

Quantum++  
v0.1

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Sat Dec 20 2014 19:35:01



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# Chapter 1

## Quantum++

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

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

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

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### Building instructions

#### Configuration:

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

#### Building without a build system

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

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

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

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

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

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

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

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

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

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

### Building using **cmake**

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

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

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

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

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

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

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



## Additional remarks

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

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

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

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

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

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



## Chapter 2

# Namespace Index

### 2.1 Namespace List

Here is a list of all namespaces with brief descriptions:

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## Chapter 3

# Hierarchical Index

### 3.1 Class Hierarchy

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## Chapter 4

# Class Index

### 4.1 Class List

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

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<a href="#">qpp::internal::IOManipEigen</a>	. . . . .	86
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<a href="#">qpp::RandomDevices</a>	Singleton class that manages the source of randomness in the library . . . . .	90
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<a href="#">qpp::States</a>	Const Singleton class that implements most commonly used states . . . . .	93
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## Chapter 5

# File Index

### 5.1 File List

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

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

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

- Matrix sin.*

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

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

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

  - `template<typename Derived >`  
`double Schatten` (const Eigen::MatrixBase< Derived > &A, `idx` p)
- Schatten norm.*

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

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

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

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

  - `template<typename Derived >`  
`dyn_mat`< typename Derived::Scalar > `kron` (const std::initializer\_list< Derived > &As)
- Kronecker power.*

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

  - `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 power.*

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

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

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



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

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

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

*Partial trace.*

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

*Partial trace.*

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

*Partial transpose.*

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

*Partial transpose.*

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

*Subsystem permutation.*

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

*Subsystem permutation.*

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

- `cmat randU` (`idx` D)

*Generates a random unitary matrix.*

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

*Generates a random isometry matrix.*

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

- Generates a set of random Kraus operators.*

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

## Variables

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

### 6.1.1 Detailed Description

Quantum++ main namespace.

### 6.1.2 Typedef Documentation

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

Complex (double precision) dynamic Eigen row vector.

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

Complex (double precision) dynamic Eigen matrix.

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

Complex number in double precision.

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

Real (double precision) dynamic Eigen matrix.

#### 6.1.2.5 template<typename Scalar > using qpp::dyn\_col\_vect = typedef Eigen::Matrix<Scalar, Eigen::Dynamic, 1>

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

Example:

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

#### 6.1.2.6 template<typename Scalar > using qpp::dyn\_mat = typedef Eigen::Matrix<Scalar, Eigen::Dynamic, Eigen::Dynamic>

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

Example:

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

#### 6.1.2.7 template<typename Scalar > using qpp::dyn\_row\_vect = typedef Eigen::Matrix<Scalar, 1, Eigen::Dynamic>

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

Example:

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

#### 6.1.2.8 using qpp::idx = typedef std::size\_t

Non-negative integer index.

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

Complex (double precision) dynamic Eigen column vector.

### 6.1.3 Function Documentation

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

Matrix absolut value.

## Parameters

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

## Returns

Matrix absolut value of  $A$

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

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

## Parameters

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

## Returns

Real vector consisting of the range absolut values squared

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

Computes the absolut values squared of a column vector.

## Parameters

$V$	Eigen expression
-----	------------------

## Returns

Real vector consisting of the absolut values squared

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

Adjoint.

## Parameters

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

## Returns

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

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

Anti-commutator.

## See also

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

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

## Parameters

$A$	Eigen expression
$B$	Eigen expression

## Returns

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

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

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

## Note

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

## Parameters

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

## Returns

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

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

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

## Note

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

## Parameters

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

## Returns

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

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

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



## Parameters

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

## Returns

Output density matrix after the action of the channel

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

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

## Parameters

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

## Returns

Output density matrix after the action of the channel

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

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

## Parameters

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

## Returns

Output density matrix after the action of the channel

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

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

## See also

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

## Note

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

## Parameters

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

## Returns

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

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

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

## See also

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

## Note

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

## Parameters

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

## Returns

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

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

Orthogonal Kraus operators from Choi matrix.

## See also

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

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

## Note

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

## Parameters

$A$	Choi matrix
-----	-------------

## Returns

Set of orthogonal Kraus operators

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

Converts Choi matrix to superoperator matrix.

## See also

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

## Parameters

$A$	Choi matrix
-----	-------------

## Returns

Superoperator matrix

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

Commutator.

## See also

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

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

## Parameters

$A$	Eigen expression
$B$	Eigen expression

## Returns

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

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

Compose permutations.

## Parameters

$perm$	Permutation
$sigma$	Permutation

## Returns

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

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

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

## Parameters

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

## Returns

Wootters concurrence

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

Complex conjugate.

## Parameters

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

## Returns

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

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

Real representation of a simple continued fraction.

See also

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

## Parameters

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

## Returns

Real representation of the simple continued fraction

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

Real representation of a simple continued fraction.

See also

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

## Parameters

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

## Returns

Real representation of the simple continued fraction

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

Matrix cos.

## Parameters

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

## Returns

Matrix cosine of  $A$

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

## Functor.

## Parameters

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

## Returns

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

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

## Determinant.

## Parameters

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

## Returns

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

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

## Direct sum.

## See also

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

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

## Parameters

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

## Returns

Its argument *head*

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

Direct sum.

See also

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

Parameters

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

Returns

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

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

Direct sum.

See also

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

Parameters

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

Returns

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

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

Direct sum.

See also

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

Parameters

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

Returns

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

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

Direct sum power.

See also

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

Parameters

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

Returns

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

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

Eigen expression ostream manipulator.

Parameters

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

Returns

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

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

Complex number ostream manipulator.

Parameters

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

Returns

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

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

Range ostream manipulator.

Parameters



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

**Returns**

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

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

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

**Parameters**

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

**Returns**

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

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

C-style pointer ostream manipulator.

**Parameters**

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

**Returns**

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

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

Full eigen decomposition.

**See also**

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

## Parameters

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

## Returns

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

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

Entanglement of the bi-partite pure state *A*.

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

## See also

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

## Parameters

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

## Returns

Entanglement, with the logarithm in base 2

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

von-Neumann entropy of the density matrix *A*

## Parameters

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

## Returns

von-Neumann entropy, with the logarithm in base 2

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

Shannon entropy of the probability distribution *prob*.

## Parameters

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

## Returns

Shannon entropy, with the logarithm in base 2

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

Eigenvalues.

See also

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

Parameters

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

Returns

Eigenvalues of  $A$ , as a complex dynamic column vector

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

Eigenvectors.

See also

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

Parameters

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

Returns

Eigenvectors of  $A$ , as columns of a complex dynamic matrix

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

Matrix exponential.

Parameters

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

Returns

Matrix exponential of  $A$

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

Functional calculus  $f(A)$

Parameters

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

Returns

$f(A)$

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

Greatest common divisor of two non-negative integers.

See also

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

Parameters

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

Returns

Greatest common divisor of *m* and *n*

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

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

See also

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

Parameters

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

Returns

Greatest common divisor of all numbers in *ns*

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

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

Note

Both local dimensions must be equal

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

See also

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

Parameters

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

Returns

G-concurrence

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

Gram-Schmidt orthogonalization.

## Parameters

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

## Returns

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

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

Gram-Schmidt orthogonalization.

## Parameters

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

## Returns

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

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

Gram-Schmidt orthogonalization.

## Parameters

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

## Returns

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

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

Full eigen decomposition of Hermitian expression.

## See also

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

## Parameters

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

## Returns

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

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

Hermitian eigenvalues.

See also

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

Parameters

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

Returns

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

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

Hermitian eigenvectors.

See also

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

Parameters

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

Returns

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

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

Inverse.

Parameters

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

Returns

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

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

Inverse permutation.

Parameters

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

Returns

Inverse of the permutation *perm*

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

Choi matrix.

See also

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

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

**Note**

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

**Parameters**

$Ks$	Set of Kraus operators
------	------------------------

**Returns**

Choi matrix

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

Superoperator matrix.

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

**Parameters**

$Ks$	Set of Kraus operators
------	------------------------

**Returns**

Superoperator matrix

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

Kronecker product.

See also

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

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

**Parameters**

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

**Returns**

Its argument *head*

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

Kronecker product.

See also

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

Parameters

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

Returns

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

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

Kronecker product.

See also

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

Parameters

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

Returns

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

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

Kronecker product.

See also

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

Parameters

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

Returns

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



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

Kronecker power.

See also

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

Parameters

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

Returns

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

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

Least common multiple of two positive integers.

See also

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

Parameters

$m$	Positive integer
$n$	Positive integer

Returns

Least common multiple of  $m$  and  $n$

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

Least common multiple of a list of positive integers.

See also

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

Parameters

$ns$	List of positive integers
------	---------------------------

Returns

Least common multiple of all numbers in  $ns$

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

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

See also

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

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

Example:

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

Parameters

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

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

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

See also

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

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

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

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

See also

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

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

Example:

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

Note

If *var\_name* is a complex matrix, only the real part is loaded

Parameters

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

Returns

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

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

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

See also

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

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

Example:

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

Parameters

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

Returns

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

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

Logarithm of the determinant.

Useful when the determinant overflows/underflows

Parameters

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

Returns

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

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

Matrix logarithm.

Parameters

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

Returns

Matrix logarithm of *A*

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

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

## Parameters

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

## Returns

Logarithmic negativity, with the logarithm in base 2

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

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

## Note

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

## Parameters

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

## Returns

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

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

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

## Note

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

## Parameters

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

## Returns

Tuple consisting of 1. Result of the measurement,

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

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

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

#### Note

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

#### Parameters

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

#### Returns

Tuple consisting of 1. Result of the measurement,

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

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

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

#### Note

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

#### Parameters

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

#### Returns

Tuple consisting of 1. Result of the measurement,

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

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

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

#### Note

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

## Parameters

$A$	Eigen expression
$subsys$	Subsystem indexes that are measured
$dims$	Dimensions of the multi-partite system
$U$	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

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

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

## Note

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

## Parameters

$A$	Eigen expression
$subsys$	Subsystem indexes that are measured
$d$	Subsystem dimensions
$U$	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

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

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

## Parameters

$A$	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

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

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

## Parameters

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

## Returns

Tuple consisting of 1. Result of the measurement,

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

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

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

## Parameters

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

## Returns

Tuple consisting of 1. Result of the measurement,

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

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

Multi-partite qudit ket.

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

## Parameters

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

## Returns

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

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

Multi-partite qudit ket.

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

## Parameters

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

## Returns

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

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

Projector onto multi-partite qudit ket.

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

Parameters

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

Returns

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

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

Projector onto multi-partite qudit ket.

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

Parameters

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

Returns

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

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

Multi-index to non-negative integer index.

See also

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

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

Parameters

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

Returns

Non-negative integer index

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

Non-negative integer index to multi-index.

See also

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

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



## Parameters

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

## Returns

Multi-index of the same size as  $dims$

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

Negativity of the bi-partite mixed state  $A$ .

## Parameters

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

## Returns

Negativity

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

Frobenius norm.

## Parameters

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

## Returns

Frobenius norm of  $A$ , as a real number

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

$D$ -th root of unity.

## Parameters

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

## Returns

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

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

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

Example:

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

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

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

Example:

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

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

Matrix power.

See also

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

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

Parameters

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

Returns

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

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

Projector.

Normalized projector onto state vector

Parameters

$V$	Eigen expression
-----	------------------

Returns

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

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

Element-wise product of  $A$ .

Parameters

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

Returns

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

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

Element-wise product of a range.

## Parameters

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

## Returns

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

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

Partial trace.

See also

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

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

## Parameters

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

## Returns

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

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

Partial trace.

See also

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

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

## Parameters

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

## Returns

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

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

Partial trace.

See also

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

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

Parameters

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

Returns

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

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

Partial trace.

See also

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

Parameters

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

Returns

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

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

Partial transpose.

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

Parameters

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

Returns

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

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

Partial transpose.

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

## Parameters

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

## Returns

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

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

Quantum mutual information between 2 subsystems of a composite system.

## Parameters

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

## Returns

Mutual information between the 2 subsystems

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

Quantum mutual information between 2 subsystems of a composite system.

## Parameters

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

## Returns

Mutual information between the 2 subsystems

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

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

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

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

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

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

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

Example:

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

#### Parameters

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

#### Returns

Random real matrix

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

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

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

Example:

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

#### Parameters

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

#### Returns

Random complex matrix

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

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

#### Parameters

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

#### Returns

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

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

Generates a random Hermitian matrix.

## Parameters

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

## Returns

Random Hermitian matrix

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

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

## Parameters

$a$	Beginning of the interval, belongs to it
$b$	End of the interval, belongs to it

## Returns

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

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

Generates a random normalized ket (pure state vector)

## Parameters

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

## Returns

Random normalized ket

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

Generates a set of random Kraus operators.

## Note

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

## Parameters

$N$	Number of Kraus operators
$D$	Dimension of the Hilbert space

## Returns

Set of  $N$  Kraus operators satisfying the closure condition

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

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

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`

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

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

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

Example:

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

##### Parameters

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

##### Returns

Random real matrix

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

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

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

Example:

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

##### Parameters

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

##### Returns

Random complex matrix

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

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

##### Parameters

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



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

**Returns**

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

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

Generates a random uniformly distributed permutation.

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

**Parameters**

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

**Returns**

Random permutation of size *n*

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

Generates a random density matrix.

**Parameters**

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

**Returns**

Random density matrix

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

Generates a random unitary matrix.

**Parameters**

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

**Returns**

Random unitary

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

Generates a random isometry matrix.

**Parameters**

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

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

**Returns**

Random isometry matrix

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

Renyi-  $\alpha$  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 <a href="#">qpp::infy</a> for $\alpha = \infty$

**Returns**

Renyi-  $\alpha$  entropy, with the logarithm in base 2

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

Renyi-  $\alpha$  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 <a href="#">qpp::infy</a> for $\alpha = \infty$

**Returns**

Renyi-  $\alpha$  entropy, with the logarithm in base 2

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

Reshape.

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

**Parameters**

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

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

**Returns**

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

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

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

**Note**

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

**Parameters**

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

**Returns**

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

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

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

**See also**

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

**Parameters**

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

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

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

**See also**

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

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

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

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

See also

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

Parameters

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

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

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

See also

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

Parameters

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

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

Schatten norm.

Parameters

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

Returns

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

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

Schmidt basis on Alice side.

Parameters

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

**Returns**

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

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

Schmidt basis on Bob side.

**Parameters**

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

**Returns**

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

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

Schmidt coefficients of the bi-partite pure state  $A$ .

**Note**

The sum of the squares of the Schmidt coefficients equals 1

**See also**

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

**Parameters**

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

**Returns**

Schmidt coefficients of  $A$ , as a real dynamic column vector

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

Schmidt probabilities of the bi-partite pure state  $A$ .

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

**See also**

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

## Parameters

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

## Returns

Real vector consisting of the Schmidt probabilities of  $A$

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

Matrix sin.

## Parameters

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

## Returns

Matrix sine of  $A$

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

Matrix power.

See also

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

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

## Parameters

$A$	Eigen expression
$z$	Complex number

## Returns

Matrix power  $A^z$

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

Matrix square root.

## Parameters

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

## Returns

Matrix square root of  $A$

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

Element-wise sum of  $A$ .

## Parameters

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

## Returns

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

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

Element-wise sum of a range.

## Parameters

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

## Returns

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

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

Converts superoperator matrix to Choi matrix.

## See also

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

## Parameters

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

## Returns

Choi matrix

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

Singular values.

## Parameters

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

## Returns

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

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

Full singular value decomposition.

## Parameters

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

## Returns

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

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

Left singular vectors.

## Parameters

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

## Returns

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

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

Right singular vectors.

## Parameters

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

## Returns

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

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

Subsystem permutation.

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

## Parameters

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

## Returns

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

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

Subsystem permutation.

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



## Parameters

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

## Returns

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

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

Trace.

## Parameters

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

## Returns

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

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

Transpose.

## Parameters

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

## Returns

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

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

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

## Note

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

## Parameters

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

## Returns

Tsallis-  $q$  entropy

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

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

## Note

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

## Parameters

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

## Returns

Tsallis-  $q$  entropy

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

Simple continued fraction expansion.

## See also

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

## Parameters

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

## Returns

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

## 6.1.4 Variable Documentation

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

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

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

[qpp::Codes](#) const Singleton

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

6.1.4.3 `constexpr double qpp::ee = 2.718281828459045235360287471352662497`

Base of natural logarithm,  $e$ .

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

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

Example:

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

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

[qpp::Gates](#) const Singleton

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

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

Used to denote infinity in double precision.

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

[qpp::Init](#) const Singleton

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

6.1.4.8 `constexpr idx qpp::maxn = 64`

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

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

6.1.4.9 `constexpr double qpp::pi = 3.141592653589793238462643383279502884`

$\pi$

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

[qpp::RandomDevices](#) Singleton

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

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

[qpp::States](#) const Singleton

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

## 6.2 qpp::experimental Namespace Reference

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

### 6.2.1 Detailed Description

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

## 6.3 qpp::internal Namespace Reference

Internal utility functions, do not use/modify.

### Classes

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

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

## Functions

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

### 6.3.1 Detailed Description

Internal utility functions, do not use/modify.

### 6.3.2 Function Documentation

6.3.2.1 template<typename Derived > bool qpp::internal::\_check\_col\_vector ( const Eigen::MatrixBase< Derived > & A )

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

6.3.2.3 template<typename Derived > bool qpp::internal::\_check\_dims\_match\_cvect ( const std::vector< `idx` > & dims,  
const Eigen::MatrixBase< Derived > & V )

6.3.2.4 template<typename Derived > bool qpp::internal::\_check\_dims\_match\_mat ( const std::vector< `idx` > & dims, const  
Eigen::MatrixBase< Derived > & A )

6.3.2.5 template<typename Derived > bool qpp::internal::\_check\_dims\_match\_rvect ( const std::vector< `idx` > & dims,  
const Eigen::MatrixBase< Derived > & V )

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



## Chapter 7

# Class Documentation

### 7.1 qpp::Codes Class Reference

const Singleton class that defines quantum error correcting codes

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

Inheritance diagram for qpp::Codes:



Collaboration diagram for qpp::Codes:



## Public Types

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

## Public Member Functions

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

## Private Member Functions

- `Codes` ()  
*Default constructor.*

## Friends

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

## Additional Inherited Members

### 7.1.1 Detailed Description

const Singleton class that defines quantum error correcting codes

### 7.1.2 Member Enumeration Documentation

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

Code types, add more codes here if needed.

See also

`qpp::Codes::codeword()`

Enumerator

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

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

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

### 7.1.3 Constructor & Destructor Documentation

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

Default constructor.



### 7.1.4 Member Function Documentation

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

Returns the codeword of the specified code type.

See also

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

#### Parameters

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

#### Returns

*i*-th codeword of the code *type*

### 7.1.5 Friends And Related Function Documentation

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

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

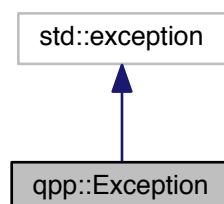
- [classes/codes.h](#)

## 7.2 qpp::Exception Class Reference

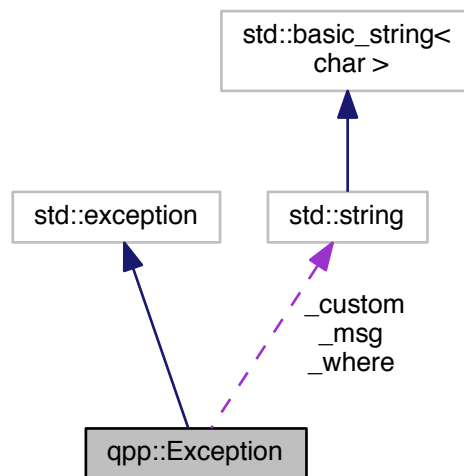
Generates custom exceptions, used when validating function parameters.

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

Inheritance diagram for qpp::Exception:



Collaboration diagram for qpp::Exception:



## Public Types

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

## Public Member Functions

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

## Private Member Functions

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

## Private Attributes

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

### 7.2.1 Detailed Description

Generates custom exceptions, used when validating function parameters.

Customize this class if more exceptions are needed

### 7.2.2 Member Enumeration Documentation

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

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

See also

[qpp::Exception::\\_construct\\_exception\\_msg\(\)](#)

#### Enumerator

- UNKNOWN\_EXCEPTION** Unknown exception
- ZERO\_SIZE** Zero sized object, e.g. empty `Eigen::Matrix` or `std::vector<>` with no elements
- MATRIX\_NOT\_SQUARE** `Eigen::Matrix` is not square
- MATRIX\_NOT\_CVECTOR** `Eigen::Matrix` is not a column vector
- MATRIX\_NOT\_RVECTOR** `Eigen::Matrix` is not a row vector
- MATRIX\_NOT\_VECTOR** `Eigen::Matrix` is not a row/column vector
- MATRIX\_NOT\_SQUARE\_OR\_CVECTOR** `Eigen::Matrix` is not square nor a column vector
- MATRIX\_NOT\_SQUARE\_OR\_RVECTOR** `Eigen::Matrix` is not square nor a row vector
- MATRIX\_NOT\_SQUARE\_OR\_VECTOR** `Eigen::Matrix` is not square nor a row/column vector
- MATRIX\_MISMATCH\_SUBSYS** Matrix size mismatch subsystem sizes (e.g. in [qpp::apply\(\)](#))
- DIMS\_INVALID** `std::vector<idx>` of dimensions has zero size or contains zeros
- DIMS\_NOT\_EQUAL** Local/global dimensions are not equal
- DIMS\_MISMATCH\_MATRIX** Product of the elements of `std::vector<idx>` of dimensions is not equal to the number of rows of `Eigen::Matrix` (assumed to be a square matrix)
- DIMS\_MISMATCH\_CVECTOR** Product of the elements of `std::vector<idx>` of dimensions is not equal to the number of elements of `Eigen::Matrix` (assumed to be a column vector)
- DIMS\_MISMATCH\_RVECTOR** Product of the elements of `std::vector<idx>` of dimensions is not equal to the number of elements of `Eigen::Matrix` (assumed to be a row vector)
- DIMS\_MISMATCH\_VECTOR** Product of the elements of `std::vector<idx>` of dimensions is not equal to the number of elements of `Eigen::Matrix` (assumed to be a row/column vector)
- SUBSYS\_MISMATCH\_DIMS** `std::vector<idx>` of subsystem labels has duplicates, or has entries that are larger than the size of the `std::vector<idx>` of dimensions
- PERM\_INVALID** `std::vector<idx>` does not represent a valid permutation
- PERM\_MISMATCH\_DIMS** Size of the `std::vector<idx>` representing the permutation is different from the size of the `std::vector<idx>` of dimensions
- NOT\_QUBIT\_GATE** `Eigen::Matrix` is not 2 x 2

**NOT\_QUBIT\_SUBSYS** Subsystems are not 2-dimensional

**NOT\_BIPARTITE** `std::vector<idx>` of dimensions has size different from 2

**NO\_CODEWORD** Codeword does not exist, thrown when calling `qpp::Codes::codeword()` with invalid index *i*

**OUT\_OF\_RANGE** Parameter out of range

**TYPE\_MISMATCH** Scalar types do not match

**UNDEFINED\_TYPE** Templated specialization not defined for this type

**CUSTOM\_EXCEPTION** Custom exception, user must provide a custom message

## 7.2.3 Constructor & Destructor Documentation

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

Constructs an exception.

Parameters

<i>where</i>	Text representing where the exception occurred
<i>type</i>	<a href="#">Exception</a> type, defined in <code>qpp::Exception::Type</code>

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

Constructs an exception.

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

Parameters

<i>where</i>	Text representing where the exception occurred
<i>custom</i>	<a href="#">Exception</a> description

## 7.2.4 Member Function Documentation

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

Constructs the exception description from its type.

See also

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

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

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

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

Returns

[Exception](#) description

## 7.2.5 Member Data Documentation

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

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

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

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

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

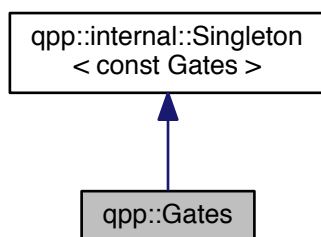
- [classes/exception.h](#)

## 7.3 qpp::Gates Class Reference

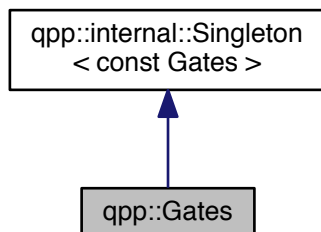
const Singleton class that implements most commonly used gates

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

Inheritance diagram for qpp::Gates:



Collaboration diagram for qpp::Gates:



## Public Member Functions

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

## Public Attributes

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

## Private Member Functions

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

## Friends

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

## Additional Inherited Members

### 7.3.1 Detailed Description

const Singleton class that implements most commonly used gates

### 7.3.2 Constructor & Destructor Documentation

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

Initializes the gates.

### 7.3.3 Member Function Documentation

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

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

See also

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

Note

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

#### Parameters

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

#### Returns

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

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

Expands out.

See also

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

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

Parameters

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

Returns

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

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

Fourier transform gate for qudits.

Note

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

Parameters

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

Returns

Fourier transform gate for qudits

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

Identity gate.

Note

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

Parameters

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

Returns

Identity gate

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

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



## Parameters

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

## Returns

Rotation gate

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

Generalized X gate for qudits.

## Note

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

## Parameters

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

## Returns

Generalized X gate for qudits

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

Generalized Z gate for qudits.

## Note

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

## Parameters

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

## Returns

Generalized Z gate for qudits

## 7.3.4 Friends And Related Function Documentation

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

## 7.3.5 Member Data Documentation

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

Controlled-NOT control target gate.

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

Controlled-NOT target control gate.

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

Controlled-Phase gate.

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

Fredkin gate.

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

Hadamard gate.

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

Identity gate.

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

S gate.

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

SWAP gate.

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

T gate.

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

Toffoli gate.

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

Pauli Sigma-X gate.

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

Pauli Sigma-Y gate.

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

Pauli Sigma-Z gate.

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

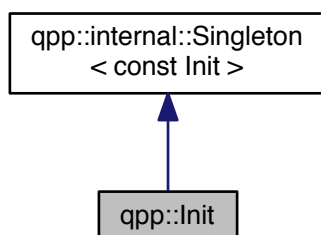
- [classes/gates.h](#)

## 7.4 qpp::Init Class Reference

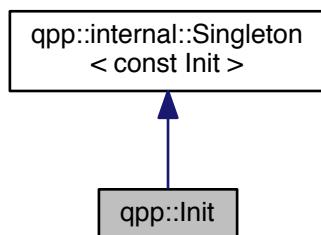
const Singleton class that performs additional initializations/cleanups

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

Inheritance diagram for qpp::Init:



Collaboration diagram for qpp::Init:



### Public Member Functions

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

### Private Member Functions

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

### Friends

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

## Additional Inherited Members

### 7.4.1 Detailed Description

const Singleton class that performs additional initializations/cleanups

### 7.4.2 Constructor & Destructor Documentation

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

Additional initializations.

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

Cleanups.

### 7.4.3 Friends And Related Function Documentation

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

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

- [classes/init.h](#)

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

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

### Public Member Functions

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

### Private Attributes

- `cmat_A`
- `double _chop`

### Friends

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

### 7.5.1 Constructor & Destructor Documentation

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

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

## 7.5.2 Friends And Related Function Documentation

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

## 7.5.3 Member Data Documentation

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

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

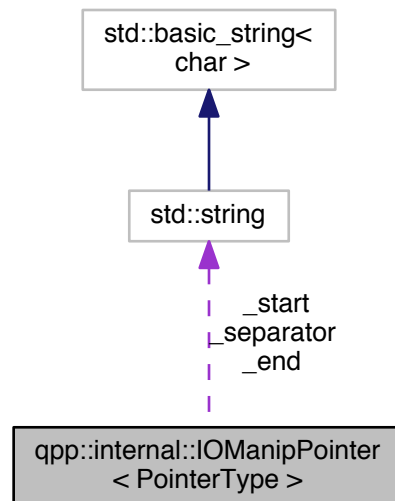
The documentation for this class was generated from the following file:

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

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

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

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



## Public Member Functions

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

## Private Attributes

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

## Friends

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

## 7.6.1 Constructor & Destructor Documentation

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

## 7.6.2 Member Function Documentation

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

## 7.6.3 Friends And Related Function Documentation

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

## 7.6.4 Member Data Documentation

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

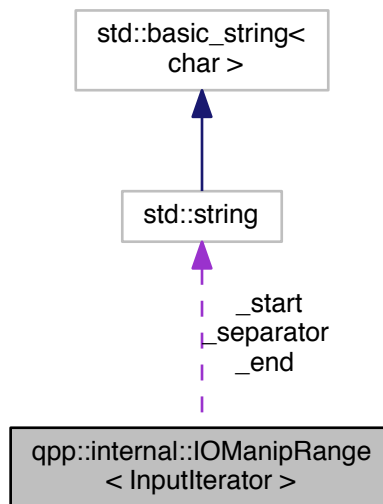
The documentation for this class was generated from the following file:

- `internal/classes/iomanip.h`

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

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

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



### Public Member Functions

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

### Private Attributes

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

### Friends

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

### 7.7.1 Constructor & Destructor Documentation

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

## 7.7.2 Friends And Related Function Documentation

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

## 7.7.3 Member Data Documentation

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

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

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

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

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

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

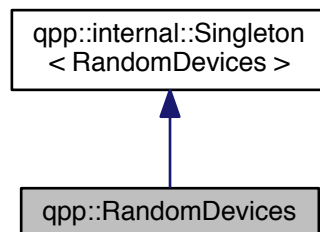
- [internal/classes/iomanip.h](#)

## 7.8 qpp::RandomDevices Class Reference

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

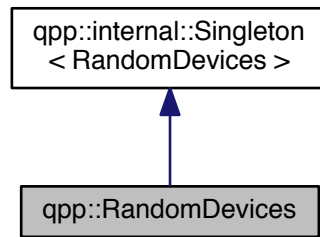
```
#include <classes/random_devices.h>
```

Inheritance diagram for qpp::RandomDevices:





Collaboration diagram for qpp::RandomDevices:



### Public Attributes

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

### Private Member Functions

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

### Private Attributes

- `std::random_device _rd`  
*used to seed std::mt19937 \_rng*

### Friends

- class `internal::Singleton < RandomDevices >`

### Additional Inherited Members

#### 7.8.1 Detailed Description

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

It consists of a wrapper around an `std::mt19937` Mersenne twister random number generator engine and an `std::random_device` engine. The latter is used to seed the Mersenne twister. The class also seeds the standard `std::srand` C number generator, as it is used by Eigen.

#### 7.8.2 Constructor & Destructor Documentation

##### 7.8.2.1 `qpp::RandomDevices::RandomDevices ( )` `[inline]`, `[private]`

Initializes and seeds the random number generators.

### 7.8.3 Friends And Related Function Documentation

7.8.3.1 friend class `internal::Singleton< RandomDevices >` [`friend`]

### 7.8.4 Member Data Documentation

7.8.4.1 `std::random_device qpp::RandomDevices::_rd` [`private`]

used to seed `std::mt19937 _rng`

7.8.4.2 `std::mt19937 qpp::RandomDevices::_rng`

Mersenne twister random number generator.

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

- [classes/random\\_devices.h](#)

## 7.9 `qpp::internal::Singleton< T >` Class Template Reference

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

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

### Static Public Member Functions

- static `T & get_instance ()`

### Protected Member Functions

- `Singleton ()`
- virtual `~Singleton ()`
- `Singleton (const Singleton &)=delete`
- `Singleton & operator= (const Singleton &)=delete`

#### 7.9.1 Detailed Description

```
template<typename T>class qpp::internal::Singleton< T >
```

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

To implement a singleton, derive your class from `qpp::internal::Singleton`, make `qpp::internal::Singleton` a friend of your class, then declare the constructor of your class as private. To get an instance, use the static member function `qpp::internal::Singleton::get_instance()`, which returns a reference to your newly created singleton (thread-safe in C++11).

Example:

```
class MySingleton: public qpp::internal::Singleton<MySingleton>
{
    friend class qpp::internal::Singleton<MySingleton>;
public:
    // Declare all public members here
private:
    MySingleton()
```

```

    {
        // Implement the constructor here
    }
};

MySingleton& mySingleton = MySingleton::get_instance(); // Get an instance

```

**See also**

Code of [qpp::Codes](#), [qpp::Gates](#), [qpp::Init](#), [qpp::RandomDevices](#), [qpp::States](#) or [qpp.h](#) for real world examples of usage.

**7.9.2 Constructor & Destructor Documentation**

**7.9.2.1** `template<typename T> qpp::internal::Singleton< T >::Singleton ( )` `[inline], [protected]`

**7.9.2.2** `template<typename T> virtual qpp::internal::Singleton< T >::~~Singleton ( )` `[inline], [protected], [virtual]`

**7.9.2.3** `template<typename T> qpp::internal::Singleton< T >::Singleton ( const Singleton< T > & )` `[protected], [delete]`

**7.9.3 Member Function Documentation**

**7.9.3.1** `template<typename T> static T& qpp::internal::Singleton< T >::get_instance ( )` `[inline], [static]`

**7.9.3.2** `template<typename T> Singleton& qpp::internal::Singleton< T >::operator= ( const Singleton< T > & )` `[protected], [delete]`

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

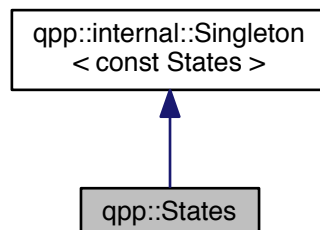
- [internal/classes/singleton.h](#)

**7.10 qpp::States Class Reference**

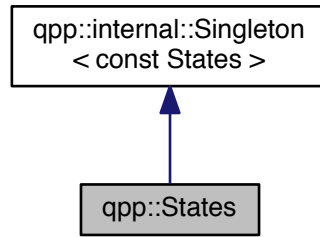
const Singleton class that implements most commonly used states

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

Inheritance diagram for qpp::States:



Collaboration diagram for `qpp::States`:



## Public Attributes

- `ket x0` {ket::Zero(2)}  
Pauli Sigma-X 0-eigenstate  $|+\rangle$
- `ket x1` {ket::Zero(2)}  
Pauli Sigma-X 1-eigenstate  $|-\rangle$
- `ket y0` {ket::Zero(2)}  
Pauli Sigma-Y 0-eigenstate  $|y+\rangle$
- `ket y1` {ket::Zero(2)}  
Pauli Sigma-Y 1-eigenstate  $|y-\rangle$
- `ket z0` {ket::Zero(2)}  
Pauli Sigma-Z 0-eigenstate  $|0\rangle$
- `ket z1` {ket::Zero(2)}  
Pauli Sigma-Z 1-eigenstate  $|1\rangle$
- `cmat px0` {cmat::Zero(2, 2)}  
Projector onto the Pauli Sigma-X 0-eigenstate  $|+\rangle\langle+|$ .
- `cmat px1` {cmat::Zero(2, 2)}  
Projector onto the Pauli Sigma-X 1-eigenstate  $|-\rangle\langle-|$ .
- `cmat py0` {cmat::Zero(2, 2)}  
Projector onto the Pauli Sigma-Y 0-eigenstate  $|y+\rangle\langle y+|$ .
- `cmat py1` {cmat::Zero(2, 2)}  
Projector onto the Pauli Sigma-Y 1-eigenstate  $|y-\rangle\langle y-|$ .
- `cmat pz0` {cmat::Zero(2, 2)}  
Projector onto the Pauli Sigma-Z 0-eigenstate  $|0\rangle\langle 0|$ .
- `cmat pz1` {cmat::Zero(2, 2)}  
Projector onto the Pauli Sigma-Z 1-eigenstate  $|1\rangle\langle 1|$ .
- `ket b00` {ket::Zero(4)}  
Bell-00 state (following the convention in Nielsen and Chuang)
- `ket b01` {ket::Zero(4)}  
Bell-01 state (following the convention in Nielsen and Chuang)
- `ket b10` {ket::Zero(4)}  
Bell-10 state (following the convention in Nielsen and Chuang)
- `ket b11` {ket::Zero(4)}  
Bell-11 state (following the convention in Nielsen and Chuang)
- `cmat pb00` {cmat::Zero(4, 4)}

- Projector onto the Bell-00 state.*
- [cmat pb01](#) {cmat::Zero(4, 4)}
- Projector onto the Bell-01 state.*
- [cmat pb10](#) {cmat::Zero(4, 4)}
- Projector onto the Bell-10 state.*
- [cmat pb11](#) {cmat::Zero(4, 4)}
- Projector onto the Bell-11 state.*
- [ket GHZ](#) {ket::Zero(8)}
- GHZ state.*
- [ket W](#) {ket::Zero(8)}
- W state.*
- [cmat pGHZ](#) {cmat::Zero(8, 8)}
- Projector onto the GHZ state.*
- [cmat pW](#) {cmat::Zero(8, 8)}
- Projector onto the W state.*

## Private Member Functions

- [States](#) ()

## Friends

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

## Additional Inherited Members

### 7.10.1 Detailed Description

const Singleton class that implements most commonly used states

### 7.10.2 Constructor & Destructor Documentation

#### 7.10.2.1 `qpp::States::States ( ) [inline], [private]`

Initialize the states

### 7.10.3 Friends And Related Function Documentation

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

### 7.10.4 Member Data Documentation

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

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

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

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

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

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

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

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

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

GHZ state.

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

Projector onto the Bell-00 state.

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

Projector onto the Bell-01 state.

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

Projector onto the Bell-10 state.

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

Projector onto the Bell-11 state.

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

Projector onto the GHZ state.

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

Projector onto the W state.

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

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

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

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

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

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

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

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

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

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

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

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

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

W state.

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

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

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

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

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

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

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

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

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

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

7.10.4.24 `ket qpp::States::z1 {ket::Zero(2)}`

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

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

- [classes/states.h](#)

## 7.11 qpp::Timer Class Reference

Measures time.

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

## Public Member Functions

- [Timer](#) ()  
*Constructs an instance with the current time as the starting point.*
- void [tic](#) ()  
*Resets the chronometer.*
- const [Timer](#) & [toc](#) ()  
*Stops the chronometer.*
- double [seconds](#) () const  
*Time passed in seconds.*

## Protected Attributes

- std::chrono::steady\_clock::time\_point [\\_start](#)
- std::chrono::steady\_clock::time\_point [\\_end](#)

## Friends

- template<typename charT , typename traits >  
std::basic\_ostream< charT,  
traits > & [operator<<](#) (std::basic\_ostream< charT, traits > &os, const [Timer](#) &rhs)  
*Overload for std::ostream operators.*

### 7.11.1 Detailed Description

Measures time.

Uses a std::chrono::steady\_clock. It is not affected by wall clock changes during runtime.

### 7.11.2 Constructor & Destructor Documentation

#### 7.11.2.1 `qpp::Timer::Timer ( )` `[inline]`

Constructs an instance with the current time as the starting point.

### 7.11.3 Member Function Documentation

#### 7.11.3.1 `double qpp::Timer::seconds ( )` `const` `[inline]`

Time passed in seconds.

#### Returns

Number of seconds that passed between the instantiation/reset and invocation of `qpp::Timer::toc()`

#### 7.11.3.2 `void qpp::Timer::tic ( )` `[inline]`

Resets the chronometer.

Resets the starting/ending point to the current time



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

Stops the chronometer.

Set the current time as the ending point

**Returns**

Current instance

## 7.11.4 Friends And Related Function Documentation

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

Overload for std::ostream operators.

**Parameters**

<i>os</i>	Output stream
<i>rhs</i>	<a href="#">Timer</a> instance

**Returns**

Writes to the output stream the number of seconds that passed between the instantiation/reset and invocation of [qpp::Timer::toc\(\)](#).

## 7.11.5 Member Data Documentation

7.11.5.1 `std::chrono::steady_clock::time_point qpp::Timer::_end [protected]`7.11.5.2 `std::chrono::steady_clock::time_point qpp::Timer::_start [protected]`

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

- [classes/timer.h](#)



## Chapter 8

# File Documentation

### 8.1 classes/codes.h File Reference

Quantum error correcting codes.

This graph shows which files directly or indirectly include this file:



#### Classes

- class [qpp::Codes](#)  
*const Singleton class that defines quantum error correcting codes*

#### Namespaces

- [qpp](#)  
*Quantum++ main namespace.*

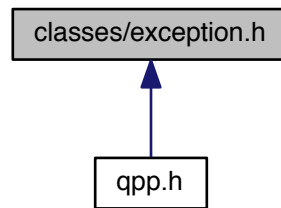
#### 8.1.1 Detailed Description

Quantum error correcting codes.

### 8.2 classes/exception.h File Reference

Exceptions.

This graph shows which files directly or indirectly include this file:



## Classes

- class [qpp::Exception](#)  
*Generates custom exceptions, used when validating function parameters.*

## Namespaces

- [qpp](#)  
*Quantum++ main namespace.*

### 8.2.1 Detailed Description

Exceptions.

## 8.3 classes/gates.h File Reference

Quantum gates.

This graph shows which files directly or indirectly include this file:



## Classes

- class [qpp::Gates](#)  
*const Singleton class that implements most commonly used gates*

## Namespaces

- [qpp](#)  
*Quantum++ main namespace.*

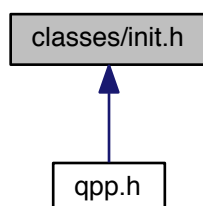
### 8.3.1 Detailed Description

Quantum gates.

## 8.4 classes/init.h File Reference

Initialization.

This graph shows which files directly or indirectly include this file:



## Classes

- class [qpp::Init](#)  
*const Singleton class that performs additional initializations/cleanups*

## Namespaces

- [qpp](#)  
*Quantum++ main namespace.*

### 8.4.1 Detailed Description

Initialization.

## 8.5 classes/random\_devices.h File Reference

Random devices.

This graph shows which files directly or indirectly include this file:



### Classes

- class [qpp::RandomDevices](#)  
*Singleton class that manages the source of randomness in the library.*

### Namespaces

- [qpp](#)  
*Quantum++ main namespace.*

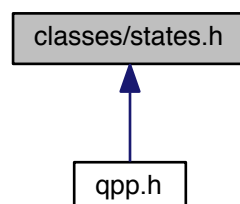
### 8.5.1 Detailed Description

Random devices.

## 8.6 classes/states.h File Reference

Quantum states.

This graph shows which files directly or indirectly include this file:



## Classes

- class [qpp::States](#)  
*const Singleton class that implements most commonly used states*

## Namespaces

- [qpp](#)  
*Quantum++ main namespace.*

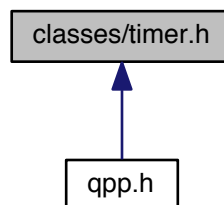
### 8.6.1 Detailed Description

Quantum states.

## 8.7 classes/timer.h File Reference

Timing.

This graph shows which files directly or indirectly include this file:



## Classes

- class [qpp::Timer](#)  
*Measures time.*

## Namespaces

- [qpp](#)  
*Quantum++ main namespace.*

### 8.7.1 Detailed Description

Timing.

## 8.8 constants.h File Reference

Constants.

This graph shows which files directly or indirectly include this file:



### Namespaces

- [qpp](#)  
*Quantum++ main namespace.*

### Functions

- constexpr cplx [qpp::operator""\\_i](#) (unsigned long long int x)  
*User-defined literal for complex  $i = \sqrt{-1}$  (integer overload)*
- constexpr cplx [qpp::operator""\\_i](#) (long double x)  
*User-defined literal for complex  $i = \sqrt{-1}$  (real overload)*
- cplx [qpp::omega](#) (idx D)  
*D-th root of unity.*

### Variables

- constexpr double [qpp::chop](#) = 1e-10  
*Used in [qpp::disp\(\)](#) for setting to zero numbers that have their absolute value smaller than [qpp::chop](#).*
- constexpr double [qpp::eps](#) = 1e-12  
*Used to decide whether a number or expression in double precision is zero or not.*
- constexpr idx [qpp::maxn](#) = 64  
*Maximum number of allowed qu(d)its (subsystems)*
- constexpr double [qpp::pi](#) = 3.141592653589793238462643383279502884  
 $\pi$
- 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

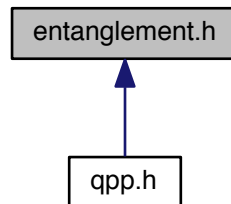
Constants.



## 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.*

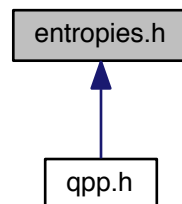
### 8.9.1 Detailed Description

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-  $\alpha$  entropy of the density matrix A, for  $\alpha \geq 0$ .*
- `double qpp::renyi (const std::vector< double > &prob, double alpha)`  
*Renyi-  $\alpha$  entropy of the probability distribution prob, for  $\alpha \geq 0$ .*
- `template<typename Derived >`  
`double qpp::tsallis (const Eigen::MatrixBase< Derived > &A, double q)`  
*Tsallis- q entropy of the density matrix A, for  $q \geq 0$ .*
- `double qpp::tsallis (const std::vector< double > &prob, double q)`  
*Tsallis- q entropy of the probability distribution prob, for  $q \geq 0$ .*

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

*Quantum mutual information between 2 subsystems of a composite system.*

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

*Quantum mutual information between 2 subsystems of a composite system.*

### 8.10.1 Detailed Description

Entropy functions.

## 8.11 experimental/test.h File Reference

Experimental/test functions/classes.

### Namespaces

- `qpp`  
*Quantum++ main namespace.*
- `qpp::experimental`  
*Experimental/test functions/classes, do not use or modify.*

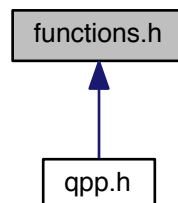
### 8.11.1 Detailed Description

Experimental/test functions/classes.

## 8.12 functions.h File Reference

Generic quantum computing functions.

This graph shows which files directly or indirectly include this file:



## Namespaces

- [qpp](#)  
*Quantum++ main namespace.*

## Functions

- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::transpose (const Eigen::MatrixBase< Derived > &A)`  
*Transpose.*
- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::conjugate (const Eigen::MatrixBase< Derived > &A)`  
*Complex conjugate.*
- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::adjoint (const Eigen::MatrixBase< Derived > &A)`  
*Adjoint.*
- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::inverse (const Eigen::MatrixBase< Derived > &A)`  
*Inverse.*
- `template<typename Derived >`  
`Derived::Scalar qpp::trace (const Eigen::MatrixBase< Derived > &A)`  
*Trace.*
- `template<typename Derived >`  
`Derived::Scalar qpp::det (const Eigen::MatrixBase< Derived > &A)`  
*Determinant.*
- `template<typename Derived >`  
`Derived::Scalar qpp::logdet (const Eigen::MatrixBase< Derived > &A)`  
*Logarithm of the determinant.*
- `template<typename Derived >`  
`Derived::Scalar qpp::sum (const Eigen::MatrixBase< Derived > &A)`  
*Element-wise sum of A.*
- `template<typename Derived >`  
`Derived::Scalar qpp::prod (const Eigen::MatrixBase< Derived > &A)`  
*Element-wise product of A.*
- `template<typename Derived >`  
`double qpp::norm (const Eigen::MatrixBase< Derived > &A)`  
*Frobenius norm.*
- `template<typename Derived >`  
`std::pair< dyn_col_vect< cplx >`  
`, cmat > qpp::eig (const Eigen::MatrixBase< Derived > &A)`  
*Full eigen decomposition.*
- `template<typename Derived >`  
`dyn_col_vect< cplx > qpp::evals (const Eigen::MatrixBase< Derived > &A)`  
*Eigenvalues.*
- `template<typename Derived >`  
`cmat qpp::evecs (const Eigen::MatrixBase< Derived > &A)`  
*Eigenvectors.*
- `template<typename Derived >`  
`std::pair< dyn_col_vect`  
`< double >, cmat > qpp::heig (const Eigen::MatrixBase< Derived > &A)`  
*Full eigen decomposition of Hermitian expression.*
- `template<typename Derived >`  
`dyn_col_vect< double > qpp::hevals (const Eigen::MatrixBase< Derived > &A)`

*Hermitian eigenvalues.*

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

*Hermitian eigenvectors.*

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

*Full singular value decomposition.*

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

*Singular values.*

- `template<typename Derived >`  
`cmat qpp::svdU (const Eigen::MatrixBase< Derived > &A)`

*Left singular vectors.*

- `template<typename Derived >`  
`cmat qpp::svdV (const Eigen::MatrixBase< Derived > &A)`

*Right singular vectors.*

- `template<typename Derived >`  
`cmat qpp::funm (const Eigen::MatrixBase< Derived > &A, cplx(*f)(const cplx &))`

*Functional calculus  $f(A)$*

- `template<typename Derived >`  
`cmat qpp::sqrtm (const Eigen::MatrixBase< Derived > &A)`

*Matrix square root.*

- `template<typename Derived >`  
`cmat qpp::absm (const Eigen::MatrixBase< Derived > &A)`

*Matrix absolut value.*

- `template<typename Derived >`  
`cmat qpp::expm (const Eigen::MatrixBase< Derived > &A)`

*Matrix exponential.*

- `template<typename Derived >`  
`cmat qpp::logm (const Eigen::MatrixBase< Derived > &A)`

*Matrix logarithm.*

- `template<typename Derived >`  
`cmat qpp::sinm (const Eigen::MatrixBase< Derived > &A)`

*Matrix sin.*

- `template<typename Derived >`  
`cmat qpp::cosm (const Eigen::MatrixBase< Derived > &A)`

*Matrix cos.*

- `template<typename Derived >`  
`cmat qpp::spectralpowm (const Eigen::MatrixBase< Derived > &A, const cplx z)`

*Matrix power.*

- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::powm (const Eigen::MatrixBase< Derived > &A, idx n)`

*Matrix power.*

- `template<typename Derived >`  
`double qpp::schatten (const Eigen::MatrixBase< Derived > &A, idx p)`

*Schatten norm.*

- `template<typename OutputScalar, typename Derived >`  
`dyn_mat< OutputScalar > qpp::cwise (const Eigen::MatrixBase< Derived > &A, OutputScalar(*f)(const`  
`typename Derived::Scalar &))`

*Functor.*

- `template<typename T >`  
`dyn_mat< typename T::Scalar > qpp::kron (const T &head)`

*Kronecker product.*

- `template<typename T , typename... Args>`  
`dyn_mat< typename T::Scalar > qpp::kron (const T &head, const Args &...tail)`

*Kronecker product.*

- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::kron (const std::vector< Derived > &As)`

*Kronecker product.*

- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::kron (const std::initializer_list< Derived > &As)`

*Kronecker product.*

- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::kronpow (const Eigen::MatrixBase< Derived > &A, idx n)`

*Kronecker power.*

- `template<typename T >`  
`dyn_mat< typename T::Scalar > qpp::dirsum (const T &head)`

*Direct sum.*

- `template<typename T , typename... Args>`  
`dyn_mat< typename T::Scalar > qpp::dirsum (const T &head, const Args &...tail)`

*Direct sum.*

- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::dirsum (const std::vector< Derived > &As)`

*Direct sum.*

- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::dirsum (const std::initializer_list< Derived > &As)`

*Direct sum.*

- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::dirsumpow (const Eigen::MatrixBase< Derived > &A, idx n)`

*Direct sum power.*

- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::reshape (const Eigen::MatrixBase< Derived > &A, idx rows, idx cols)`

*Reshape.*

- `template<typename Derived1 , typename Derived2 >`  
`dyn_mat< typename`  
`Derived1::Scalar > qpp::comm (const Eigen::MatrixBase< Derived1 > &A, const Eigen::MatrixBase< Derived2 > &B)`

*Commutator.*

- `template<typename Derived1 , typename Derived2 >`  
`dyn_mat< typename`  
`Derived1::Scalar > qpp::anticomm (const Eigen::MatrixBase< Derived1 > &A, const Eigen::MatrixBase< Derived2 > &B)`

*Anti-commutator.*

- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::prj (const Eigen::MatrixBase< Derived > &V)`

*Projector.*

- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::grams (const std::vector< Derived > &Vs)`

*Gram-Schmidt orthogonalization.*

- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::grams (const std::initializer_list< Derived > &Vs)`

*Gram-Schmidt orthogonalization.*

- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::grams (const Eigen::MatrixBase< Derived > &A)`

- *Gram-Schmidt orthogonalization.*  
std::vector< idx > [qpp::n2multiidx](#) (idx n, const std::vector< idx > &dims)
- *Non-negative integer index to multi-index.*  
idx [qpp::multiidx2n](#) (const std::vector< idx > &midx, const std::vector< idx > &dims)
- *Multi-index to non-negative integer index.*  
ket [qpp::mket](#) (const std::vector< idx > &mask, const std::vector< idx > &dims)
- *Multi-partite qudit ket.*  
ket [qpp::mket](#) (const std::vector< idx > &mask, idx d=2)
- *Multi-partite qudit ket.*  
cmat [qpp::mprj](#) (const std::vector< idx > &mask, const std::vector< idx > &dims)
- *Projector onto multi-partite qudit ket.*  
cmat [qpp::mprj](#) (const std::vector< idx > &mask, idx d=2)
- *Projector onto multi-partite qudit ket.*  
template<typename InputIterator >  
std::vector< double > [qpp::abssq](#) (InputIterator first, InputIterator last)  
*Computes the absolut values squared of a range of complex numbers.*
- template<typename Derived >  
std::vector< double > [qpp::abssq](#) (const Eigen::MatrixBase< Derived > &V)  
*Computes the absolut values squared of a column vector.*
- template<typename InputIterator >  
InputIterator::value\_type [qpp::sum](#) (InputIterator first, InputIterator last)  
*Element-wise sum of a range.*
- template<typename InputIterator >  
InputIterator::value\_type [qpp::prod](#) (InputIterator first, InputIterator last)  
*Element-wise product of a range.*
- template<typename Derived >  
dyn\_col\_vect< typename  
Derived::Scalar > [qpp::rho2pure](#) (const Eigen::MatrixBase< Derived > &A)  
*Finds the pure state representation of a matrix proportional to a projector onto a pure state.*

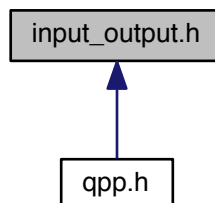
### 8.12.1 Detailed Description

Generic quantum computing functions.

## 8.13 input\_output.h File Reference

Input/output functions.

This graph shows which files directly or indirectly include this file:



## Namespaces

- [qpp](#)

*Quantum++ main namespace.*

## Functions

- `template<typename Derived >`  
`internal::IOManipEigen qpp::disp (const Eigen::MatrixBase< Derived > &A, double chop=qpp::chop)`  
*Eigen expression ostream manipulator.*
- `internal::IOManipEigen qpp::disp (cplx z, double chop=qpp::chop)`  
*Complex number ostream manipulator.*
- `template<typename InputIterator >`  
`internal::IOManipRange`  
`< InputIterator > qpp::disp (const InputIterator &first, const InputIterator &last, const std::string &separator,`  
`const std::string &start="["`, `const std::string &end=""]")`  
*Range ostream manipulator.*
- `template<typename Container >`  
`internal::IOManipRange`  
`< typename`  
`Container::const_iterator > qpp::disp (const Container &c, const std::string &separator, const std::string`  
`&start="["`, `const std::string &end=""]")`  
*Standard container ostream manipulator. The container must support std::begin(), std::end() and forward iteration.*
- `template<typename PointerType >`  
`internal::IOManipPointer`  
`< PointerType > qpp::disp (const PointerType *p, idx n, const std::string &separator, const std::string`  
`&start="["`, `const std::string &end=""]")`  
*C-style pointer ostream manipulator.*
- `template<typename Derived >`  
`void qpp::save (const Eigen::MatrixBase< Derived > &A, const std::string &fname)`  
*Saves Eigen expression to a binary file (internal format) in double precision.*
- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::load (const std::string &fname)`  
*Loads Eigen matrix from a binary file (internal format) in double precision.*

### 8.13.1 Detailed Description

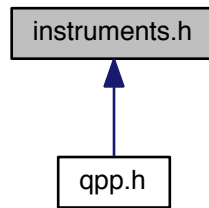
Input/output functions.

## 8.14 instruments.h File Reference

Measurement functions.



This graph shows which files directly or indirectly include this file:



## Namespaces

- [qpp](#)  
*Quantum++ main namespace.*

## Functions

- `template<typename Derived >`  
`std::tuple< idx, std::vector`  
`< double >, std::vector< cmat > > qpp::measure (const Eigen::MatrixBase< Derived > &A, const std::vector< cmat > &Ks, const std::vector< idx > &subsys, const std::vector< idx > &dims)`  
*Measures the part subsys of the multi-partite state vector or density matrix A using the set of Kraus operators Ks.*
- `template<typename Derived >`  
`std::tuple< idx, std::vector`  
`< double >, std::vector< cmat > > qpp::measure (const Eigen::MatrixBase< Derived > &A, const std::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.*

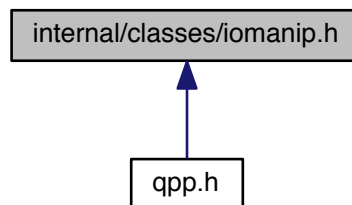
### 8.14.1 Detailed Description

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.*

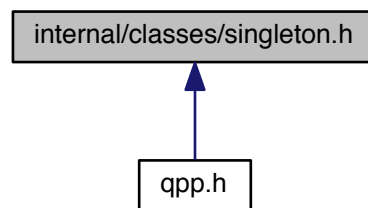
### 8.15.1 Detailed Description

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.*

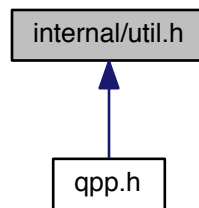
### 8.16.1 Detailed Description

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)
- idx [qpp::internal::\\_multiidx2n](#) (const idx \*midx, idx numdims, const idx \*dims)
- template<typename Derived >  
bool [qpp::internal::\\_check\\_square\\_mat](#) (const Eigen::MatrixBase< Derived > &A)
- template<typename Derived >  
bool [qpp::internal::\\_check\\_vector](#) (const Eigen::MatrixBase< Derived > &A)
- template<typename Derived >  
bool [qpp::internal::\\_check\\_row\\_vector](#) (const Eigen::MatrixBase< Derived > &A)
- template<typename Derived >  
bool [qpp::internal::\\_check\\_col\\_vector](#) (const Eigen::MatrixBase< Derived > &A)
- template<typename T >  
bool [qpp::internal::\\_check\\_nonzero\\_size](#) (const T &x)
- bool [qpp::internal::\\_check\\_dims](#) (const std::vector< idx > &dims)
- template<typename Derived >  
bool [qpp::internal::\\_check\\_dims\\_match\\_mat](#) (const std::vector< idx > &dims, const Eigen::MatrixBase< Derived > &A)
- template<typename Derived >  
bool [qpp::internal::\\_check\\_dims\\_match\\_cvect](#) (const std::vector< idx > &dims, const Eigen::MatrixBase< Derived > &V)
- template<typename Derived >  
bool [qpp::internal::\\_check\\_dims\\_match\\_rvect](#) (const std::vector< idx > &dims, const Eigen::MatrixBase< Derived > &V)
- bool [qpp::internal::\\_check\\_eq\\_dims](#) (const std::vector< idx > &dims, idx dim)
- bool [qpp::internal::\\_check\\_subsys\\_match\\_dims](#) (const std::vector< idx > &subsys, const std::vector< idx > &dims)
- bool [qpp::internal::\\_check\\_perm](#) (const std::vector< idx > &perm)
- template<typename Derived1 , typename Derived2 >  
dyn\_mat< typename  
Derived1::Scalar > [qpp::internal::\\_kron2](#) (const Eigen::MatrixBase< Derived1 > &A, const Eigen::MatrixBase< Derived2 > &B)

- `template<typename Derived1 , typename Derived2 >`  
`dyn_mat< typename`  
`Derived1::Scalar > qpp::internal::\_dirsum2 (const Eigen::MatrixBase< Derived1 > &A, const Eigen::MatrixBase< Derived2 > &B)`
- `template<typename T >`  
`void qpp::internal::variadic\_vector\_emplace (std::vector< T > &)`
- `template<typename T , typename First , typename... Args>`  
`void qpp::internal::variadic\_vector\_emplace (std::vector< T > &v, First &&first, Args &&...args)`

### 8.17.1 Detailed Description

Internal utility functions.

## 8.18 MATLAB/matlab.h File Reference

Input/output interfacing with MATLAB.

```
#include "mat.h"
#include "mex.h"
```

### Namespaces

- [qpp](#)  
*Quantum++ main namespace.*

### Functions

- `template<typename Derived >`  
`Derived qpp::loadMATLABmatrix (const std::string &mat_file, const std::string &var_name)`  
*Loads an Eigen dynamic matrix from a MATLAB .mat file, generic version.*
- `template<>`  
`dmat qpp::loadMATLABmatrix (const std::string &mat_file, const std::string &var_name)`  
*Loads an Eigen dynamic matrix from a MATLAB .mat file, specialization for double matrices ([qpp::dmat](#))*
- `template<>`  
`cmat qpp::loadMATLABmatrix (const std::string &mat_file, const std::string &var_name)`  
*Loads an Eigen dynamic matrix from a MATLAB .mat file, specialization for complex matrices ([qpp::cmat](#))*
- `template<typename Derived >`  
`void qpp::saveMATLABmatrix (const Eigen::MatrixBase< Derived > &A, const std::string &mat_file, const std::string &var_name, const std::string &mode)`  
*Saves an Eigen dynamic matrix to a MATLAB .mat file, generic version.*
- `template<>`  
`void qpp::saveMATLABmatrix (const Eigen::MatrixBase< dmat > &A, const std::string &mat_file, const std::string &var_name, const std::string &mode)`  
*Saves an Eigen dynamic matrix to a MATLAB .mat file, specialization for double matrices ([qpp::dmat](#))*
- `template<>`  
`void qpp::saveMATLABmatrix (const Eigen::MatrixBase< cmat > &A, const std::string &mat_file, const std::string &var_name, const std::string &mode)`  
*Saves an Eigen dynamic matrix to a MATLAB .mat file, specialization for complex matrices ([qpp::cmat](#))*

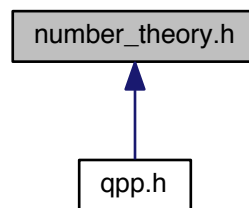
### 8.18.1 Detailed Description

Input/output interfacing with MATLAB.

## 8.19 number\_theory.h File Reference

Number theory functions.

This graph shows which files directly or indirectly include this file:



### Namespaces

- [qpp](#)  
*Quantum++ main namespace.*

### Functions

- `std::vector< long long int > qpp::x2contfrac (double x, idx n, idx cut=1e5)`  
*Simple continued fraction expansion.*
- `double qpp::contfrac2x (const std::vector< int > &cf, idx n)`  
*Real representation of a simple continued fraction.*
- `double qpp::contfrac2x (const std::vector< int > &cf)`  
*Real representation of a simple continued fraction.*
- `idx qpp::gcd (idx m, idx n)`  
*Greatest common divisor of two non-negative integers.*
- `idx qpp::gcd (const std::vector< idx > &ns)`  
*Greatest common divisor of a list of non-negative integers.*
- `idx qpp::lcm (idx m, idx n)`  
*Least common multiple of two positive integers.*
- `idx qpp::lcm (const std::vector< idx > &ns)`  
*Least common multiple of a list of positive integers.*
- `std::vector< idx > qpp::invperm (const std::vector< idx > &perm)`  
*Inverse permutation.*
- `std::vector< idx > qpp::compperm (const std::vector< idx > &perm, const std::vector< idx > &sigma)`  
*Compose permutations.*

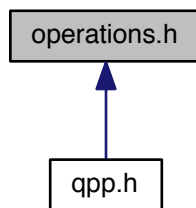
### 8.19.1 Detailed Description

Number theory functions.

## 8.20 operations.h File Reference

Quantum operation functions.

This graph shows which files directly or indirectly include this file:



### Namespaces

- [qpp](#)

*Quantum++ main namespace.*

### Functions

- `template<typename Derived1 , typename Derived2 >`  
`dyn_mat< typename`  
`Derived1::Scalar > qpp::applyCTRL (const Eigen::MatrixBase< Derived1 > &state, const Eigen::MatrixBase< Derived2 > &A, const std::vector< idx > &ctrl, const std::vector< idx > &subsys, const std::vector< idx > &dims)`  
*Applies the controlled-gate A to the part subsys of the multi-partite state vector or density matrix state.*
- `template<typename Derived1 , typename Derived2 >`  
`dyn_mat< typename`  
`Derived1::Scalar > qpp::applyCTRL (const Eigen::MatrixBase< Derived1 > &state, const Eigen::MatrixBase< Derived2 > &A, const std::vector< idx > &ctrl, const std::vector< idx > &subsys, idx d=2)`  
*Applies the controlled-gate A to the part subsys of the multi-partite state vector or density matrix state.*
- `template<typename Derived1 , typename Derived2 >`  
`dyn_mat< typename`  
`Derived1::Scalar > qpp::apply (const Eigen::MatrixBase< Derived1 > &state, const Eigen::MatrixBase< Derived2 > &A, const std::vector< idx > &subsys, const std::vector< idx > &dims)`  
*Applies the gate A to the part subsys of the multi-partite state vector or density matrix state.*
- `template<typename Derived1 , typename Derived2 >`  
`dyn_mat< typename`  
`Derived1::Scalar > qpp::apply (const Eigen::MatrixBase< Derived1 > &state, const Eigen::MatrixBase< Derived2 > &A, const std::vector< idx > &subsys, idx d=2)`  
*Applies the gate A to the part subsys of the multi-partite state vector or density matrix state.*

- `template<typename Derived >`  
`cmat qpp::apply (const Eigen::MatrixBase< Derived > &rho, const std::vector< cmat > &Ks)`  
*Applies the channel specified by the set of Kraus operators Ks to the density matrix rho.*
- `template<typename Derived >`  
`cmat qpp::apply (const Eigen::MatrixBase< Derived > &rho, const std::vector< cmat > &Ks, const std::vector< idx > &subsys, const std::vector< idx > &dims)`  
*Applies the channel specified by the set of Kraus operators Ks to the part subsys of the multi-partite density matrix rho.*
- `template<typename Derived >`  
`cmat qpp::apply (const Eigen::MatrixBase< Derived > &rho, const std::vector< cmat > &Ks, const std::vector< idx > &subsys, idx d=2)`  
*Applies the channel specified by the set of Kraus operators Ks to the part subsys of the multi-partite density matrix rho.*
- `cmat qpp::kraus2super (const std::vector< cmat > &Ks)`  
*Superoperator matrix.*
- `cmat qpp::kraus2choi (const std::vector< cmat > &Ks)`  
*Choi matrix.*
- `std::vector< cmat > qpp::choi2kraus (const cmat &A)`  
*Orthogonal Kraus operators from Choi matrix.*
- `cmat qpp::choi2super (const cmat &A)`  
*Converts Choi matrix to superoperator matrix.*
- `cmat qpp::super2choi (const cmat &A)`  
*Converts superoperator matrix to Choi matrix.*
- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::ptrace1 (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &dims)`  
*Partial trace.*
- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::ptrace2 (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &dims)`  
*Partial trace.*
- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::ptrace (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &subsys, const std::vector< idx > &dims)`  
*Partial trace.*
- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::ptrace (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &subsys, idx d=2)`  
*Partial trace.*
- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::ptranspose (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &subsys, const std::vector< idx > &dims)`  
*Partial transpose.*
- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::ptranspose (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &subsys, idx d=2)`  
*Partial transpose.*
- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::syspermute (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &perm, const std::vector< idx > &dims)`  
*Subsystem permutation.*
- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::syspermute (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &perm, idx d=2)`  
*Subsystem permutation.*



### 8.20.1 Detailed Description

Quantum operation functions.

## 8.21 qpp.h File Reference

Quantum++ main header file, includes all other necessary headers.

```
#include <algorithm>
#include <chrono>
#include <cmath>
#include <complex>
#include <cstdlib>
#include <cstring>
#include <ctime>
#include <exception>
#include <fstream>
#include <functional>
#include <initializer_list>
#include <iomanip>
#include <iostream>
#include <iterator>
#include <limits>
#include <numeric>
#include <ostream>
#include <random>
#include <sstream>
#include <stdexcept>
#include <string>
#include <tuple>
#include <type_traits>
#include <utility>
#include <vector>
#include <Eigen/Dense>
#include <Eigen/SVD>
#include "types.h"
#include "constants.h"
#include "classes/exception.h"
#include "internal/util.h"
#include "internal/classes/iomanip.h"
#include "input_output.h"
#include "internal/classes/singleton.h"
#include "classes/init.h"
#include "functions.h"
#include "classes/codes.h"
#include "classes/gates.h"
#include "classes/states.h"
#include "classes/random_devices.h"
#include "operations.h"
#include "entropies.h"
#include "entanglement.h"
#include "random.h"
#include "classes/timer.h"
#include "instruments.h"
#include "number_theory.h"
```

## Namespaces

- [qpp](#)

*Quantum++ main namespace.*

## Variables

- `const Init & qpp::init = Init::get_instance()`  
[qpp::Init](#) *const Singleton*
- `const Codes & qpp::codes = Codes::get_instance()`  
[qpp::Codes](#) *const Singleton*
- `const Gates & qpp::gt = Gates::get_instance()`  
[qpp::Gates](#) *const Singleton*
- `const States & qpp::st = States::get_instance()`  
[qpp::States](#) *const Singleton*
- `RandomDevices & qpp::rdevs = RandomDevices::get_instance()`  
[qpp::RandomDevices](#) *Singleton*

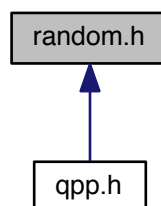
### 8.21.1 Detailed Description

Quantum++ main header file, includes all other necessary headers.

## 8.22 random.h File Reference

Randomness-related functions.

This graph shows which files directly or indirectly include this file:



## Namespaces

- [qpp](#)

*Quantum++ main namespace.*

## Functions

- `template<typename Derived >`  
`Derived qpp::rand` (idx rows, idx cols, double a=0, double b=1)  
*Generates a random matrix with entries uniformly distributed in the interval [a, b]*
- `template<>`  
`dmat qpp::rand` (idx rows, idx cols, double a, double b)  
*Generates a random real matrix with entries uniformly distributed in the interval [a, b], specialization for double matrices ([qpp::dmat](#))*
- `template<>`  
`cmat qpp::rand` (idx rows, idx cols, double a, double b)  
*Generates a random complex matrix with entries (both real and imaginary) uniformly distributed in the interval [a, b], specialization for complex matrices ([qpp::cmat](#))*
- `double qpp::rand` (double a=0, double b=1)  
*Generates a random real number uniformly distributed in the interval [a, b]*
- `idx qpp::randidx` (idx a=std::numeric\_limits< idx >::min(), idx b=std::numeric\_limits< idx >::max())  
*Generates a random index (idx) uniformly distributed in the interval [a, b].*
- `template<typename Derived >`  
`Derived qpp::randn` (idx rows, idx cols, double mean=0, double sigma=1)  
*Generates a random matrix with entries normally distributed in  $N(\text{mean}, \text{sigma})$*
- `template<>`  
`dmat qpp::randn` (idx rows, idx cols, double mean, double sigma)  
*Generates a random real matrix with entries normally distributed in  $N(\text{mean}, \text{sigma})$ , specialization for double matrices ([qpp::dmat](#))*
- `template<>`  
`cmat qpp::randn` (idx rows, idx cols, double mean, double sigma)  
*Generates a random complex matrix with entries (both real and imaginary) normally distributed in  $N(\text{mean}, \text{sigma})$ , specialization for complex matrices ([qpp::cmat](#))*
- `double qpp::randn` (double mean=0, double sigma=1)  
*Generates a random real number (double) normally distributed in  $N(\text{mean}, \text{sigma})$*
- `cmat qpp::randU` (idx D)  
*Generates a random unitary matrix.*
- `cmat qpp::randV` (idx Din, idx Dout)  
*Generates a random isometry matrix.*
- `std::vector< cmat > qpp::randkraus` (idx N, idx D)  
*Generates a set of random Kraus operators.*
- `cmat qpp::randH` (idx D)  
*Generates a random Hermitian matrix.*
- `ket qpp::randket` (idx D)  
*Generates a random normalized ket (pure state vector)*
- `cmat qpp::randrho` (idx D)  
*Generates a random density matrix.*
- `std::vector< idx > qpp::randperm` (idx n)  
*Generates a random uniformly distributed permutation.*

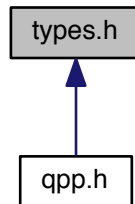
### 8.22.1 Detailed Description

Randomness-related functions.

## 8.23 types.h File Reference

Type aliases.

This graph shows which files directly or indirectly include this file:



### Namespaces

- [qpp](#)  
*Quantum++ main namespace.*

### Typedefs

- using [qpp::idx](#) = std::size\_t  
*Non-negative integer index.*
- using [qpp::cplx](#) = std::complex< double >  
*Complex number in double precision.*
- using [qpp::ket](#) = Eigen::VectorXcd  
*Complex (double precision) dynamic Eigen column vector.*
- using [qpp::bra](#) = Eigen::RowVectorXcd  
*Complex (double precision) dynamic Eigen row vector.*
- using [qpp::cmat](#) = Eigen::MatrixXcd  
*Complex (double precision) dynamic Eigen matrix.*
- using [qpp::dmat](#) = Eigen::MatrixXd  
*Real (double precision) dynamic Eigen matrix.*
- template<typename Scalar >  
using [qpp::dyn\\_mat](#) = Eigen::Matrix< Scalar, Eigen::Dynamic, Eigen::Dynamic >  
*Dynamic Eigen matrix over the field specified by Scalar.*
- template<typename Scalar >  
using [qpp::dyn\\_col\\_vect](#) = Eigen::Matrix< Scalar, Eigen::Dynamic, 1 >  
*Dynamic Eigen column vector over the field specified by Scalar.*
- template<typename Scalar >  
using [qpp::dyn\\_row\\_vect](#) = Eigen::Matrix< Scalar, 1, Eigen::Dynamic >  
*Dynamic Eigen row vector over the field specified by Scalar.*

### 8.23.1 Detailed Description

Type aliases.

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