

Quantum++ v0.1

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Chapter 1

Quantum++

Development branch, use it at your own risk!

Switch to the master branch for the latest stable version.

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](http://openmp.org/) 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 AS↔CII 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](http://eigen.tuxfamily.org/dox/).

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++.

Quantum++ is free software: you can redistribute it and/or modify it under the terms of the GNU General Public License as published by the Free Software Foundation, either version 3 of the License, or (at your option) any later version.

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Building instructions

Configuration:

- Compiler: [g++](http://gcc.gnu.org/) version 4.8 or later (for good C++11 support)
- [Eigen 3](http://eigen.tuxfamily.org/dox/) library located in `$HOME/eigen`
- Quantum++ library located in `$HOME/qpp`
- [MATLAB](http://www.mathworks.com/) compiler include header files: `/Applications/MATLAB_R2014b.app/extern/include`
- [MATLAB](http://www.mathworks.com/) 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
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qpp::internal	Internal utility functions, do not use/modify	72

Chapter 3

Hierarchical Index

3.1 Class Hierarchy

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

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qpp::internal::Singleton< T >	87
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qpp::States	88
qpp::internal::Singleton< RandomDevices >	87
qpp::RandomDevices	86
qpp::Timer	92

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	75
qpp::Exception	Generates custom exceptions, used when validating function parameters	76
qpp::Gates	Const Singleton class that implements most commonly used gates	79
qpp::Init	Const Singleton class that performs additional initializations/cleanups	83
qpp::internal::IOManipEigen	84
qpp::internal::IOManipPointer< PointerType >	85
qpp::internal::IOManipRange< InputIterator >	86
qpp::RandomDevices	Singleton class that manages the source of randomness in the library	86
qpp::internal::Singleton< T >	Singleton policy class, used internally to implement the singleton pattern via CRTP (Curiously recurring template pattern)	87
qpp::States	Const Singleton class that implements most commonly used states	88
qpp::Timer	Measures time	92

Chapter 5

File Index

5.1 File List

Here is a list of all files with brief descriptions:

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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) noexcept
User-defined literal for complex $i = \sqrt{-1}$ (integer overload)
- constexpr `cplx operator""_i` (long double x) noexcept
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, double p)

Schatten matrix norm.

- template<typename OutputScalar , typename Derived >
 `dyn_mat`< OutputScalar > `cwise` (const Eigen::MatrixBase< Derived > &A, OutputScalar(*)(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 >`
`std::iterator_traits< InputIterator >::value_type sum` (InputIterator first, InputIterator last) noexcept
Element-wise sum of a range.
- `template<typename InputIterator >`
`std::iterator_traits< InputIterator >::value_type prod` (InputIterator first, InputIterator last) noexcept
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) noexcept
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="]") noexcept
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="]") noexcept
Standard container ostream manipulator. The container must support std::cbegin(), std::cend() 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="]") noexcept
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::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::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::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< int >` `x2confrac` (double x, [idx](#) n, [idx](#) cut=1e5)
Simple continued fraction expansion.
- `double confrac2x` (const std::vector< int > &cf, [idx](#) n)
Real representation of a simple continued fraction.
- `double confrac2x` (const std::vector< int > &cf)
Real representation of a simple continued fraction.
- `unsigned long long int gcd` (unsigned long long int m, unsigned long long int n) noexcept
Greatest common divisor of two non-negative integers.
- `unsigned long long int gcd` (const std::vector< unsigned long long int > &ns)
Greatest common divisor of a list of non-negative integers.
- `unsigned long long int lcm` (unsigned long long int m, unsigned long long int n)
Least common multiple of two positive integers.
- `unsigned long long int lcm` (const std::vector< unsigned long long int > &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.
- `std::vector< unsigned long long int >` `factors` (unsigned long long int n)
Prime factor decomposition.
- `bool isprime` (unsigned long long int n)
Primality test.
- `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 controlled-gate A to the part subsys of the multi-partite state vector or density matrix state.

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 `infty` = 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
- thread_local `RandomDevices` & `rdevs` = `RandomDevices::get_thread_local_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

<i>A</i>	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

<i>V</i>	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

<i>A</i>	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

<i>A</i>	Eigen expression
<i>B</i>	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

<i>state</i>	Eigen expression
<i>A</i>	Eigen expression
<i>subsys</i>	Subsystem indexes where the gate <i>A</i> is applied
<i>dims</i>	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

<i>state</i>	Eigen expression
<i>A</i>	Eigen expression
<i>subsys</i>	Subsystem indexes where the gate <i>A</i> is applied
<i>d</i>	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

<i>A</i>	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

A	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

A	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

cf	Integer vector containing the simple continued fraction expansion
n	Number of terms considered in the continued fraction expansion. If n is greater than the size of cf , then all terms in cf 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

cf	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) [noexcept]`

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 = "] ") [noexcept]`

Range ostream manipulator.

Parameters

$first$	Iterator to the first element of the range
$last$	Iterator to the last element of the range
$separator$	Separator
$start$	Left marking
end	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 = " ] " )
    [noexcept]
```

Standard container ostream manipulator. The container must support `std::cbegin()`, `std::cend()` 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 = "] ")`
`[noexcept]`

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

<i>A</i>	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 `std::vector<unsigned long long int> qpp::factors (unsigned long long int n)`

Prime factor decomposition.

Note

Runs in $\mathcal{O}(\sqrt{n})$ time complexity

Parameters

n	Integer strictly greater than 1
-----	---------------------------------

Returns

Integer vector containing the factors

6.1.3.42 `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

$f(A)$

6.1.3.43 `unsigned long long int qpp::gcd (unsigned long long int m , unsigned long long int n)` [noexcept]

Greatest common divisor of two non-negative integers.

See also

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

Parameters

m	Non-negative integer
n	Non-negative integer

Returns

Greatest common divisor of m and n

6.1.3.44 `unsigned long long int qpp::gcd (const std::vector< unsigned long long int > & ns)`

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

See also

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

Parameters

ns	List of non-negative integers
------	-------------------------------

Returns

Greatest common divisor of all numbers in ns

6.1.3.45 `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

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

Returns

G-concurrence

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

Gram-Schmidt orthogonalization.

Parameters

Vs	<code>std::vector</code> 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 std::initializer_list<Derived> & Vs)`

Gram-Schmidt orthogonalization.

Parameters

Vs	<code>std::initializer_list</code> 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

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

Gram-Schmidt orthogonalization.

Parameters

A	Eigen expression, the input vectors are the columns of A
-----	--

Returns

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

6.1.3.49 `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

A	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

6.1.3.50 `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

6.1.3.51 `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

6.1.3.52 `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*

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

Inverse permutation.

Parameters

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

Returns

Inverse of the permutation *perm*

6.1.3.54 `bool qpp::isprime (unsigned long long int n)`

Primality test.

Note

Runs in $\mathcal{O}(\sqrt{n})$ time complexity

Parameters

n	Integer strictly greater than 1
-----	---------------------------------

Returns

True if the number is prime, false otherwise

6.1.3.55 `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

6.1.3.56 `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

6.1.3.57 `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*

6.1.3.58 `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

6.1.3.59 `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

6.1.3.60 `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 {A1, A2, ... ,Ak}
-----------	---

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

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

Kronecker power.

See also

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

Parameters

<i>A</i>	Eigen expression
<i>n</i>	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*

6.1.3.62 `unsigned long long int qpp::lcm (unsigned long long int m, unsigned long long int n)`

Least common multiple of two positive integers.

See also

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

Parameters

<i>m</i>	Positive integer
<i>n</i>	Positive integer

Returns

Least common multiple of *m* and *n*

6.1.3.63 `unsigned long long int qpp::lcm (const std::vector< unsigned long long int > & ns)`

Least common multiple of a list of positive integers.

See also

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

Parameters

<i>ns</i>	List of positive integers
-----------	---------------------------

Returns

Least common multiple of all numbers in *ns*

6.1.3.64 `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

6.1.3.65 `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)

6.1.3.66 `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](#))

6.1.3.67 `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](#))

6.1.3.68 `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*

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

Matrix logarithm.

Parameters

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

Returns

Matrix logarithm of *A*

6.1.3.70 `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

6.1.3.71 `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 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

6.1.3.72 `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 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

6.1.3.73 `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

6.1.3.74 `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

6.1.3.75 `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

6.1.3.76 `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

6.1.3.77 `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

6.1.3.78 `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

A	Eigen expression
Ks	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

6.1.3.79 `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

A	Eigen expression
U	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

6.1.3.80 `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

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

Returns

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

6.1.3.81 `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

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

Returns

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

6.1.3.82 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>	std::vector 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

6.1.3.83 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>	std::vector of non-negative integers
<i>d</i>	Subsystem dimensions

Returns

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

6.1.3.84 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

6.1.3.85 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 $dims$

6.1.3.86 `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

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

Frobenius norm.

Parameters

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

Returns

Frobenius norm of A

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

D-th root of unity.

Parameters

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

Returns

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

6.1.3.89 `constexpr cplx qpp::operator""_i (unsigned long long int x) [noexcept]`

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

Example:

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

6.1.3.90 `constexpr cplx qpp::operator""_i (long double x) [noexcept]`

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

Example:

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

6.1.3.91 `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

6.1.3.92 `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

6.1.3.93 `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

6.1.3.94 `template<typename InputIterator> std::iterator_traits<InputIterator>::value_type qpp::prod (InputIterator first, InputIterator last) [noexcept]`

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

6.1.3.95 `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*

6.1.3.96 `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*

6.1.3.97 `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

6.1.3.98 `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

6.1.3.99 `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

6.1.3.100 `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

6.1.3.101 `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

6.1.3.102 `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

6.1.3.103 `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`

6.1.3.104 `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

6.1.3.105 `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

6.1.3.106 `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)

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

Generates a random Hermitian matrix.

Parameters

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

Returns

Random Hermitian matrix

6.1.3.108 `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]

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

Generates a random normalized ket (pure state vector)

Parameters

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

Returns

Random normalized ket

6.1.3.110 `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

6.1.3.111 `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 $N(\text{mean}, \text{sigma})$

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

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

6.1.3.112 `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

6.1.3.113 `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

6.1.3.114 `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 $N(\text{mean}, \text{sigma})$

6.1.3.115 `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*

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

Generates a random density matrix.

Parameters

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

Returns

Random density matrix

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

Generates a random unitary matrix.

Parameters

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

Returns

Random unitary

6.1.3.118 `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

6.1.3.119 `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::infy for $\alpha = \infty$

Returns

Renyi- α entropy, with the logarithm in base 2

6.1.3.120 `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::infy for $\alpha = \infty$

Returns

Renyi- α entropy, with the logarithm in base 2

6.1.3.121 `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*

6.1.3.122 `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*

6.1.3.123 `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

6.1.3.124 `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)

6.1.3.125 `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

6.1.3.126 `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

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

Schatten matrix norm.

Parameters

<i>A</i>	Eigen expression
<i>p</i>	Real number, greater or equal to 1, use qpp::infy for $p = \infty$

Returns

Schatten- p matrix norm of A

6.1.3.128 `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.

6.1.3.129 `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.

6.1.3.130 `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

6.1.3.131 `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

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

Matrix sin.

Parameters

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

Returns

Matrix sine of A

6.1.3.133 `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

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

Matrix square root.

Parameters

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

Returns

Matrix square root of A

6.1.3.135 `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*

6.1.3.136 `template<typename InputIterator > std::iterator_traits<InputIterator>::value_type qpp::sum (InputIterator first, InputIterator last) [noexcept]`

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

6.1.3.137 `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

6.1.3.138 `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

6.1.3.139 `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

6.1.3.140 `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

6.1.3.141 `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

6.1.3.142 `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

6.1.3.143 `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

6.1.3.144 `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

6.1.3.145 `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

6.1.3.146 `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

6.1.3.147 `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

6.1.3.148 `std::vector<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 `thread_local RandomDevices& qpp::rdevs = RandomDevices::get_thread_local_instance()`

[qpp::RandomDevices](#) Singleton

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

Note

Has thread storage duration, due to mutability of its public member `std::mt19937` and possible data races

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 [IManipEigen](#)
- class [IManipPointer](#)
- class [IManipRange](#)
- 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) noexcept
- idx [_multiidx2n](#) (const idx *midx, idx numdims, const idx *dims) noexcept
- template<typename Derived >
bool [_check_square_mat](#) (const Eigen::MatrixBase< Derived > &A) noexcept
- template<typename Derived >
bool [_check_vector](#) (const Eigen::MatrixBase< Derived > &A) noexcept
- template<typename Derived >
bool [_check_row_vector](#) (const Eigen::MatrixBase< Derived > &A) noexcept
- template<typename Derived >
bool [_check_col_vector](#) (const Eigen::MatrixBase< Derived > &A) noexcept
- template<typename T >
bool [_check_nonzero_size](#) (const T &x) noexcept
- bool [_check_dims](#) (const std::vector< idx > &dims) noexcept
- template<typename Derived >
bool [_check_dims_match_mat](#) (const std::vector< idx > &dims, const Eigen::MatrixBase< Derived > &A) noexcept
- template<typename Derived >
bool [_check_dims_match_cvect](#) (const std::vector< idx > &dims, const Eigen::MatrixBase< Derived > &V) noexcept
- template<typename Derived >
bool [_check_dims_match_rvect](#) (const std::vector< idx > &dims, const Eigen::MatrixBase< Derived > &V) noexcept
- bool [_check_eq_dims](#) (const std::vector< idx > &dims, idx dim) noexcept
- bool [_check_subsys_match_dims](#) (const std::vector< idx > &subsys, const std::vector< idx > &dims) noexcept
- bool [_check_perm](#) (const std::vector< idx > &perm) noexcept
- 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< Derived2 > &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)`
[noexcept]
- 6.3.2.2 `bool qpp::internal::_check_dims (const std::vector< idx > & dims)` [noexcept]
- 6.3.2.3 `template<typename Derived > bool qpp::internal::_check_dims_match_cvect (const std::vector< idx > & dims, const Eigen::MatrixBase< Derived > & V)` [noexcept]
- 6.3.2.4 `template<typename Derived > bool qpp::internal::_check_dims_match_mat (const std::vector< idx > & dims, const Eigen::MatrixBase< Derived > & A)` [noexcept]
- 6.3.2.5 `template<typename Derived > bool qpp::internal::_check_dims_match_rvect (const std::vector< idx > & dims, const Eigen::MatrixBase< Derived > & V)` [noexcept]
- 6.3.2.6 `bool qpp::internal::_check_eq_dims (const std::vector< idx > & dims, idx dim)` [noexcept]
- 6.3.2.7 `template<typename T > bool qpp::internal::_check_nonzero_size (const T & x)` [noexcept]
- 6.3.2.8 `bool qpp::internal::_check_perm (const std::vector< idx > & perm)` [noexcept]
- 6.3.2.9 `template<typename Derived > bool qpp::internal::_check_row_vector (const Eigen::MatrixBase< Derived > & A)`
[noexcept]
- 6.3.2.10 `template<typename Derived > bool qpp::internal::_check_square_mat (const Eigen::MatrixBase< Derived > & A)`
[noexcept]
- 6.3.2.11 `bool qpp::internal::_check_subsys_match_dims (const std::vector< idx > & subsys, const std::vector< idx > & dims)` [noexcept]
- 6.3.2.12 `template<typename Derived > bool qpp::internal::_check_vector (const Eigen::MatrixBase< Derived > & A)`
[noexcept]
- 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],
[noexcept]
- 6.3.2.16 `void qpp::internal::_n2multiidx (idx n, idx numdims, const idx * dims, idx * result)` [inline],
[noexcept]
- 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.

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 Member Function Documentation

7.1.3.1 `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*

7.1.4 Friends And Related Function Documentation

7.1.4.1 `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_C↵](#)
[VECTOR](#), [Type::MATRIX_NOT_SQUARE_OR_RVECTOR](#),
[Type::MATRIX_NOT_SQUARE_OR_VECTOR](#), [Type::MATRIX_MISMATCH_SUBSYS](#), [Type::DIMS_INVA↵](#)
[LID](#), [Type::DIMS_NOT_EQUAL](#),
[Type::DIMS_MISMATCH_MATRIX](#), [Type::DIMS_MISMATCH_CVECTOR](#), [Type::DIMS_MISMATCH_RVE↵](#)


```

CTOR, 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) noexcept
Constructs an exception.
- [Exception](#) (const std::string &where, const std::string &custom) noexcept
Constructs an exception.
- virtual const char * [what](#) () const noexcept override
Overrides std::exception::what()

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]`, `[noexcept]`

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]`, `[noexcept]`

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

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

Returns

[Exception](#) description

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.

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 Member Function Documentation

7.3.2.1 `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

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

Returns

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

7.3.2.2 `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

<i>A</i>	Eigen expression
<i>pos</i>	Position
<i>dims</i>	Dimensions of the multi-partite system

Returns

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

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

Fourier transform gate for qudits.

Note

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

Parameters

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

Returns

Fourier transform gate for qudits

7.3.2.4 `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

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

Returns

Identity gate

7.3.2.5 `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

7.3.2.6 `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

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

Returns

Generalized X gate for qudits

7.3.2.7 `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

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

Returns

Generalized Z gate for qudits

7.3.3 Friends And Related Function Documentation

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

7.3.4 Member Data Documentation

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

Controlled-NOT control target gate.

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

Controlled-NOT target control gate.

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

Controlled-Phase gate.

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

Fredkin gate.

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

Hadamard gate.

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

Identity gate.

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

S gate.

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

SWAP gate.

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

T gate.

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

Toffoli gate.

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

Pauli Sigma-X gate.

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

Pauli Sigma-Y gate.

7.3.4.13 `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.

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.

7.4.3 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`) noexcept

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],[noexcept]`

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]`

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>
```

Public Member Functions

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

Friends

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

7.6.1 Constructor & Destructor Documentation

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

7.6.1.2 `template<typename PointerType> qpp::internal::IOManipPointer< PointerType >::IOManipPointer (const IOManipPointer< PointerType > &) [default]`

7.6.2 Member Function Documentation

7.6.2.1 `template<typename PointerType> IOManipPointer& qpp::internal::IOManipPointer< PointerType >::operator= (const IOManipPointer< 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 IOManipPointer< PointerType > & rhs )
[friend]
```

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>
```

Public Member Functions

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

Friends

- template<typename charT , typename traits > std::basic_ostream< charT, traits > & [operator<<](#) (std::basic_ostream< charT, traits > &os, const [IO↵ManipRange](#) &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],[noexcept]
```

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]
```

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.

Friends

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

Additional Inherited Members

7.8.1 Detailed Description

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

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. This class also seeds the standard C number generator, as it is used by Eigen.

7.8.2 Friends And Related Function Documentation

7.8.2.1 friend class [internal::Singleton< RandomDevices >](#) [friend]

7.8.3 Member Data Documentation

7.8.3.1 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](#) () noexcept(std::is_nothrow_constructible< T >::value)
- static thread_local T & [get_thread_local_instance](#) () noexcept(std::is_nothrow_constructible< T >::value)

Protected Member Functions

- [Singleton](#) () noexcept
- 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()` (`qpp::internal::Singleton::get_thread_local_instance()`), which returns a reference (thread_local 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
thread_local MySingleton& tls = MySingleton::get_thread_local_instance();
// Get a thread_local 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]`, `[noexcept]`

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]`, `[noexcept]`

7.9.3.2 `template<typename T> static thread_local T& qpp::internal::Singleton< T >::get_thread_local_instance ()` `[inline]`, `[static]`, `[noexcept]`

7.9.3.3 `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.

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 Friends And Related Function Documentation

7.10.2.1 `friend class internal::Singleton< const States > [friend]`

7.10.3 Member Data Documentation

7.10.3.1 `ket qpp::States::b00 {ket::Zero(4)}`

Bell-00 state (following the convention in Nielsen and Chuang)

7.10.3.2 `ket qpp::States::b01 {ket::Zero(4)}`

Bell-01 state (following the convention in Nielsen and Chuang)

7.10.3.3 `ket qpp::States::b10 {ket::Zero(4)}`

Bell-10 state (following the convention in Nielsen and Chuang)

7.10.3.4 `ket qpp::States::b11 {ket::Zero(4)}`

Bell-11 state (following the convention in Nielsen and Chuang)

7.10.3.5 `ket qpp::States::GHZ {ket::Zero(8)}`

GHZ state.

7.10.3.6 `cmat qpp::States::pb00 {cmat::Zero(4, 4)}`

Projector onto the Bell-00 state.

7.10.3.7 `cmat qpp::States::pb01 {cmat::Zero(4, 4)}`

Projector onto the Bell-01 state.

7.10.3.8 `cmat qpp::States::pb10 {cmat::Zero(4, 4)}`

Projector onto the Bell-10 state.

7.10.3.9 `cmat qpp::States::pb11 {cmat::Zero(4, 4)}`

Projector onto the Bell-11 state.

7.10.3.10 `cmat qpp::States::pGHZ {cmat::Zero(8, 8)}`

Projector onto the GHZ state.

7.10.3.11 `cmat qpp::States::pW {cmat::Zero(8, 8)}`

Projector onto the W state.

7.10.3.12 `cmat qpp::States::px0 {cmat::Zero(2, 2)}`

Projector onto the Pauli Sigma-X 0-eigenstate $|+\rangle\langle+|$.

7.10.3.13 `cmat qpp::States::px1 {cmat::Zero(2, 2)}`

Projector onto the Pauli Sigma-X 1-eigenstate $|-\rangle\langle-|$.

7.10.3.14 `cmat qpp::States::py0 {cmat::Zero(2, 2)}`

Projector onto the Pauli Sigma-Y 0-eigenstate $|y+\rangle\langle y+|$.

7.10.3.15 `cmat qpp::States::py1 {cmat::Zero(2, 2)}`

Projector onto the Pauli Sigma-Y 1-eigenstate $|y-\rangle\langle y-|$.

7.10.3.16 `cmat qpp::States::pz0 {cmat::Zero(2, 2)}`

Projector onto the Pauli Sigma-Z 0-eigenstate $|0\rangle\langle 0|$.

7.10.3.17 `cmat qpp::States::pz1 {cmat::Zero(2, 2)}`

Projector onto the Pauli Sigma-Z 1-eigenstate $|1\rangle\langle 1|$.

7.10.3.18 `ket qpp::States::W {ket::Zero(8)}`

W state.

7.10.3.19 `ket qpp::States::x0 {ket::Zero(2)}`

Pauli Sigma-X 0-eigenstate $|+\rangle$

7.10.3.20 `ket qpp::States::x1 {ket::Zero(2)}`

Pauli Sigma-X 1-eigenstate $|-\rangle$

7.10.3.21 `ket qpp::States::y0 {ket::Zero(2)}`

Pauli Sigma-Y 0-eigenstate $|y+\rangle$

7.10.3.22 `ket qpp::States::y1 {ket::Zero(2)}`

Pauli Sigma-Y 1-eigenstate $|y-\rangle$

7.10.3.23 `ket qpp::States::z0 {ket::Zero(2)}`

Pauli Sigma-Z 0-eigenstate $|0\rangle$

7.10.3.24 `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 ()` noexcept
Constructs an instance with the current time as the starting point.
- `void tic ()` noexcept
Resets the chronometer.
- `const Timer & toc ()` noexcept
Stops the chronometer.
- `double seconds ()` const noexcept
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]`, `[noexcept]`

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]`, `[noexcept]`

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]`, `[noexcept]`

Resets the chronometer.

Resets the starting/ending point to the current time

7.11.3.3 `const Timer& qpp::Timer::toc ()` `[inline]`, `[noexcept]`

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

<code>os</code>	Output stream
<code>rhs</code>	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:

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.

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

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) noexcept

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

- constexpr cplx [qpp::operator""_i](#) (long double x) noexcept

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::evects (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, double p)`
Schatten matrix 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 >`
`std::iterator_traits< InputIterator >::value_type qpp::sum` (InputIterator first, InputIterator last) noexcept
Element-wise sum of a range.
- `template<typename InputIterator >`
`std::iterator_traits< InputIterator >::value_type qpp::prod` (InputIterator first, InputIterator last) noexcept
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`) noexcept
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="]") noexcept

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="]") noexcept`

Standard container ostream manipulator. The container must support `std::cbegin()`, `std::cend()` 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="]") noexcept`

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::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::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) noexcept
- idx [qpp::internal::_multiidx2n](#) (const idx *midx, idx numdims, const idx *dims) noexcept
- template<typename Derived >
bool [qpp::internal::_check_square_mat](#) (const Eigen::MatrixBase< Derived > &A) noexcept
- template<typename Derived >
bool [qpp::internal::_check_vector](#) (const Eigen::MatrixBase< Derived > &A) noexcept
- template<typename Derived >
bool [qpp::internal::_check_row_vector](#) (const Eigen::MatrixBase< Derived > &A) noexcept
- template<typename Derived >
bool [qpp::internal::_check_col_vector](#) (const Eigen::MatrixBase< Derived > &A) noexcept
- template<typename T >
bool [qpp::internal::_check_nonzero_size](#) (const T &x) noexcept
- bool [qpp::internal::_check_dims](#) (const std::vector< idx > &dims) noexcept

- `template<typename Derived >`
`bool qpp::internal::_check_dims_match_mat (const std::vector< idx > &dims, const Eigen::MatrixBase< Derived > &A) noexcept`
- `template<typename Derived >`
`bool qpp::internal::_check_dims_match_cvect (const std::vector< idx > &dims, const Eigen::MatrixBase< Derived > &V) noexcept`
- `template<typename Derived >`
`bool qpp::internal::_check_dims_match_rvect (const std::vector< idx > &dims, const Eigen::MatrixBase< Derived > &V) noexcept`
- `bool qpp::internal::_check_eq_dims (const std::vector< idx > &dims, idx dim) noexcept`
- `bool qpp::internal::_check_subsys_match_dims (const std::vector< idx > &subsys, const std::vector< idx > &dims) noexcept`
- `bool qpp::internal::_check_perm (const std::vector< idx > &perm) noexcept`
- `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< 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.
- `unsigned long long int qpp::gcd (unsigned long long int m, unsigned long long int n) noexcept`
Greatest common divisor of two non-negative integers.
- `unsigned long long int qpp::gcd (const std::vector< unsigned long long int > &ns)`
Greatest common divisor of a list of non-negative integers.
- `unsigned long long int qpp::lcm (unsigned long long int m, unsigned long long int n)`
Least common multiple of two positive integers.
- `unsigned long long int qpp::lcm (const std::vector< unsigned long long int > &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.
- `std::vector< unsigned long long int > qpp::factors (unsigned long long int n)`
Prime factor decomposition.
- `bool qpp::isprime (unsigned long long int n)`
Primality test.

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*
- `thread_local RandomDevices & qpp::rdevs = RandomDevices::get_thread_local_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.

8.24 /Users/vlad/Dropbox/programming/cpp/qpp_clion/README.md File Reference

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