/classes/iomanip.h](#)

7.8 qpp::RandomDevices Class Reference

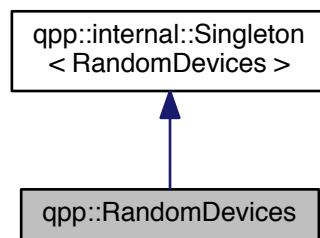
Singleton class that manages the source of randomness in the library.

```
#include <classes/random_devices.h>
```

Inheritance diagram for qpp::RandomDevices:



Collaboration diagram for qpp::RandomDevices:



Public Attributes

- `std::mt19937 _rng`
Mersenne twister random number generator.

Private Member Functions

- `RandomDevices ()`
Initializes and seeds the random number generators.

Private Attributes

- `std::random_device _rd`
used to seed std::mt19937 _rng

Friends

- class `internal::Singleton < RandomDevices >`

Additional Inherited Members

7.8.1 Detailed Description

Singleton class that manages the source of randomness in the library.

It consists of a wrapper around an `std::mt19937` Mersenne twister random number generator engine and an `std::random_device` engine. The latter is used to seed the Mersenne twister. The class also seeds the standard `std::srand` C number generator, as it is used by Eigen.

7.8.2 Constructor & Destructor Documentation

7.8.2.1 `qpp::RandomDevices::RandomDevices ()` `[inline]`, `[private]`

Initializes and seeds the random number generators.

7.8.3 Friends And Related Function Documentation

7.8.3.1 friend class `internal::Singleton< RandomDevices >` `[friend]`

7.8.4 Member Data Documentation

7.8.4.1 `std::random_device qpp::RandomDevices::_rd` `[private]`

used to seed `std::mt19937 _rng`

7.8.4.2 `std::mt19937 qpp::RandomDevices::_rng`

Mersenne twister random number generator.

The documentation for this class was generated from the following file:

- [classes/random_devices.h](#)

7.9 `qpp::internal::Singleton< T >` Class Template Reference

`Singleton` policy class, used internally to implement the singleton pattern via CRTP (Curiously recurring template pattern)

```
#include <internal/classes/singleton.h>
```

Static Public Member Functions

- static `T & get_instance ()`

Protected Member Functions

- `Singleton ()`
- virtual `~Singleton ()`
- `Singleton (const Singleton &)=delete`
- `Singleton & operator= (const Singleton &)=delete`

7.9.1 Detailed Description

```
template<typename T>class qpp::internal::Singleton< T >
```

`Singleton` policy class, used internally to implement the singleton pattern via CRTP (Curiously recurring template pattern)

To implement a singleton, derive your class from `qpp::internal::Singleton`, make `qpp::internal::Singleton` a friend of your class, then declare the constructor of your class as private. To get an instance, use the static member function `qpp::internal::Singleton::get_instance()`, which returns a reference to your newly created singleton (thread-safe in C++11).

Example:

```
class MySingleton: public qpp::internal::Singleton<MySingleton>
{
    friend class qpp::internal::Singleton<MySingleton>;
public:
    // Declare all public members here
private:
    MySingleton()
```

```

    {
        // Implement the constructor here
    }
};

MySingleton& mySingleton = MySingleton::get_instance(); // Get an instance

```

See also

Code of [qpp::Codes](#), [qpp::Gates](#), [qpp::Init](#), [qpp::RandomDevices](#), [qpp::States](#) or [qpp.h](#) for real world examples of usage.

7.9.2 Constructor & Destructor Documentation

7.9.2.1 `template<typename T> qpp::internal::Singleton< T >::Singleton ()` `[inline], [protected]`

7.9.2.2 `template<typename T> virtual qpp::internal::Singleton< T >::~~Singleton ()` `[inline], [protected], [virtual]`

7.9.2.3 `template<typename T> qpp::internal::Singleton< T >::Singleton (const Singleton< T > &)` `[protected], [delete]`

7.9.3 Member Function Documentation

7.9.3.1 `template<typename T> static T& qpp::internal::Singleton< T >::get_instance ()` `[inline], [static]`

7.9.3.2 `template<typename T> Singleton& qpp::internal::Singleton< T >::operator= (const Singleton< T > &)` `[protected], [delete]`

The documentation for this class was generated from the following file:

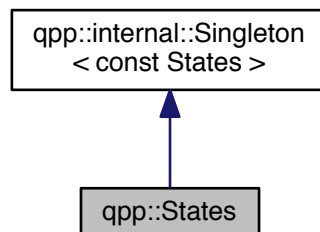
- [internal/classes/singleton.h](#)

7.10 qpp::States Class Reference

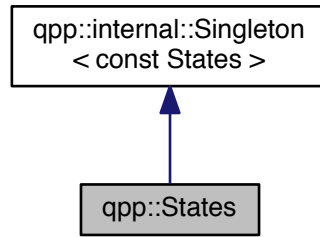
const Singleton class that implements most commonly used states

```
#include <classes/states.h>
```

Inheritance diagram for qpp::States:



Collaboration diagram for `qpp::States`:



Public Attributes

- `ket x0` {ket::Zero(2)}
Pauli Sigma-X 0-eigenstate $|+\rangle$
- `ket x1` {ket::Zero(2)}
Pauli Sigma-X 1-eigenstate $|-\rangle$
- `ket y0` {ket::Zero(2)}
Pauli Sigma-Y 0-eigenstate $|y+\rangle$
- `ket y1` {ket::Zero(2)}
Pauli Sigma-Y 1-eigenstate $|y-\rangle$
- `ket z0` {ket::Zero(2)}
Pauli Sigma-Z 0-eigenstate $|0\rangle$
- `ket z1` {ket::Zero(2)}
Pauli Sigma-Z 1-eigenstate $|1\rangle$
- `cmat px0` {cmat::Zero(2, 2)}
Projector onto the Pauli Sigma-X 0-eigenstate $|+\rangle\langle+|$.
- `cmat px1` {cmat::Zero(2, 2)}
Projector onto the Pauli Sigma-X 1-eigenstate $|-\rangle\langle-|$.
- `cmat py0` {cmat::Zero(2, 2)}
Projector onto the Pauli Sigma-Y 0-eigenstate $|y+\rangle\langle y+|$.
- `cmat py1` {cmat::Zero(2, 2)}
Projector onto the Pauli Sigma-Y 1-eigenstate $|y-\rangle\langle y-|$.
- `cmat pz0` {cmat::Zero(2, 2)}
Projector onto the Pauli Sigma-Z 0-eigenstate $|0\rangle\langle 0|$.
- `cmat pz1` {cmat::Zero(2, 2)}
Projector onto the Pauli Sigma-Z 1-eigenstate $|1\rangle\langle 1|$.
- `ket b00` {ket::Zero(4)}
Bell-00 state (following the convention in Nielsen and Chuang)
- `ket b01` {ket::Zero(4)}
Bell-01 state (following the convention in Nielsen and Chuang)
- `ket b10` {ket::Zero(4)}
Bell-10 state (following the convention in Nielsen and Chuang)
- `ket b11` {ket::Zero(4)}
Bell-11 state (following the convention in Nielsen and Chuang)
- `cmat pb00` {cmat::Zero(4, 4)}

- Projector onto the Bell-00 state.*
- [cmat pb01](#) {cmat::Zero(4, 4)}
- Projector onto the Bell-01 state.*
- [cmat pb10](#) {cmat::Zero(4, 4)}
- Projector onto the Bell-10 state.*
- [cmat pb11](#) {cmat::Zero(4, 4)}
- Projector onto the Bell-11 state.*
- [ket GHZ](#) {ket::Zero(8)}
- GHZ state.*
- [ket W](#) {ket::Zero(8)}
- W state.*
- [cmat pGHZ](#) {cmat::Zero(8, 8)}
- Projector onto the GHZ state.*
- [cmat pW](#) {cmat::Zero(8, 8)}
- Projector onto the W state.*

Private Member Functions

- [States](#) ()

Friends

- class [internal::Singleton< const States >](#)

Additional Inherited Members

7.10.1 Detailed Description

const Singleton class that implements most commonly used states

7.10.2 Constructor & Destructor Documentation

7.10.2.1 [qpp::States::States \(\)](#) [inline], [private]

Initialize the states

7.10.3 Friends And Related Function Documentation

7.10.3.1 [friend class internal::Singleton< const States >](#) [friend]

7.10.4 Member Data Documentation

7.10.4.1 [ket qpp::States::b00](#) {ket::Zero(4)}

Bell-00 state (following the convention in Nielsen and Chuang)

7.10.4.2 [ket qpp::States::b01](#) {ket::Zero(4)}

Bell-01 state (following the convention in Nielsen and Chuang)

7.10.4.3 `ket qpp::States::b10 {ket::Zero(4)}`

Bell-10 state (following the convention in Nielsen and Chuang)

7.10.4.4 `ket qpp::States::b11 {ket::Zero(4)}`

Bell-11 state (following the convention in Nielsen and Chuang)

7.10.4.5 `ket qpp::States::GHZ {ket::Zero(8)}`

GHZ state.

7.10.4.6 `cmat qpp::States::pb00 {cmat::Zero(4, 4)}`

Projector onto the Bell-00 state.

7.10.4.7 `cmat qpp::States::pb01 {cmat::Zero(4, 4)}`

Projector onto the Bell-01 state.

7.10.4.8 `cmat qpp::States::pb10 {cmat::Zero(4, 4)}`

Projector onto the Bell-10 state.

7.10.4.9 `cmat qpp::States::pb11 {cmat::Zero(4, 4)}`

Projector onto the Bell-11 state.

7.10.4.10 `cmat qpp::States::pGHZ {cmat::Zero(8, 8)}`

Projector onto the GHZ state.

7.10.4.11 `cmat qpp::States::pW {cmat::Zero(8, 8)}`

Projector onto the W state.

7.10.4.12 `cmat qpp::States::px0 {cmat::Zero(2, 2)}`

Projector onto the Pauli Sigma-X 0-eigenstate $|+\rangle\langle+|$.

7.10.4.13 `cmat qpp::States::px1 {cmat::Zero(2, 2)}`

Projector onto the Pauli Sigma-X 1-eigenstate $|-\rangle\langle-|$.

7.10.4.14 `cmat qpp::States::py0 {cmat::Zero(2, 2)}`

Projector onto the Pauli Sigma-Y 0-eigenstate $|y+\rangle\langle y+|$.

7.10.4.15 `cmat qpp::States::py1 {cmat::Zero(2, 2)}`

Projector onto the Pauli Sigma-Y 1-eigenstate $|y-\rangle\langle y-|$.

7.10.4.16 `cmat qpp::States::pz0 {cmat::Zero(2, 2)}`

Projector onto the Pauli Sigma-Z 0-eigenstate $|0\rangle\langle 0|$.

7.10.4.17 `cmat qpp::States::pz1 {cmat::Zero(2, 2)}`

Projector onto the Pauli Sigma-Z 1-eigenstate $|1\rangle\langle 1|$.

7.10.4.18 `ket qpp::States::W {ket::Zero(8)}`

W state.

7.10.4.19 `ket qpp::States::x0 {ket::Zero(2)}`

Pauli Sigma-X 0-eigenstate $|+\rangle$

7.10.4.20 `ket qpp::States::x1 {ket::Zero(2)}`

Pauli Sigma-X 1-eigenstate $|-\rangle$

7.10.4.21 `ket qpp::States::y0 {ket::Zero(2)}`

Pauli Sigma-Y 0-eigenstate $|y+\rangle$

7.10.4.22 `ket qpp::States::y1 {ket::Zero(2)}`

Pauli Sigma-Y 1-eigenstate $|y-\rangle$

7.10.4.23 `ket qpp::States::z0 {ket::Zero(2)}`

Pauli Sigma-Z 0-eigenstate $|0\rangle$

7.10.4.24 `ket qpp::States::z1 {ket::Zero(2)}`

Pauli Sigma-Z 1-eigenstate $|1\rangle$

The documentation for this class was generated from the following file:

- [classes/states.h](#)

7.11 qpp::Timer Class Reference

Measures time.

```
#include <classes/timer.h>
```

Public Member Functions

- [Timer](#) ()
Constructs an instance with the current time as the starting point.
- void [tic](#) ()
Resets the chronometer.
- const [Timer](#) & [toc](#) ()
Stops the chronometer.
- double [seconds](#) () const
Time passed in seconds.

Protected Attributes

- std::chrono::steady_clock::time_point [_start](#)
- std::chrono::steady_clock::time_point [_end](#)

Friends

- template<typename charT , typename traits >
std::basic_ostream< charT,
traits > & [operator<<](#) (std::basic_ostream< charT, traits > &os, const [Timer](#) &rhs)
Overload for std::ostream operators.

7.11.1 Detailed Description

Measures time.

Uses a std::chrono::steady_clock. It is not affected by wall clock changes during runtime.

7.11.2 Constructor & Destructor Documentation

7.11.2.1 `qpp::Timer::Timer ()` `[inline]`

Constructs an instance with the current time as the starting point.

7.11.3 Member Function Documentation

7.11.3.1 `double qpp::Timer::seconds ()` `const` `[inline]`

Time passed in seconds.

Returns

Number of seconds that passed between the instantiation/reset and invocation of `qpp::Timer::toc()`

7.11.3.2 `void qpp::Timer::tic ()` `[inline]`

Resets the chronometer.

Resets the starting/ending point to the current time

7.11.3.3 const Timer& qpp::Timer::toc () [inline]

Stops the chronometer.

Set the current time as the ending point

Returns

Current instance

7.11.4 Friends And Related Function Documentation

7.11.4.1 template<typename charT , typename traits > std::basic_ostream<charT, traits>& operator<< (std::basic_ostream< charT, traits > & os, const Timer & rhs) [friend]

Overload for std::ostream operators.

Parameters

| | |
|------------|--------------------------------|
| <i>os</i> | Output stream |
| <i>rhs</i> | Timer instance |

Returns

Writes to the output stream the number of seconds that passed between the instantiation/reset and invocation of [qpp::Timer::toc\(\)](#).

7.11.5 Member Data Documentation

7.11.5.1 std::chrono::steady_clock::time_point qpp::Timer::_end [protected]

7.11.5.2 std::chrono::steady_clock::time_point qpp::Timer::_start [protected]

The documentation for this class was generated from the following file:

- [classes/timer.h](#)

Chapter 8

File Documentation

8.1 classes/codes.h File Reference

Quantum error correcting codes.

This graph shows which files directly or indirectly include this file:



Classes

- class [qpp::Codes](#)
const Singleton class that defines quantum error correcting codes

Namespaces

- [qpp](#)
Quantum++ main namespace.

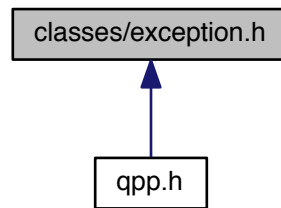
8.1.1 Detailed Description

Quantum error correcting codes.

8.2 classes/exception.h File Reference

Exceptions.

This graph shows which files directly or indirectly include this file:



Classes

- class [qpp::Exception](#)
Generates custom exceptions, used when validating function parameters.

Namespaces

- [qpp](#)
Quantum++ main namespace.

8.2.1 Detailed Description

Exceptions.

8.3 classes/gates.h File Reference

Quantum gates.

This graph shows which files directly or indirectly include this file:



Classes

- class [qpp::Gates](#)
const Singleton class that implements most commonly used gates

Namespaces

- [qpp](#)
Quantum++ main namespace.

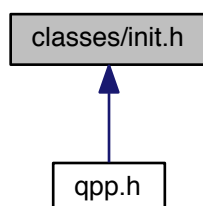
8.3.1 Detailed Description

Quantum gates.

8.4 classes/init.h File Reference

Initialization.

This graph shows which files directly or indirectly include this file:



Classes

- class [qpp::Init](#)
const Singleton class that performs additional initializations/cleanups

Namespaces

- [qpp](#)
Quantum++ main namespace.

8.4.1 Detailed Description

Initialization.

8.5 classes/random_devices.h File Reference

Random devices.

This graph shows which files directly or indirectly include this file:



Classes

- class [qpp::RandomDevices](#)
Singleton class that manages the source of randomness in the library.

Namespaces

- [qpp](#)
Quantum++ main namespace.

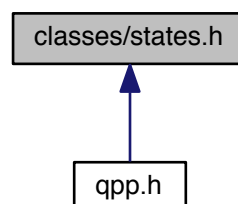
8.5.1 Detailed Description

Random devices.

8.6 classes/states.h File Reference

Quantum states.

This graph shows which files directly or indirectly include this file:



Classes

- class [qpp::States](#)
const Singleton class that implements most commonly used states

Namespaces

- [qpp](#)
Quantum++ main namespace.

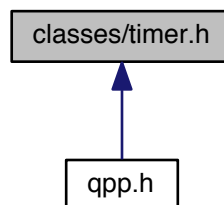
8.6.1 Detailed Description

Quantum states.

8.7 classes/timer.h File Reference

Timing.

This graph shows which files directly or indirectly include this file:



Classes

- class [qpp::Timer](#)
Measures time.

Namespaces

- [qpp](#)
Quantum++ main namespace.

8.7.1 Detailed Description

Timing.

8.8 constants.h File Reference

Constants.

This graph shows which files directly or indirectly include this file:



Namespaces

- [qpp](#)
Quantum++ main namespace.

Functions

- constexpr cplx [qpp::operator""_i](#) (unsigned long long int x)
User-defined literal for complex $i = \sqrt{-1}$ (integer overload)
- constexpr cplx [qpp::operator""_i](#) (long double x)
User-defined literal for complex $i = \sqrt{-1}$ (real overload)
- cplx [qpp::omega](#) (idx D)
D-th root of unity.

Variables

- constexpr double [qpp::chop](#) = 1e-10
Used in [qpp::disp\(\)](#) for setting to zero numbers that have their absolute value smaller than [qpp::chop](#).
- constexpr double [qpp::eps](#) = 1e-12
Used to decide whether a number or expression in double precision is zero or not.
- constexpr idx [qpp::maxn](#) = 64
Maximum number of allowed qu(d)its (subsystems)
- constexpr double [qpp::pi](#) = 3.141592653589793238462643383279502884
 π
- constexpr double [qpp::ee](#) = 2.718281828459045235360287471352662497
Base of natural logarithm, e .
- constexpr double [qpp::infy](#) = std::numeric_limits<double>::infinity()
Used to denote infinity in double precision.

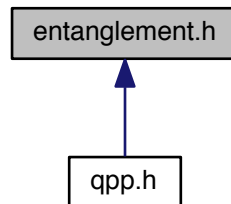
8.8.1 Detailed Description

Constants.

8.9 entanglement.h File Reference

Entanglement functions.

This graph shows which files directly or indirectly include this file:



Namespaces

- [qpp](#)
Quantum++ main namespace.

Functions

- `template<typename Derived >
dyn_col_vect< double > qpp::schmidtcoeffs (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &dims)`
Schmidt coefficients of the bi-partite pure state A.
- `template<typename Derived >
cmat qpp::schmidtA (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &dims)`
Schmidt basis on Alice side.
- `template<typename Derived >
cmat qpp::schmidtB (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &dims)`
Schmidt basis on Bob side.
- `template<typename Derived >
std::vector< double > qpp::schmidtprobs (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &dims)`
Schmidt probabilities of the bi-partite pure state A.
- `template<typename Derived >
double qpp::entanglement (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &dims)`
Entanglement of the bi-partite pure state A.
- `template<typename Derived >
double qpp::gconcurrence (const Eigen::MatrixBase< Derived > &A)`
G-concurrence of the bi-partite pure state A.
- `template<typename Derived >
double qpp::negativity (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &dims)`
Negativity of the bi-partite mixed state A.
- `template<typename Derived >
double qpp::lognegativity (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &dims)`
Logarithmic negativity of the bi-partite mixed state A.

- `template<typename Derived >`
`double qpp::concurrence (const Eigen::MatrixBase< Derived > &A)`
Wootters concurrence of the bi-partite qubit mixed state A.

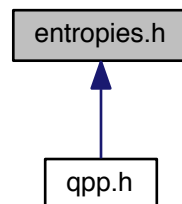
8.9.1 Detailed Description

Entanglement functions.

8.10 entropies.h File Reference

Entropy functions.

This graph shows which files directly or indirectly include this file:



Namespaces

- `qpp`
Quantum++ main namespace.

Functions

- `template<typename Derived >`
`double qpp::entropy (const Eigen::MatrixBase< Derived > &A)`
von-Neumann entropy of the density matrix A
- `double qpp::entropy (const std::vector< double > &prob)`
Shannon entropy of the probability distribution prob.
- `template<typename Derived >`
`double qpp::renyi (const Eigen::MatrixBase< Derived > &A, double alpha)`
Renyi- α entropy of the density matrix A, for $\alpha \geq 0$.
- `double qpp::renyi (const std::vector< double > &prob, double alpha)`
Renyi- α entropy of the probability distribution prob, for $\alpha \geq 0$.
- `template<typename Derived >`
`double qpp::tsallis (const Eigen::MatrixBase< Derived > &A, double q)`
Tsallis- q entropy of the density matrix A, for $q \geq 0$.
- `double qpp::tsallis (const std::vector< double > &prob, double q)`
Tsallis- q entropy of the probability distribution prob, for $q \geq 0$.

- `template<typename Derived >`
`double qpp::qmutualinfo (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &subsysA, const std::vector< idx > &subsysB, const std::vector< idx > &dims)`

Quantum mutual information between 2 subsystems of a composite system.

- `template<typename Derived >`
`double qpp::qmutualinfo (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &subsysA, const std::vector< idx > &subsysB, idx d=2)`

Quantum mutual information between 2 subsystems of a composite system.

8.10.1 Detailed Description

Entropy functions.

8.11 experimental/test.h File Reference

Experimental/test functions/classes.

Namespaces

- `qpp`
Quantum++ main namespace.
- `qpp::experimental`
Experimental/test functions/classes, do not use or modify.

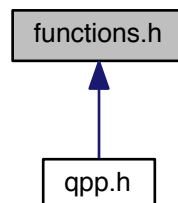
8.11.1 Detailed Description

Experimental/test functions/classes.

8.12 functions.h File Reference

Generic quantum computing functions.

This graph shows which files directly or indirectly include this file:



Namespaces

- [qpp](#)

Quantum++ main namespace.

Functions

- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > qpp::transpose (const Eigen::MatrixBase< Derived > &A)`
Transpose.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > qpp::conjugate (const Eigen::MatrixBase< Derived > &A)`
Complex conjugate.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > qpp::adjoint (const Eigen::MatrixBase< Derived > &A)`
Adjoint.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > qpp::inverse (const Eigen::MatrixBase< Derived > &A)`
Inverse.
- `template<typename Derived >`
`Derived::Scalar qpp::trace (const Eigen::MatrixBase< Derived > &A)`
Trace.
- `template<typename Derived >`
`Derived::Scalar qpp::det (const Eigen::MatrixBase< Derived > &A)`
Determinant.
- `template<typename Derived >`
`Derived::Scalar qpp::logdet (const Eigen::MatrixBase< Derived > &A)`
Logarithm of the determinant.
- `template<typename Derived >`
`Derived::Scalar qpp::sum (const Eigen::MatrixBase< Derived > &A)`
Element-wise sum of A.
- `template<typename Derived >`
`Derived::Scalar qpp::prod (const Eigen::MatrixBase< Derived > &A)`
Element-wise product of A.
- `template<typename Derived >`
`double qpp::norm (const Eigen::MatrixBase< Derived > &A)`
Frobenius norm.
- `template<typename Derived >`
`std::pair< dyn_col_vect< cplx >`
`, cmat > qpp::eig (const Eigen::MatrixBase< Derived > &A)`
Full eigen decomposition.
- `template<typename Derived >`
`dyn_col_vect< cplx > qpp::evals (const Eigen::MatrixBase< Derived > &A)`
Eigenvalues.
- `template<typename Derived >`
`cmat qpp::evecs (const Eigen::MatrixBase< Derived > &A)`
Eigenvectors.
- `template<typename Derived >`
`std::pair< dyn_col_vect`
`< double >, cmat > qpp::heig (const Eigen::MatrixBase< Derived > &A)`
Full eigen decomposition of Hermitian expression.
- `template<typename Derived >`
`dyn_col_vect< double > qpp::hevals (const Eigen::MatrixBase< Derived > &A)`

Hermitian eigenvalues.

- template<typename Derived >
cmat [qpp::hevects](#) (const Eigen::MatrixBase< Derived > &A)

Hermitian eigenvectors.

- template<typename Derived >
std::tuple< cmat, dyn_col_vect
< double >, cmat > [qpp::svd](#) (const Eigen::MatrixBase< Derived > &A)

Full singular value decomposition.

- template<typename Derived >
dyn_col_vect< double > [qpp::svals](#) (const Eigen::MatrixBase< Derived > &A)

Singular values.

- template<typename Derived >
cmat [qpp::svdU](#) (const Eigen::MatrixBase< Derived > &A)

Left singular vectors.

- template<typename Derived >
cmat [qpp::svdV](#) (const Eigen::MatrixBase< Derived > &A)

Right singular vectors.

- template<typename Derived >
cmat [qpp::funm](#) (const Eigen::MatrixBase< Derived > &A, cplx(*f)(const cplx &))

Functional calculus $f(A)$

- template<typename Derived >
cmat [qpp::sqrtm](#) (const Eigen::MatrixBase< Derived > &A)

Matrix square root.

- template<typename Derived >
cmat [qpp::absm](#) (const Eigen::MatrixBase< Derived > &A)

Matrix absolut value.

- template<typename Derived >
cmat [qpp::expm](#) (const Eigen::MatrixBase< Derived > &A)

Matrix exponential.

- template<typename Derived >
cmat [qpp::logm](#) (const Eigen::MatrixBase< Derived > &A)

Matrix logarithm.

- template<typename Derived >
cmat [qpp::sinm](#) (const Eigen::MatrixBase< Derived > &A)

Matrix sin.

- template<typename Derived >
cmat [qpp::cosm](#) (const Eigen::MatrixBase< Derived > &A)

Matrix cos.

- template<typename Derived >
cmat [qpp::spectralpowm](#) (const Eigen::MatrixBase< Derived > &A, const cplx z)

Matrix power.

- template<typename Derived >
dyn_mat< typename Derived::Scalar > [qpp::powm](#) (const Eigen::MatrixBase< Derived > &A, idx n)

Matrix power.

- template<typename Derived >
double [qpp::schatten](#) (const Eigen::MatrixBase< Derived > &A, idx p)

Schatten norm.

- template<typename OutputScalar , typename Derived >
dyn_mat< OutputScalar > [qpp::cwise](#) (const Eigen::MatrixBase< Derived > &A, OutputScalar(*f)(const
typename Derived::Scalar &))

Functor.

- template<typename T >
dyn_mat< typename T::Scalar > [qpp::kron](#) (const T &head)

- Kronecker product.*

 - `template<typename T , typename... Args>`
`dyn_mat< typename T::Scalar > qpp::kron (const T &head, const Args &...tail)`

Kronecker product.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > qpp::kron (const std::vector< Derived > &As)`

Kronecker product.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > qpp::kron (const std::initializer_list< Derived > &As)`

Kronecker product.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > qpp::kronpow (const Eigen::MatrixBase< Derived > &A, idx n)`

Kronecker power.
- `template<typename T >`
`dyn_mat< typename T::Scalar > qpp::dirsum (const T &head)`

Direct sum.
- `template<typename T , typename... Args>`
`dyn_mat< typename T::Scalar > qpp::dirsum (const T &head, const Args &...tail)`

Direct sum.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > qpp::dirsum (const std::vector< Derived > &As)`

Direct sum.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > qpp::dirsum (const std::initializer_list< Derived > &As)`

Direct sum.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > qpp::dirsumpow (const Eigen::MatrixBase< Derived > &A, idx n)`

Direct sum power.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > qpp::reshape (const Eigen::MatrixBase< Derived > &A, idx rows, idx cols)`

Reshape.
- `template<typename Derived1 , typename Derived2 >`
`dyn_mat< typename`
`Derived1::Scalar > qpp::comm (const Eigen::MatrixBase< Derived1 > &A, const Eigen::MatrixBase< Derived2 > &B)`

Commutator.
- `template<typename Derived1 , typename Derived2 >`
`dyn_mat< typename`
`Derived1::Scalar > qpp::anticomm (const Eigen::MatrixBase< Derived1 > &A, const Eigen::MatrixBase< Derived2 > &B)`

Anti-commutator.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > qpp::prj (const Eigen::MatrixBase< Derived > &V)`

Projector.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > qpp::grams (const std::vector< Derived > &Vs)`

Gram-Schmidt orthogonalization.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > qpp::grams (const std::initializer_list< Derived > &Vs)`

Gram-Schmidt orthogonalization.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > qpp::grams (const Eigen::MatrixBase< Derived > &A)`

- *Gram-Schmidt orthogonalization.*
std::vector< idx > [qpp::n2multiidx](#) (idx n, const std::vector< idx > &dims)
- *Non-negative integer index to multi-index.*
idx [qpp::multiidx2n](#) (const std::vector< idx > &midx, const std::vector< idx > &dims)
- *Multi-index to non-negative integer index.*
ket [qpp::mket](#) (const std::vector< idx > &mask, const std::vector< idx > &dims)
- *Multi-partite qudit ket.*
ket [qpp::mket](#) (const std::vector< idx > &mask, idx d=2)
- *Multi-partite qudit ket.*
cmat [qpp::mprj](#) (const std::vector< idx > &mask, const std::vector< idx > &dims)
- *Projector onto multi-partite qudit ket.*
cmat [qpp::mprj](#) (const std::vector< idx > &mask, idx d=2)
- *Projector onto multi-partite qudit ket.*
template<typename InputIterator >
std::vector< double > [qpp::abssq](#) (InputIterator first, InputIterator last)
Computes the absolut values squared of a range of complex numbers.
- template<typename Derived >
std::vector< double > [qpp::abssq](#) (const Eigen::MatrixBase< Derived > &V)
Computes the absolut values squared of a column vector.
- template<typename InputIterator >
InputIterator::value_type [qpp::sum](#) (InputIterator first, InputIterator last)
Element-wise sum of a range.
- template<typename InputIterator >
InputIterator::value_type [qpp::prod](#) (InputIterator first, InputIterator last)
Element-wise product of a range.
- template<typename Derived >
dyn_col_vect< typename
Derived::Scalar > [qpp::rho2pure](#) (const Eigen::MatrixBase< Derived > &A)
Finds the pure state representation of a matrix proportional to a projector onto a pure state.

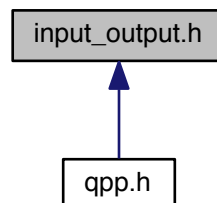
8.12.1 Detailed Description

Generic quantum computing functions.

8.13 input_output.h File Reference

Input/output functions.

This graph shows which files directly or indirectly include this file:



Namespaces

- [qpp](#)

Quantum++ main namespace.

Functions

- `template<typename Derived >`
`internal::IOManipEigen qpp::disp (const Eigen::MatrixBase< Derived > &A, double chop=qpp::chop)`
Eigen expression ostream manipulator.
- `internal::IOManipEigen qpp::disp (cplx z, double chop=qpp::chop)`
Complex number ostream manipulator.
- `template<typename InputIterator >`
`internal::IOManipRange`
`< InputIterator > qpp::disp (const InputIterator &first, const InputIterator &last, const std::string &separator,`
`const std::string &start="[", const std::string &end=""])`
Range ostream manipulator.
- `template<typename Container >`
`internal::IOManipRange`
`< typename`
`Container::const_iterator > qpp::disp (const Container &c, const std::string &separator, const std::string`
`&start="[", const std::string &end=""])`
Standard container ostream manipulator. The container must support std::begin(), std::end() and forward iteration.
- `template<typename PointerType >`
`internal::IOManipPointer`
`< PointerType > qpp::disp (const PointerType *p, idx n, const std::string &separator, const std::string`
`&start="[", const std::string &end=""])`
C-style pointer ostream manipulator.
- `template<typename Derived >`
`void qpp::save (const Eigen::MatrixBase< Derived > &A, const std::string &fname)`
Saves Eigen expression to a binary file (internal format) in double precision.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > qpp::load (const std::string &fname)`
Loads Eigen matrix from a binary file (internal format) in double precision.

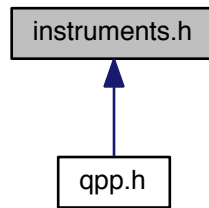
8.13.1 Detailed Description

Input/output functions.

8.14 instruments.h File Reference

Measurement functions.

This graph shows which files directly or indirectly include this file:



Namespaces

- [qpp](#)
Quantum++ main namespace.

Functions

- `template<typename Derived >
std::tuple< idx, std::vector
< double >, std::vector< cmat > > qpp::measure (const Eigen::MatrixBase< Derived > &A, const std::vector< cmat > &Ks, const std::vector< idx > &subsys, const std::vector< idx > &dims)`
Measures the part subsys of the multi-partite state vector or density matrix A using the set of Kraus operators Ks.
- `template<typename Derived >
std::tuple< idx, std::vector
< double >, std::vector< cmat > > qpp::measure (const Eigen::MatrixBase< Derived > &A, const std::vector< initializer_list< cmat > &Ks, const std::vector< idx > &subsys, const std::vector< idx > &dims)`
Measures the part subsys of the multi-partite state vector or density matrix A using the set of Kraus operators Ks.
- `template<typename Derived >
std::tuple< idx, std::vector
< double >, std::vector< cmat > > qpp::measure (const Eigen::MatrixBase< Derived > &A, const std::vector< cmat > &Ks, const std::vector< idx > &subsys, const idx d=2)`
Measures the part subsys of the multi-partite state vector or density matrix A using the set of Kraus operators Ks.
- `template<typename Derived >
std::tuple< idx, std::vector
< double >, std::vector< cmat > > qpp::measure (const Eigen::MatrixBase< Derived > &A, const std::vector< initializer_list< cmat > &Ks, const std::vector< idx > &subsys, const idx d=2)`
Measures the part subsys of the multi-partite state vector or density matrix A using the set of Kraus operators Ks.
- `template<typename Derived >
std::tuple< idx, std::vector
< double >, std::vector< cmat > > qpp::measure (const Eigen::MatrixBase< Derived > &A, const cmat &U, const std::vector< idx > &subsys, const std::vector< idx > &dims)`
Measures the part subsys of the multi-partite state A in the orthonormal basis specified by the unitary matrix U.
- `template<typename Derived >
std::tuple< idx, std::vector
< double >, std::vector< cmat > > qpp::measure (const Eigen::MatrixBase< Derived > &A, const cmat &U, const std::vector< idx > &subsys, const idx d=2)`
Measures the part subsys of the multi-partite state A in the orthonormal basis specified by the unitary matrix U.

- `template<typename Derived >`
`std::tuple< idx, std::vector`
`< double >, std::vector< cmat > > qpp::measure (const Eigen::MatrixBase< Derived > &A, const std::vector< cmat > &Ks)`
Measures the state A using the set of Kraus operators Ks.
- `template<typename Derived >`
`std::tuple< idx, std::vector`
`< double >, std::vector< cmat > > qpp::measure (const Eigen::MatrixBase< Derived > &A, const std::initializer_list< cmat > &Ks)`
Measures the state A using the set of Kraus operators Ks.
- `template<typename Derived >`
`std::tuple< idx, std::vector`
`< double >, std::vector< cmat > > qpp::measure (const Eigen::MatrixBase< Derived > &A, const cmat &U)`
Measures the state A in the orthonormal basis specified by the unitary matrix U.

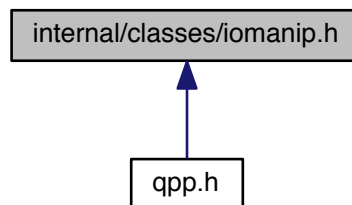
8.14.1 Detailed Description

Measurement functions.

8.15 internal/classes/iomanip.h File Reference

Input/output manipulators.

This graph shows which files directly or indirectly include this file:



Classes

- class [qpp::internal::IOManipRange< InputIterator >](#)
- class [qpp::internal::IOManipPointer< PointerType >](#)
- class [qpp::internal::IOManipEigen](#)

Namespaces

- [qpp](#)
Quantum++ main namespace.
- [qpp::internal](#)
Internal utility functions, do not use/modify.

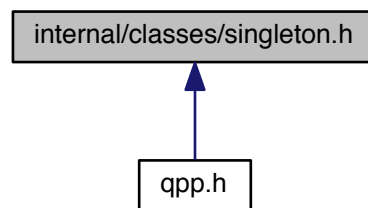
8.15.1 Detailed Description

Input/output manipulators.

8.16 internal/classes/singleton.h File Reference

Singleton pattern via CRTP.

This graph shows which files directly or indirectly include this file:



Classes

- class [qpp::internal::Singleton< T >](#)

Singleton policy class, used internally to implement the singleton pattern via CRTP (Curiously recurring template pattern)

Namespaces

- [qpp](#)

Quantum++ main namespace.

- [qpp::internal](#)

Internal utility functions, do not use/modify.

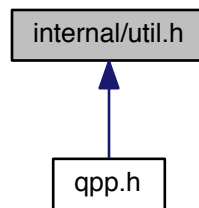
8.16.1 Detailed Description

Singleton pattern via CRTP.

8.17 internal/util.h File Reference

Internal utility functions.

This graph shows which files directly or indirectly include this file:



Namespaces

- [qpp](#)
Quantum++ main namespace.
- [qpp::internal](#)
Internal utility functions, do not use/modify.

Functions

- void [qpp::internal::_n2multiidx](#) (idx n, idx numdims, const idx *dims, idx *result)
- idx [qpp::internal::_multiidx2n](#) (const idx *midx, idx numdims, const idx *dims)
- template<typename Derived >
bool [qpp::internal::_check_square_mat](#) (const Eigen::MatrixBase< Derived > &A)
- template<typename Derived >
bool [qpp::internal::_check_vector](#) (const Eigen::MatrixBase< Derived > &A)
- template<typename Derived >
bool [qpp::internal::_check_row_vector](#) (const Eigen::MatrixBase< Derived > &A)
- template<typename Derived >
bool [qpp::internal::_check_col_vector](#) (const Eigen::MatrixBase< Derived > &A)
- template<typename T >
bool [qpp::internal::_check_nonzero_size](#) (const T &x)
- bool [qpp::internal::_check_dims](#) (const std::vector< idx > &dims)
- template<typename Derived >
bool [qpp::internal::_check_dims_match_mat](#) (const std::vector< idx > &dims, const Eigen::MatrixBase< Derived > &A)
- template<typename Derived >
bool [qpp::internal::_check_dims_match_cvect](#) (const std::vector< idx > &dims, const Eigen::MatrixBase< Derived > &V)
- template<typename Derived >
bool [qpp::internal::_check_dims_match_rvect](#) (const std::vector< idx > &dims, const Eigen::MatrixBase< Derived > &V)
- bool [qpp::internal::_check_eq_dims](#) (const std::vector< idx > &dims, idx dim)
- bool [qpp::internal::_check_subsys_match_dims](#) (const std::vector< idx > &subsys, const std::vector< idx > &dims)
- bool [qpp::internal::_check_perm](#) (const std::vector< idx > &perm)
- template<typename Derived1 , typename Derived2 >
dyn_mat< typename
Derived1::Scalar > [qpp::internal::_kron2](#) (const Eigen::MatrixBase< Derived1 > &A, const Eigen::MatrixBase< Derived2 > &B)

- `template<typename Derived1 , typename Derived2 >`
`dyn_mat< typename`
`Derived1::Scalar > qpp::internal::_dirsum2 (const Eigen::MatrixBase< Derived1 > &A, const Eigen::MatrixBase< Derived2 > &B)`
- `template<typename T >`
`void qpp::internal::variadic_vector_emplace (std::vector< T > &)`
- `template<typename T , typename First , typename... Args>`
`void qpp::internal::variadic_vector_emplace (std::vector< T > &v, First &&first, Args &&...args)`

8.17.1 Detailed Description

Internal utility functions.

8.18 MATLAB/matlab.h File Reference

Input/output interfacing with MATLAB.

```
#include "mat.h"
#include "mex.h"
```

Namespaces

- [qpp](#)
Quantum++ main namespace.

Functions

- `template<typename Derived >`
`Derived qpp::loadMATLABmatrix (const std::string &mat_file, const std::string &var_name)`
Loads an Eigen dynamic matrix from a MATLAB .mat file, generic version.
- `template<>`
`dmat qpp::loadMATLABmatrix (const std::string &mat_file, const std::string &var_name)`
Loads an Eigen dynamic matrix from a MATLAB .mat file, specialization for double matrices ([qpp::dmat](#))
- `template<>`
`cmat qpp::loadMATLABmatrix (const std::string &mat_file, const std::string &var_name)`
Loads an Eigen dynamic matrix from a MATLAB .mat file, specialization for complex matrices ([qpp::cmat](#))
- `template<typename Derived >`
`void qpp::saveMATLABmatrix (const Eigen::MatrixBase< Derived > &A, const std::string &mat_file, const std::string &var_name, const std::string &mode)`
Saves an Eigen dynamic matrix to a MATLAB .mat file, generic version.
- `template<>`
`void qpp::saveMATLABmatrix (const Eigen::MatrixBase< dmat > &A, const std::string &mat_file, const std::string &var_name, const std::string &mode)`
Saves an Eigen dynamic matrix to a MATLAB .mat file, specialization for double matrices ([qpp::dmat](#))
- `template<>`
`void qpp::saveMATLABmatrix (const Eigen::MatrixBase< cmat > &A, const std::string &mat_file, const std::string &var_name, const std::string &mode)`
Saves an Eigen dynamic matrix to a MATLAB .mat file, specialization for complex matrices ([qpp::cmat](#))

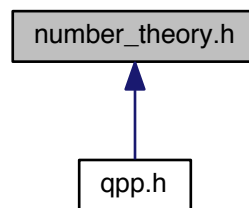
8.18.1 Detailed Description

Input/output interfacing with MATLAB.

8.19 number_theory.h File Reference

Number theory functions.

This graph shows which files directly or indirectly include this file:



Namespaces

- [qpp](#)
Quantum++ main namespace.

Functions

- `std::vector< long long int > qpp::x2contfrac (double x, idx n, idx cut=1e5)`
Simple continued fraction expansion.
- `double qpp::contfrac2x (const std::vector< int > &cf, idx n)`
Real representation of a simple continued fraction.
- `double qpp::contfrac2x (const std::vector< int > &cf)`
Real representation of a simple continued fraction.
- `idx qpp::gcd (idx m, idx n)`
Greatest common divisor of two non-negative integers.
- `idx qpp::gcd (const std::vector< idx > &ns)`
Greatest common divisor of a list of non-negative integers.
- `idx qpp::lcm (idx m, idx n)`
Least common multiple of two positive integers.
- `idx qpp::lcm (const std::vector< idx > &ns)`
Least common multiple of a list of positive integers.
- `std::vector< idx > qpp::invperm (const std::vector< idx > &perm)`
Inverse permutation.
- `std::vector< idx > qpp::compperm (const std::vector< idx > &perm, const std::vector< idx > &sigma)`
Compose permutations.

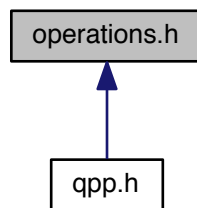
8.19.1 Detailed Description

Number theory functions.

8.20 operations.h File Reference

Quantum operation functions.

This graph shows which files directly or indirectly include this file:



Namespaces

- [qpp](#)

Quantum++ main namespace.

Functions

- `template<typename Derived1 , typename Derived2 >`
`dyn_mat< typename`
`Derived1::Scalar > qpp::applyCTRL (const Eigen::MatrixBase< Derived1 > &state, const Eigen::MatrixBase< Derived2 > &A, const std::vector< idx > &ctrl, const std::vector< idx > &subsys, const std::vector< idx > &dims)`
Applies the controlled-gate A to the part subsys of the multi-partite state vector or density matrix state.
- `template<typename Derived1 , typename Derived2 >`
`dyn_mat< typename`
`Derived1::Scalar > qpp::applyCTRL (const Eigen::MatrixBase< Derived1 > &state, const Eigen::MatrixBase< Derived2 > &A, const std::vector< idx > &ctrl, const std::vector< idx > &subsys, idx d=2)`
Applies the controlled-gate A to the part subsys of the multi-partite state vector or density matrix state.
- `template<typename Derived1 , typename Derived2 >`
`dyn_mat< typename`
`Derived1::Scalar > qpp::apply (const Eigen::MatrixBase< Derived1 > &state, const Eigen::MatrixBase< Derived2 > &A, const std::vector< idx > &subsys, const std::vector< idx > &dims)`
Applies the gate A to the part subsys of the multi-partite state vector or density matrix state.
- `template<typename Derived1 , typename Derived2 >`
`dyn_mat< typename`
`Derived1::Scalar > qpp::apply (const Eigen::MatrixBase< Derived1 > &state, const Eigen::MatrixBase< Derived2 > &A, const std::vector< idx > &subsys, idx d=2)`
Applies the gate A to the part subsys of the multi-partite state vector or density matrix state.

- `template<typename Derived >`
`cmat qpp::apply (const Eigen::MatrixBase< Derived > &rho, const std::vector< cmat > &Ks)`
Applies the channel specified by the set of Kraus operators Ks to the density matrix rho.
- `template<typename Derived >`
`cmat qpp::apply (const Eigen::MatrixBase< Derived > &rho, const std::vector< cmat > &Ks, const std::vector< idx > &subsys, const std::vector< idx > &dims)`
Applies the channel specified by the set of Kraus operators Ks to the part subsys of the multi-partite density matrix rho.
- `template<typename Derived >`
`cmat qpp::apply (const Eigen::MatrixBase< Derived > &rho, const std::vector< cmat > &Ks, const std::vector< idx > &subsys, idx d=2)`
Applies the channel specified by the set of Kraus operators Ks to the part subsys of the multi-partite density matrix rho.
- `cmat qpp::kraus2super (const std::vector< cmat > &Ks)`
Superoperator matrix.
- `cmat qpp::kraus2choi (const std::vector< cmat > &Ks)`
Choi matrix.
- `std::vector< cmat > qpp::choi2kraus (const cmat &A)`
Orthogonal Kraus operators from Choi matrix.
- `cmat qpp::choi2super (const cmat &A)`
Converts Choi matrix to superoperator matrix.
- `cmat qpp::super2choi (const cmat &A)`
Converts superoperator matrix to Choi matrix.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > qpp::ptrace1 (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &dims)`
Partial trace.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > qpp::ptrace2 (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &dims)`
Partial trace.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > qpp::ptrace (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &subsys, const std::vector< idx > &dims)`
Partial trace.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > qpp::ptrace (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &subsys, idx d=2)`
Partial trace.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > qpp::ptranspose (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &subsys, const std::vector< idx > &dims)`
Partial transpose.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > qpp::ptranspose (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &subsys, idx d=2)`
Partial transpose.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > qpp::syspermute (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &perm, const std::vector< idx > &dims)`
Subsystem permutation.
- `template<typename Derived >`
`dyn_mat< typename Derived::Scalar > qpp::syspermute (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &perm, idx d=2)`
Subsystem permutation.

8.20.1 Detailed Description

Quantum operation functions.

8.21 qpp.h File Reference

Quantum++ main header file, includes all other necessary headers.

```
#include <algorithm>
#include <chrono>
#include <cmath>
#include <complex>
#include <cstdlib>
#include <cstring>
#include <ctime>
#include <exception>
#include <fstream>
#include <functional>
#include <initializer_list>
#include <iomanip>
#include <iostream>
#include <iterator>
#include <limits>
#include <numeric>
#include <ostream>
#include <random>
#include <sstream>
#include <stdexcept>
#include <string>
#include <tuple>
#include <type_traits>
#include <utility>
#include <vector>
#include <Eigen/Dense>
#include <Eigen/SVD>
#include "types.h"
#include "constants.h"
#include "classes/exception.h"
#include "internal/util.h"
#include "internal/classes/iomanip.h"
#include "input_output.h"
#include "internal/classes/singleton.h"
#include "classes/init.h"
#include "functions.h"
#include "classes/codes.h"
#include "classes/gates.h"
#include "classes/states.h"
#include "classes/random_devices.h"
#include "operations.h"
#include "entropies.h"
#include "entanglement.h"
#include "random.h"
#include "classes/timer.h"
#include "instruments.h"
#include "number_theory.h"
```

Namespaces

- [qpp](#)

Quantum++ main namespace.

Variables

- `const Init & qpp::init = Init::get_instance()`
[qpp::Init](#) *const Singleton*
- `const Codes & qpp::codes = Codes::get_instance()`
[qpp::Codes](#) *const Singleton*
- `const Gates & qpp::gt = Gates::get_instance()`
[qpp::Gates](#) *const Singleton*
- `const States & qpp::st = States::get_instance()`
[qpp::States](#) *const Singleton*
- `RandomDevices & qpp::rdevs = RandomDevices::get_instance()`
[qpp::RandomDevices](#) *Singleton*

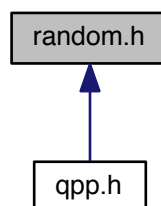
8.21.1 Detailed Description

Quantum++ main header file, includes all other necessary headers.

8.22 random.h File Reference

Randomness-related functions.

This graph shows which files directly or indirectly include this file:



Namespaces

- [qpp](#)

Quantum++ main namespace.

Functions

- `template<typename Derived >`
`Derived qpp::rand` (idx rows, idx cols, double a=0, double b=1)
Generates a random matrix with entries uniformly distributed in the interval [a, b]
- `template<>`
`dmat qpp::rand` (idx rows, idx cols, double a, double b)
Generates a random real matrix with entries uniformly distributed in the interval [a, b], specialization for double matrices ([qpp::dmat](#))
- `template<>`
`cmat qpp::rand` (idx rows, idx cols, double a, double b)
Generates a random complex matrix with entries (both real and imaginary) uniformly distributed in the interval [a, b], specialization for complex matrices ([qpp::cmat](#))
- `double qpp::rand` (double a=0, double b=1)
Generates a random real number uniformly distributed in the interval [a, b]
- `idx qpp::randidx` (idx a=std::numeric_limits< idx >::min(), idx b=std::numeric_limits< idx >::max())
Generates a random index (idx) uniformly distributed in the interval [a, b].
- `template<typename Derived >`
`Derived qpp::randn` (idx rows, idx cols, double mean=0, double sigma=1)
Generates a random matrix with entries normally distributed in $N(\text{mean}, \text{sigma})$
- `template<>`
`dmat qpp::randn` (idx rows, idx cols, double mean, double sigma)
Generates a random real matrix with entries normally distributed in $N(\text{mean}, \text{sigma})$, specialization for double matrices ([qpp::dmat](#))
- `template<>`
`cmat qpp::randn` (idx rows, idx cols, double mean, double sigma)
Generates a random complex matrix with entries (both real and imaginary) normally distributed in $N(\text{mean}, \text{sigma})$, specialization for complex matrices ([qpp::cmat](#))
- `double qpp::randn` (double mean=0, double sigma=1)
Generates a random real number (double) normally distributed in $N(\text{mean}, \text{sigma})$
- `cmat qpp::randU` (idx D)
Generates a random unitary matrix.
- `cmat qpp::randV` (idx Din, idx Dout)
Generates a random isometry matrix.
- `std::vector< cmat > qpp::randkraus` (idx N, idx D)
Generates a set of random Kraus operators.
- `cmat qpp::randH` (idx D)
Generates a random Hermitian matrix.
- `ket qpp::randket` (idx D)
Generates a random normalized ket (pure state vector)
- `cmat qpp::randrho` (idx D)
Generates a random density matrix.
- `std::vector< idx > qpp::randperm` (idx n)
Generates a random uniformly distributed permutation.

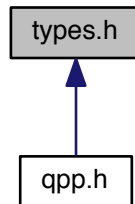
8.22.1 Detailed Description

Randomness-related functions.

8.23 types.h File Reference

Type aliases.

This graph shows which files directly or indirectly include this file:



Namespaces

- [qpp](#)
Quantum++ main namespace.

Typedefs

- using [qpp::idx](#) = std::size_t
Non-negative integer index.
- using [qpp::cplx](#) = std::complex< double >
Complex number in double precision.
- using [qpp::ket](#) = Eigen::VectorXcd
Complex (double precision) dynamic Eigen column vector.
- using [qpp::bra](#) = Eigen::RowVectorXcd
Complex (double precision) dynamic Eigen row vector.
- using [qpp::cmat](#) = Eigen::MatrixXcd
Complex (double precision) dynamic Eigen matrix.
- using [qpp::dmat](#) = Eigen::MatrixXd
Real (double precision) dynamic Eigen matrix.
- template<typename Scalar >
using [qpp::dyn_mat](#) = Eigen::Matrix< Scalar, Eigen::Dynamic, Eigen::Dynamic >
Dynamic Eigen matrix over the field specified by Scalar.
- template<typename Scalar >
using [qpp::dyn_col_vect](#) = Eigen::Matrix< Scalar, Eigen::Dynamic, 1 >
Dynamic Eigen column vector over the field specified by Scalar.
- template<typename Scalar >
using [qpp::dyn_row_vect](#) = Eigen::Matrix< Scalar, 1, Eigen::Dynamic >
Dynamic Eigen row vector over the field specified by Scalar.

8.23.1 Detailed Description

Type aliases.

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