

Quantum++

v1.0.0-rc2

Generated by Doxygen 1.8.13



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# Chapter 1

## Quantum++

Version 1.0-rc2 - Release Candidate 2, 6 September 2017

**Build status:** Master Devel

Quantum++ is a modern C++11 general purpose quantum computing library, composed solely of template header files. Quantum++ is written in standard C++11 and has very low external dependencies, using only the [Eigen 3](#) linear algebra header-only template library and, if available, the [OpenMP](#) multi-processing library.

Quantum++ is not restricted to qubit systems or specific quantum information processing tasks, being capable of simulating arbitrary quantum processes. The main design factors taken in consideration were the ease of use, high portability, and high performance. The library's simulation capabilities are only restricted by the amount of available physical memory. On a typical machine (Intel i5 8Gb RAM) Quantum++ can successfully simulate the evolution of 25 qubits in a pure state or of 12 qubits in a mixed state reasonably fast.

To report any bugs or ask for additional features/enhancements, please [submit an issue](#) with an appropriate label.

If you are interesting in contributing to this project, feel free to contact me. Alternatively, create a custom branch, add your contribution, then finally create a pull request. If I accept the pull request, I will merge your custom branch with the latest development branch. The latter will eventually be merged into a future release version. To contribute, you need to have a solid knowledge of C++ (preferably C++11), including templates and the standard library, a basic knowledge of quantum computing and linear algebra, and working experience with [Eigen 3](#).

For additional [Eigen 3](#) documentation see <http://eigen.tuxfamily.org/dox/>. For a simple [Eigen 3](#) quick ASCII reference see <http://eigen.tuxfamily.org/dox/AsciiQuickReference.txt>.

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## Building instructions for POSIX-compliant platforms

### Configuration

- Compiler: `g++` version 4.8.2 or later (for good C++11 support)
- `Eigen 3` linear algebra library. I assume here that the library is installed in `$HOME/eigen`, although the location may vary, e.g. if the library was installed using a package manager.
- Quantum++ library located in `$HOME/qpp`

### Optional

- `CMake` version 3.0 or later, highly recommended
- `MATLAB` compiler include header files: `/Applications/MATLAB_R2016a.app/extern/include`
- `MATLAB` compiler shared library files: `/Applications/MATLAB_R2016a.app/bin/maci64`

### Building using `CMake` (version 3.0 or later)

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 commands above build the release version (default) executable `qpp`, from the source file `./examples/minimal.cpp`, without `MATLAB` support (default), inside the directory `./build`.

If the location of `Eigen 3` is not detected automatically by the `CMake` build script, then the build script will fail (with an error message). In this case the location of `Eigen 3` needs to be specified manually in the `CMake` build command line by passing the `-DEIGEN3_INCLUDE_DIR=path_to_eigen3` flag, e.g.

```
cmake .. -DEIGEN3_INCLUDE_DIR=/usr/local/eigen3
```

To build a different configuration, e.g. the 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 or the location of `MATLAB` installation, edit the `./CMakeLists.txt` file. Inspect also `./CMakeLists.txt` for additional fine-tuning options. Do not forget to clean the `./build` directory before a fresh build!

## Building without an automatic build system

- Example file: `$HOME/qpp/examples/minimal.cpp`
- Output executable: `$HOME/qpp/examples/minimal`
- You 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 \
    minimal.cpp -o minimal
```

### Debug version (without MATLAB support)

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

### 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_R2016a.app/extern/include \
    -L/Applications/MATLAB_R2016a.app/bin/maci64 \
    -lmx -lmat minimal.cpp -o minimal
```

### 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_R2016a.app/extern/include \
    -L /Applications/MATLAB_R2016a.app/bin/maci64 \
    -lmx -lmat minimal.cpp -o minimal
```

## Additional building instructions for particular platforms

### Windows via Cygwin

- Some earlier versions of **Cygwin** had a bug related to lack of support for some C++11 math functions, see <http://stackoverflow.com/questions/28997206/cygwin-support-for-c11-in-g4-9-2> for more details. Quick fix: patch the standard library header file `<cmath>` using the provided patch `./cmath_cygwin.patch`. Latest **Cygwin** (as of Nov. 11, 2016) seem to have fixed the issue.

## Windows via Visual Studio

- **Visual Studio** versions preceeding version 2015 do not have full C++11 support. If you decide to use **Visual Studio** make sure you install version 2015 or later.
- **Visual Studio 2015** only supports **OpenMP 2.0**. Quantum++ uses features from **OpenMP 3.4**, hence Quantum++ will not compile on **Visual Studio 2015** if you enable **OpenMP** (disabled by default) in

```
*Project/Properties/Configuration Properties/C_C++/Language/Open MP Support*
```

and `#define WITH_OPENMP_` in your source file.

- To create a **Visual Studio 2015** or later console solution, start by creating a *Win32 Console Application*

```
*File/New/Project.../Installed/Templates/Visual C++/Win32/Win32 Console Application*
```

Click *\*Next\** then select *\*Console Application\** as *\*Application Type\**.  
Click *\*Finish\** to create the solution. Next select

```
*Project/Properties*
```

from the main menu. The *\*Property Pages\** configuration window will open.  
From the latter select *\*All configurations\** from the top left  
*\*Configuration\** drop box. Next select

```
*Configuration Properties/C_C++/General*
```

and add to the field *\*Additional Include Directories\** the location of  
Quantum++ `./include` folder as well as the location of  
[Eigen 3] (<http://eigen.tuxfamily.org>). It should look similar to

```
**C:\Users\User\Downloads\eigen;C:\Users\User\Downloads\qpp\include;% (AdditionalIncludeDirectories) **
```

Finally select

```
*Configuration Properties/C_C++/Advanced*
```

and add to the field *\*Disable Specific Warnings\** the values `**4503;4996**`.  
Click *\*Ok\** to save the settings and close the *\*Property Pages\** window.  
You are now ready to go.

## OS X/macOS

- If you want to compile with **clang++** version 3.7 or later, I highly recommend to install it via **macports**.
- If you run the program 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_mac_MATLAB` script. Otherwise, you get a runtime error similar to

```
> 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**' **CMake** installation (in case you use **CMake** from **macports**). 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 script, assumed to be located in the root directory of Quantum++

```
#!/bin/sh
```

```
MATLAB=/Applications/MATLAB_R2016a.app  
export DYLD_LIBRARY_PATH=$DYLD_LIBRARY_PATH:$MATLAB/bin/maci64
```

```
./build/qpp
```

- If you build a debug version with **g++** 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-st> for more details about this problem.

## Unit testing

Quantum++ was extensively tested under multiple flavours of Linux, OS X/macOS, Windows XP/7/10, Solaris 11.x via a suite of unit tests constructed with Google Test 1.8.0 (included with the project in ./unit\_tests/lib/gtest-1.8.0). The source code of the unit tests is provided under ./unit\_tests/tests. To build and run the unit tests, I strongly recommend to use CMake version 3.0 or later. Assuming you do use CMake, switch to the ./unit\_tests directory, create a build directory inside it, then from the newly created ./unit\_tests/build type

```
cmake ..  
make
```

The commands above build ./unit\_tests/build/tests/qpp\_testing, which you then may run. Note that qpp::Timer tests or tests related to random functions such as qpp::rand() may sometime (very rarely) fail, due to timing imprecision or statistical errors. Such behaviour is perfectly normal.

### Note

The CMake configuration file ./unit\_tests/CMakeLists.txt defines the same building options and default choices as the main ./CMakeLists.txt of Quantum++. Therefore you can use the same flags as the ones mentioned at the beginning of this document when customizing the build. You should modify ./unit\_tests/CMakeLists.txt accordingly in case your Eigen 3 library or MATLAB include/library files are in a different location than the one assumed in this document.

## Additional remarks

- If you use clang++ version 3.7 or later and want to use OpenMP (enabled by default), make sure to modify CLANG\_LIBOMP and CLANG\_LIBOMP\_INCLUDE in CMakeLists.txt so they point to the correct location of the OpenMP library, as otherwise clang++ will not find <omp.h> and the libomp shared library.



## Chapter 2

# Namespace Index

### 2.1 Namespace List

Here is a list of all namespaces with brief descriptions:

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<a href="#">qpp::exception</a>	Quantum++ exception hierarchy namespace . . . . .	118
<a href="#">qpp::experimental</a>	Experimental/test functions/classes, do not use or modify . . . . .	120
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## Chapter 3

# Hierarchical Index

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## Chapter 4

# Class Index

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## Chapter 5

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## Chapter 6

# Namespace Documentation

### 6.1 qpp Namespace Reference

Quantum++ main namespace.

#### Namespaces

- [exception](#)  
*Quantum++ exception hierarchy namespace.*
- [experimental](#)  
*Experimental/test functions/classes, do not use or modify.*
- [internal](#)  
*Internal utility functions, do not use them directly or modify them.*

#### Classes

- class [Codes](#)  
*const Singleton class that defines quantum error correcting codes*
- class [Gates](#)  
*const Singleton class that implements most commonly used gates*
- class [IDisplay](#)  
*Abstract class (interface) that mandates the definition of virtual `std::ostream& display(std::ostream& os) const`.*
- class [Init](#)  
*const Singleton class that performs additional initializations/cleanups*
- struct [is\\_complex](#)  
*Checks whether the type is a complex type.*
- struct [is\\_complex< std::complex< T > >](#)  
*Checks whether the type is a complex number type, specialization for complex types.*
- struct [is\\_iterable](#)  
*Checks whether T is compatible with an STL-like iterable container.*
- struct [is\\_iterable< T, to\\_void< decltype\(std::declval< T >\(\).begin\(\)\), decltype\(std::declval< T >\(\).end\(\)\), typename T::value\\_type > >](#)  
*Checks whether T is compatible with an STL-like iterable container, specialization for STL-like iterable containers.*
- struct [is\\_matrix\\_expression](#)

- Checks whether the type is an Eigen matrix expression.
- struct `make_void`  
Helper for `qpp::to_void<>` alias template.
- 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`  
Chronometer.

## Typedefs

- template<typename... Ts>  
using `to_void` = typename `make_void`< Ts... >::type  
Alias template that implements the proposal for `void_t`.
- using `idx` = std::size\_t  
Non-negative integer index.
- using `bigint` = long long int  
Big integer.
- using `cplx` = std::complex< double >  
Complex number in double precision.
- using `ket` = Eigen::VectorXcd  
Complex (double precision) dynamic Eigen column vector.
- using `bra` = Eigen::RowVectorXcd  
Complex (double precision) dynamic Eigen row vector.
- using `cmat` = Eigen::MatrixXcd  
Complex (double precision) dynamic Eigen matrix.
- using `dmat` = Eigen::MatrixXd  
Real (double precision) dynamic Eigen matrix.
- template<typename Scalar >  
using `dyn_mat` = Eigen::Matrix< Scalar, Eigen::Dynamic, Eigen::Dynamic >  
Dynamic Eigen matrix over the field specified by Scalar.
- template<typename Scalar >  
using `dyn_col_vect` = Eigen::Matrix< Scalar, Eigen::Dynamic, 1 >  
Dynamic Eigen column vector over the field specified by Scalar.
- template<typename Scalar >  
using `dyn_row_vect` = Eigen::Matrix< Scalar, 1, Eigen::Dynamic >  
Dynamic Eigen row vector over the field specified by Scalar.

## Functions

- constexpr `cplx operator"" _i` (unsigned long long int x) noexcept  
User-defined literal for complex  $i = \sqrt{-1}$  (integer overload)
- constexpr `cplx operator"" _i` (long double x) noexcept  
User-defined literal for complex  $i = \sqrt{-1}$  (real overload)
- `cplx omega` (idx D)  
D-th root of unity.
- template<typename Derived >  
`dyn_col_vect`< double > `schmidtcoeffs` (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &dims)

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

  - `template<typename Derived >`  
`dyn_col_vect< double > schmidtcoeffs (const Eigen::MatrixBase< Derived > &A, idx d=2)`

*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 schmidtA (const Eigen::MatrixBase< Derived > &A, idx d=2)`

*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 >`  
`cmat schmidtB (const Eigen::MatrixBase< Derived > &A, idx d=2)`

*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 >`  
`std::vector< double > schmidtprobs (const Eigen::MatrixBase< Derived > &A, idx d=2)`

*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 entanglement (const Eigen::MatrixBase< Derived > &A, idx d=2)`

*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 negativity (const Eigen::MatrixBase< Derived > &A, idx d=2)`

*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 lognegativity (const Eigen::MatrixBase< Derived > &A, idx d=2)`

*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 absolute 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)

*Fast matrix power based on the SQUARE-AND-MULTIPLY algorithm.*

- `template<typename Derived >`  
`double schatten (const Eigen::MatrixBase< Derived > &A, double p)`  
*Schatten matrix norm.*
- `template<typename OutputScalar , typename Derived >`  
`dyn\_mat< OutputScalar > cwise (const Eigen::MatrixBase< Derived > &A, OutputScalar(*)(const type-  
name Derived::Scalar &))`  
*Functor.*
- `template<typename T >`  
`dyn\_mat< typename T::Scalar > kron (const T &head)`  
*Kronecker product.*
- `template<typename T , typename ... Args>`  
`dyn\_mat< typename T::Scalar > kron (const T &head, const Args &... tail)`  
*Kronecker product.*
- `template<typename Derived >`  
`dyn\_mat< typename Derived::Scalar > kron (const std::vector< Derived > &As)`  
*Kronecker product.*
- `template<typename Derived >`  
`dyn\_mat< typename Derived::Scalar > kron (const std::initializer_list< Derived > &As)`  
*Kronecker product.*
- `template<typename Derived >`  
`dyn\_mat< typename Derived::Scalar > kronpow (const Eigen::MatrixBase< Derived > &A, idx n)`  
*Kronecker power.*
- `template<typename T >`  
`dyn\_mat< typename T::Scalar > dirsum (const T &head)`  
*Direct sum.*
- `template<typename T , typename ... Args>`  
`dyn\_mat< typename T::Scalar > dirsum (const T &head, const Args &... tail)`  
*Direct sum.*
- `template<typename Derived >`  
`dyn\_mat< typename Derived::Scalar > dirsum (const std::vector< Derived > &As)`  
*Direct sum.*
- `template<typename Derived >`  
`dyn\_mat< typename Derived::Scalar > dirsum (const std::initializer_list< Derived > &As)`  
*Direct sum.*
- `template<typename Derived >`  
`dyn\_mat< typename Derived::Scalar > dirsumpow (const Eigen::MatrixBase< Derived > &A, idx n)`  
*Direct sum power.*
- `template<typename Derived >`  
`dyn\_mat< typename Derived::Scalar > reshape (const Eigen::MatrixBase< Derived > &A, idx rows, idx  
cols)`  
*Reshape.*
- `template<typename Derived1 , typename Derived2 >`  
`dyn\_mat< typename Derived1::Scalar > comm (const Eigen::MatrixBase< Derived1 > &A, const Eigen::↵  
MatrixBase< Derived2 > &B)`  
*Commutator.*
- `template<typename Derived1 , typename Derived2 >`  
`dyn\_mat< typename Derived1::Scalar > anticomm (const Eigen::MatrixBase< Derived1 > &A, const  
Eigen::MatrixBase< Derived2 > &B)`  
*Anti-commutator.*
- `template<typename Derived >`  
`dyn\_mat< typename Derived::Scalar > prj (const Eigen::MatrixBase< Derived > &A)`  
*Projector.*
- `template<typename Derived >`  
`dyn\_mat< typename Derived::Scalar > grams (const std::vector< Derived > &As)`

- Gram-Schmidt orthogonalization.*

  - `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > grams (const std::initializer_list< Derived > &As)`  
*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 absolute values squared of an STL-like range of complex numbers.*
- `template<typename Container >`  
`std::vector< double > abssq (const Container &c, typename std::enable_if< is\_iterable< Container >::value >::type * = nullptr)`  
*Computes the absolute values squared of an STL-like container.*
- `template<typename Derived >`  
`std::vector< double > abssq (const Eigen::MatrixBase< Derived > &A)`  
*Computes the absolute values squared of an Eigen expression.*
- `template<typename InputIterator >`  
`std::iterator_traits< InputIterator >::value_type sum (InputIterator first, InputIterator last)`  
*Element-wise sum of an STL-like range.*
- `template<typename Container >`  
`Container::value_type sum (const Container &c, typename std::enable_if< is\_iterable< Container >::value >::type * = nullptr)`  
*Element-wise sum of the elements of an STL-like container.*
- `template<typename InputIterator >`  
`std::iterator_traits< InputIterator >::value_type prod (InputIterator first, InputIterator last)`  
*Element-wise product of an STL-like range.*
- `template<typename Container >`  
`Container::value_type prod (const Container &c, typename std::enable_if< is\_iterable< Container >::value >::type * = nullptr)`  
*Element-wise product of the elements of an STL-like container.*
- `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 T >`  
`std::vector< T > complement (std::vector< T > subsys, idx N)`  
*Constructs the complement of a subsystem vector.*
- `template<typename Derived >`  
`std::vector< double > rho2bloch (const Eigen::MatrixBase< Derived > &A)`  
*Computes the 3-dimensional real Bloch vector corresponding to the qubit density matrix A.*
- `cmat bloch2rho (const std::vector< double > &r)`

- Computes the density matrix corresponding to the 3-dimensional real Bloch vector  $r$ .*
- `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` (InputIterator first, 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="]", typename std::enable\_if< `is_iterable`< Container >::value >::type \*==nullptr)  
*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 >`  
`dyn_col_vect< typename Derived::Scalar > ip` (const Eigen::MatrixBase< Derived > &phi, const Eigen::MatrixBase< Derived > &psi, const std::vector< `idx` > &subsys, const std::vector< `idx` > &dims)  
*Generalized inner product.*
  - `template<typename Derived >`  
`dyn_col_vect< typename Derived::Scalar > ip` (const Eigen::MatrixBase< Derived > &phi, const Eigen::MatrixBase< Derived > &psi, const std::vector< `idx` > &subsys, `idx` d=2)  
*Generalized inner product.*
  - `template<typename Derived >`  
`std::tuple< idx, std::vector< double >, std::vector< cmat > > measure` (const Eigen::MatrixBase< Derived > &A, const std::vector< `cmat` > &Ks)  
*Measures the state A using the set of Kraus operators Ks.*
  - `template<typename Derived >`  
`std::tuple< idx, std::vector< double >, std::vector< cmat > > measure` (const Eigen::MatrixBase< Derived > &A, const std::initializer\_list< `cmat` > &Ks)  
*Measures the state A using the set of Kraus operators Ks.*
  - `template<typename Derived >`  
`std::tuple< idx, std::vector< double >, std::vector< cmat > > measure` (const Eigen::MatrixBase< Derived > &A, const `cmat` &U)  
*Measures the state A in the orthonormal basis specified by the unitary matrix U.*
  - `template<typename Derived >`  
`std::tuple< idx, std::vector< double >, std::vector< cmat > > measure` (const Eigen::MatrixBase< Derived > &A, const std::vector< `cmat` > &Ks, const std::vector< `idx` > &subsys, const std::vector< `idx` > &dims)  
*Measures the part subsys of the multi-partite state vector or density matrix A using the set of Kraus operators Ks.*
  - `template<typename Derived >`  
`std::tuple< idx, std::vector< double >, std::vector< cmat > > measure` (const Eigen::MatrixBase< Derived > &A, const std::initializer\_list< `cmat` > &Ks, const std::vector< `idx` > &subsys, const std::vector< `idx` > &dims)  
*Measures the part subsys of the multi-partite state vector or density matrix A using the set of Kraus operators Ks.*



- `template<typename Derived >`  
`std::tuple< idx, std::vector< double >, std::vector< cmat > > measure (const Eigen::MatrixBase< Derived > &A, const std::vector< cmat > &Ks, const std::vector< idx > &subsys, idx d=2)`  
*Measures the part subsys of the multi-partite state vector or density matrix A using the set of Kraus operators Ks.*
- `template<typename Derived >`  
`std::tuple< idx, std::vector< double >, std::vector< cmat > > measure (const Eigen::MatrixBase< Derived > &A, const std::initializer_list< cmat > &Ks, const std::vector< idx > &subsys, 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 &V, const std::vector< idx > &subsys, const std::vector< idx > &dims)`  
*Measures the part subsys of the multi-partite state vector or density matrix A in the orthonormal basis or rank-1 POVM specified by the matrix V.*
- `template<typename Derived >`  
`std::tuple< idx, std::vector< double >, std::vector< cmat > > measure (const Eigen::MatrixBase< Derived > &A, const cmat &V, const std::vector< idx > &subsys, idx d=2)`  
*Measures the part subsys of the multi-partite state vector or density matrix A in the orthonormal basis or rank-1 POVM specified by the matrix V.*
- `template<typename Derived >`  
`std::tuple< std::vector< idx >, double, cmat > measure\_seq (const Eigen::MatrixBase< Derived > &A, std::vector< idx > subsys, std::vector< idx > dims)`  
*Sequentially measures the part subsys of the multi-partite state vector or density matrix A in the computational basis.*
- `template<typename Derived >`  
`std::tuple< std::vector< idx >, double, cmat > measure\_seq (const Eigen::MatrixBase< Derived > &A, std::vector< idx > subsys, idx d=2)`  
*Sequentially measures the part subsys of the multi-partite state vector or density matrix A in the computational basis.*
- `template<typename Derived >`  
`std::enable_if< std::is_same< typename Derived::Scalar, cplx >::value, dyn\_mat< cplx > >::type loadMATLAB (const std::string &mat_file, const std::string &var_name)`  
*Loads a complex Eigen dynamic matrix from a MATLAB .mat file,.*
- `template<typename Derived >`  
`std::enable_if<!std::is_same< typename Derived::Scalar, cplx >::value, dyn\_mat< typename Derived::Scalar > >::type loadMATLAB (const std::string &mat_file, const std::string &var_name)`  
*Loads a non-complex Eigen dynamic matrix from a MATLAB .mat file,.*
- `template<typename Derived >`  
`std::enable_if< std::is_same< typename Derived::Scalar, cplx >::value >::type saveMATLAB (const Eigen::MatrixBase< Derived > &A, const std::string &mat_file, const std::string &var_name, const std::string &mode)`  
*Saves a complex Eigen dynamic matrix to a MATLAB .mat file,.*
- `template<typename Derived >`  
`std::enable_if<!std::is_same< typename Derived::Scalar, cplx >::value >::type saveMATLAB (const Eigen::MatrixBase< Derived > &A, const std::string &mat_file, const std::string &var_name, const std::string &mode)`  
*Saves a non-complex Eigen dynamic matrix to a MATLAB .mat file,.*
- `std::vector< int > x2contfrac (double x, idx N, idx cut=1e5)`  
*Simple continued fraction expansion.*
- `double contfrac2x (const std::vector< int > &cf, idx N=idx(-1))`  
*Real representation of a simple continued fraction.*
- `bigint gcd (bigint a, bigint b)`  
*Greatest common divisor of two integers.*
- `bigint gcd (const std::vector< bigint > &as)`  
*Greatest common divisor of a list of integers.*
- `bigint lcm (bigint a, bigint b)`  
*Least common multiple of two integers.*

- `bigint lcm` (const std::vector< `bigint` > &as)  
*Least common multiple of a list of integers.*
- `std::vector< idx > invperm` (const std::vector< `idx` > &perm)  
*Inverse permutation.*
- `std::vector< idx > compperm` (const std::vector< `idx` > &perm, const std::vector< `idx` > &sigma)  
*Compose permutations.*
- `std::vector< bigint > factors` (`bigint` a)  
*Prime factor decomposition.*
- `bigint modmul` (`bigint` a, `bigint` b, `bigint` p)  
*Modular multiplication without overflow.*
- `bigint modpow` (`bigint` a, `bigint` n, `bigint` p)  
*Fast integer power modulo p based on the SQUARE-AND-MULTIPLY algorithm.*
- `std::tuple< bigint, bigint, bigint > egcd` (`bigint` a, `bigint` b)  
*Extended greatest common divisor of two integers.*
- `bigint modinv` (`bigint` a, `bigint` p)  
*Modular inverse of a mod p.*
- `bool isprime` (`bigint` p, `idx` k=80)  
*Primality test based on the Miller-Rabin's algorithm.*
- `bigint randprime` (`bigint` a, `bigint` b, `idx` N=1000)  
*Generates a random big prime uniformly distributed in the interval [a, b].*
- `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 > &A, const std::vector< `cmat` > &Ks)  
*Applies the channel specified by the set of Kraus operators Ks to the density matrix A.*
- `template<typename Derived >`  
`cmat apply` (const Eigen::MatrixBase< Derived > &A, 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 A.*
- `template<typename Derived >`  
`cmat apply` (const Eigen::MatrixBase< Derived > &A, 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 A.*
- `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 > ptrace1` (const Eigen::MatrixBase< Derived > &A, [idx](#) d=2)  
*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 > ptrace2` (const Eigen::MatrixBase< Derived > &A, [idx](#) d=2)  
*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.*
- `double rand` (double a, double b)  
*Generates a random real number uniformly distributed in the interval [a, b)*
- `bigint rand` ([bigint](#) a, [bigint](#) b)  
*Generates a random big integer 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 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<>`  
`dmatrix 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::dmatrix](#))*
- `template<>`  
`cmatrix 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::cmatrix](#))*
- `template<typename Derived >`  
`Derived randn (idx rows, idx cols, double mean=0, double sigma=1)`  
*Generates a random matrix with entries normally distributed in  $N(\text{mean}, \text{sigma})$*
- `template<>`  
`dmatrix 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::dmatrix](#))*
- `template<>`  
`cmatrix 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::cmatrix](#))*
- `double randn (double mean=0, double sigma=1)`  
*Generates a random real number (double) normally distributed in  $N(\text{mean}, \text{sigma})$*
- `cmatrix randU (idx D=2)`  
*Generates a random unitary matrix.*
- `cmatrix randV (idx Din, idx Dout)`  
*Generates a random isometry matrix.*
- `std::vector< cmatrix > randkraus (idx N, idx D=2)`  
*Generates a set of random Kraus operators.*
- `cmatrix randH (idx D=2)`  
*Generates a random Hermitian matrix.*
- `ket randket (idx D=2)`  
*Generates a random normalized ket (pure state vector)*
- `cmatrix randrho (idx D=2)`  
*Generates a random density matrix.*
- `std::vector< idx > randperm (idx N)`  
*Generates a random uniformly distributed permutation.*
- `std::vector< double > randprob (idx N)`  
*Generates a random probability vector uniformly distributed over the probability simplex.*
- `std::vector< double > uniform (idx N)`  
*Uniform probability distribution vector.*
- `std::vector< double > marginalX (const dmatrix &probXY)`  
*Marginal distribution.*
- `std::vector< double > marginalY (const dmatrix &probXY)`  
*Marginal distribution.*
- `template<typename Container >`  
`double avg (const std::vector< double > &prob, const Container &X, typename std::enable_if< is\_iterable< Container >::value >::type != nullptr)`  
*Average.*
- `template<typename Container >`  
`double cov (const dmatrix &probXY, const Container &X, const Container &Y, typename std::enable_if< is\_iterable< Container >::value >::type != nullptr)`  
*Covariance.*

- `template<typename Container >`  
`double var (const std::vector< double > &prob, const Container &X, typename std::enable_if< is_iterable<`  
`Container >::value >::type * = nullptr)`  
*Variance.*
- `template<typename Container >`  
`double sigma (const std::vector< double > &prob, const Container &X, typename std::enable_if< is_↵`  
`iterable< Container >::value >::type * = nullptr)`  
*Standard deviation.*
- `template<typename Container >`  
`double cor (const dmat &probXY, const Container &X, const Container &Y, typename std::enable_if< is_↵`  
`iterable< Container >::value >::type * = nullptr)`  
*Correlation.*

## 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 qubits/qudits (subsystems)*
- `constexpr double pi = 3.141592653589793238462643383279502884`  
 $\pi$
- `constexpr double ee = 2.718281828459045235360287471352662497`  
*Base of natural logarithm, e.*
- `constexpr double infy = std::numeric_limits<double>::max()`  
*Used to denote infinity in double precision.*

### 6.1.1 Detailed Description

Quantum++ main namespace.

### 6.1.2 Typedef Documentation

#### 6.1.2.1 bigint

```
using qpp::bigint = typedef long long int
```

Big integer.

#### 6.1.2.2 bra

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

Complex (double precision) dynamic Eigen row vector.

#### 6.1.2.3 cmat

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

Complex (double precision) dynamic Eigen matrix.

#### 6.1.2.4 cplx

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

Complex number in double precision.

#### 6.1.2.5 dmat

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

Real (double precision) dynamic Eigen matrix.

#### 6.1.2.6 dyn\_col\_vect

```
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>  
dyn_col_vect<float> colvect(2);
```

#### 6.1.2.7 dyn\_mat

```
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>  
dyn_mat<float> mat(2, 3);
```

#### 6.1.2.8 dyn\_row\_vect

```
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>  
dyn_row_vect<float> rowvect(3);
```

#### 6.1.2.9 idx

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

Non-negative integer index.

#### 6.1.2.10 ket

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

Complex (double precision) dynamic Eigen column vector.

### 6.1.2.11 to\_void

```
template<typename... Ts>
using qpp::to_void = typedef typename make_void<Ts...>::type
```

Alias template that implements the proposal for void\_t.

#### See also

<http://www.open-std.org/jtc1/sc22/wg21/docs/papers/2014/n3911>

## 6.1.3 Function Documentation

### 6.1.3.1 absm()

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

Matrix absolute value.

#### Parameters

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

#### Returns

Matrix absolute value of *A*

### 6.1.3.2 abssq() [1/3]

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

Computes the absolute values squared of an STL-like 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 absolute values squared

**6.1.3.3 abssq()** [2/3]

```
template<typename Container >
std::vector<double> qpp::abssq (
    const Container & c,
    typename std::enable_if< is\_iterable< Container >::value >::type * = nullptr )
```

Computes the absolute values squared of an STL-like container.

**Parameters**

<i>c</i>	STL-like container
----------	--------------------

**Returns**

Real vector consisting of the container's absolute values squared

**6.1.3.4 abssq()** [3/3]

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

Computes the absolute values squared of an Eigen expression.

**Parameters**

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

**Returns**

Real vector consisting of the absolute values squared

**6.1.3.5 adjoint()**

```
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  $A$

6.1.3.6 `anticomm()`

```
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  $A$

6.1.3.7 `apply()` [1/5]

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

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

## Note

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

## Parameters

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

## Returns

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

6.1.3.8 `apply()` [2/5]

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

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

## Note

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

## Parameters

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

## Returns

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

6.1.3.9 `apply()` [3/5]

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

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

**Parameters**

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

**Returns**

Output density matrix after the action of the channel

**6.1.3.10 apply()** [4/5]

```
template<typename Derived >
cmat qpp::apply (
    const Eigen::MatrixBase< Derived > & A,
    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 *A*.

**Parameters**

<i>A</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

**6.1.3.11 apply()** [5/5]

```
template<typename Derived >
cmat qpp::apply (
    const Eigen::MatrixBase< Derived > & A,
    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 *A*.

## Parameters

<i>A</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

6.1.3.12 `applyCTRL()` [1/2]

```
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*

### 6.1.3.13 `applyCTRL()` [2/2]

```
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*

### 6.1.3.14 `avg()`

```
template<typename Container >
double qpp::avg (
    const std::vector< double > & prob,
    const Container & X,
    typename std::enable_if< is_iterable< Container >::value >::type * = nullptr )
```

Average.

Parameters

<i>prob</i>	Real probability vector representing the probability distribution of <i>X</i>
<i>X</i>	Real random variable values represented by an STL-like container

## Returns

Average of  $X$

## 6.1.3.15 bloch2rho()

```
cmat qpp::bloch2rho (
    const std::vector< double > & r ) [inline]
```

Computes the density matrix corresponding to the 3-dimensional real Bloch vector  $r$ .

## See also

[qpp::rho2bloch\(\)](#)

## Parameters

$r$	3-dimensional real vector
-----	---------------------------

## Returns

Qubit density matrix

## 6.1.3.16 choi2kraus()

```
std::vector<cmat> qpp::choi2kraus (
    const cmat & A ) [inline]
```

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

**6.1.3.17 choi2super()**

```
cmat qpp::choi2super (
    const cmat & A ) [inline]
```

Converts Choi matrix to superoperator matrix.

**See also**

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

**Parameters**

<i>A</i>	Choi matrix
----------	-------------

**Returns**

Superoperator matrix

**6.1.3.18 comm()**

```
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**

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



**Returns**

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

**6.1.3.19 complement()**

```
template<typename T >
std::vector<T> qpp::complement (
    std::vector< T > subsys,
    idx N )
```

Constructs the complement of a subsystem vector.

**Parameters**

<i>subsys</i>	Subsystem vector
<i>N</i>	Total number of systems

**Returns**

Complement of *subsys* with respect to the set  $\{0, 1, \dots, N - 1\}$

**6.1.3.20 compperm()**

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

Compose permutations.

**Parameters**

<i>perm</i>	Permutation
<i>sigma</i>	Permutation

**Returns**

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

**6.1.3.21 concurrence()**

```
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

## 6.1.3.22 conjugate()

```
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*

## 6.1.3.23 contfrac2x()

```
double qpp::contfrac2x (
    const std::vector< int > & cf,
    idx N = idx(-1) ) [inline]
```

Real representation of a simple continued fraction.

## See also

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

## Note

If *N* is greater than the size of *cf* (by default it is), then all terms in *cf* are considered.

## Parameters

<i>cf</i>	Integer vector containing the simple continued fraction expansion
<i>N</i>	Number of terms considered in the continued fraction expansion.

**Returns**

Real representation of the simple continued fraction

**6.1.3.24 cor()**

```
template<typename Container >
double qpp::cor (
    const dmat & probXY,
    const Container & X,
    const Container & Y,
    typename std::enable_if< is_iterable< Container >::value >::type * = nullptr )
```

Correlation.

**Parameters**

<i>probXY</i>	Real matrix representing the joint probability distribution of <i>X</i> and <i>Y</i> in lexicographical order ( <i>X</i> labels the rows, <i>Y</i> labels the columns)
<i>X</i>	Real random variable values represented by an STL-like container
<i>Y</i>	Real random variable values represented by an STL-like container

**Returns**

Correlation of *X* and *Y*

**6.1.3.25 cosm()**

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

Matrix cos.

**Parameters**

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

**Returns**

Matrix cosine of *A*

## 6.1.3.26 cov()

```
template<typename Container >
double qpp::cov (
    const dmat & probXY,
    const Container & X,
    const Container & Y,
    typename std::enable_if< is_iterable< Container >::value >::type * = nullptr )
```

Covariance.

## Parameters

<i>probXY</i>	Real matrix representing the joint probability distribution of <i>X</i> and <i>Y</i> in lexicographical order ( <i>X</i> labels the rows, <i>Y</i> labels the columns)
<i>X</i>	Real random variable values represented by an STL-like container
<i>Y</i>	Real random variable values represented by an STL-like container

## Returns

Covariance of *X* and *Y*

## 6.1.3.27 cwise()

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

Functor.

## Parameters

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

## Returns

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

## 6.1.3.28 det()

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

Determinant.

**Parameters**

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

**Returns**

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

**6.1.3.29 `dirsum()`** [1/4]

```
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*

**6.1.3.30 `dirsum()`** [2/4]

```
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

6.1.3.31 `dirsum()` [3/4]

```
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

6.1.3.32 `dirsum()` [4/4]

```
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

## 6.1.3.33 dirsumpow()

```
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

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

## 6.1.3.34 disp() [1/5]

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

Eigen expression ostream manipulator.

## Parameters

<i>A</i>	Eigen expression
<i>chop</i>	Set to zero the elements smaller in absolute value than <i>chop</i>



## Returns

Instance of [qpp::internal::IManipEigen](#)

6.1.3.35 `disp()` [2/5]

```
internal::IManipEigen qpp::disp (
    cplx z,
    double chop = qpp::chop ) [inline]
```

Complex number ostream manipulator.

## Parameters

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

## Returns

Instance of [qpp::internal::IManipEigen](#)

6.1.3.36 `disp()` [3/5]

```
template<typename InputIterator >
internal::IManipRange<InputIterator> qpp::disp (
    InputIterator first,
    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::IManipRange](#)

**6.1.3.37 disp()** [4/5]

```
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 = "]",
    typename std::enable_if< is_iterable< Container >::value >::type * = nullptr )
```

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::IOManipRange](#)

**6.1.3.38 disp()** [5/5]

```
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::IOManipPointer](#)

## 6.1.3.39 egcd()

```
std::tuple<bigint, bigint, bigint> qpp::egcd (
    bigint a,
    bigint b ) [inline]
```

Extended greatest common divisor of two integers.

See also

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

Parameters

<i>a</i>	Integer
<i>b</i>	Integer

Returns

Tuple of: 1. Integer  $m$ , 2. Integer  $n$ , and 3. Non-negative integer  $gcd(a, b)$  such that  $ma + nb = gcd(a, b)$

## 6.1.3.40 eig()

```
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

## 6.1.3.41 entanglement() [1/2]

```
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

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

#### Returns

Entanglement, with the logarithm in base 2

#### 6.1.3.42 entanglement() [2/2]

```
template<typename Derived >
double qpp::entanglement (
    const Eigen::MatrixBase< Derived > & A,
    idx d = 2 )
```

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

$A$	Eigen expression
$d$	Subsystem dimensions

#### Returns

Entanglement, with the logarithm in base 2

**6.1.3.43 entropy()** [1/2]

```
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

**6.1.3.44 entropy()** [2/2]

```
double qpp::entropy (
    const std::vector< double > & prob ) [inline]
```

Shannon entropy of the probability distribution *prob*.

**Parameters**

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

**Returns**

Shannon entropy, with the logarithm in base 2

**6.1.3.45 evals()**

```
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

**6.1.3.46 `evecs()`**

```
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

**6.1.3.47 `expm()`**

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

Matrix exponential.

**Parameters**

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

**Returns**

Matrix exponential of  $A$

## 6.1.3.48 factors()

```
std::vector<bigint> qpp::factors (
    bigint a ) [inline]
```

Prime factor decomposition.

## Note

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

## Parameters

<i>a</i>	Integer different from 0, 1 or -1
----------	-----------------------------------

## Returns

Integer vector containing the factors

## 6.1.3.49 funm()

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

Functional calculus  $f(A)$

## Parameters

<i>A</i>	Eigen expression
<i>f</i>	Pointer-to-function from complex to complex

## Returns

$f(A)$

## 6.1.3.50 gcd() [1/2]

```
bigint qpp::gcd (
    bigint a,
    bigint b ) [inline]
```

Greatest common divisor of two integers.

## See also

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

**Parameters**

<i>a</i>	Integer
<i>b</i>	Integer

**Returns**

Greatest common divisor of *a* and *b*

**6.1.3.51 gcd()** [2/2]

```
bigint qpp::gcd (
    const std::vector< bigint > & as ) [inline]
```

Greatest common divisor of a list of integers.

**See also**

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

**Parameters**

<i>as</i>	List of integers
-----------	------------------

**Returns**

Greatest common divisor of all numbers in *as*

**6.1.3.52 gconcurrency()**

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

G-concurrency 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

6.1.3.53 `grams()` [1/3]

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

Gram-Schmidt orthogonalization.

## Parameters

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

## Returns

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

6.1.3.54 `grams()` [2/3]

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

Gram-Schmidt orthogonalization.

## Parameters

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

## Returns

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

**6.1.3.55** `grams()` [3/3]

```
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*

**6.1.3.56** `heig()`

```
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

**6.1.3.57** `hevals()`

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

Hermitian eigenvalues.

**See also**

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

## Parameters

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

## Returns

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

## 6.1.3.58 hevects()

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

Hermitian eigenvectors.

## See also

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

## Parameters

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

## Returns

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

## 6.1.3.59 inverse()

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

Inverse.

## Parameters

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

## Returns

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

### 6.1.3.60 invperm()

```
std::vector<idx> qpp::invperm (
    const std::vector< idx > & perm ) [inline]
```

Inverse permutation.

#### Parameters

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

#### Returns

Inverse of the permutation *perm*

### 6.1.3.61 ip() [1/2]

```
template<typename Derived >
dyn_col_vect<typename Derived::Scalar> qpp::ip (
    const Eigen::MatrixBase< Derived > & phi,
    const Eigen::MatrixBase< Derived > & psi,
    const std::vector< idx > & subsys,
    const std::vector< idx > & dims )
```

Generalized inner product.

#### Parameters

<i>phi</i>	Column vector Eigen expression
<i>psi</i>	Column vector Eigen expression
<i>subsys</i>	Subsystem indexes over which <i>phi</i> is defined
<i>dims</i>	Dimensions of the multi-partite system

#### Returns

Inner product  $\langle \phi_{subsys} | \psi \rangle$ , as a scalar or column vector over the remaining Hilbert space

### 6.1.3.62 ip() [2/2]

```
template<typename Derived >
dyn_col_vect<typename Derived::Scalar> qpp::ip (
    const Eigen::MatrixBase< Derived > & phi,
    const Eigen::MatrixBase< Derived > & psi,
    const std::vector< idx > & subsys,
    idx d = 2 )
```

Generalized inner product.

## Parameters

<i>phi</i>	Column vector Eigen expression
<i>psi</i>	Column vector Eigen expression
<i>subsys</i>	Subsystem indexes over which <i>phi</i> is defined
<i>d</i>	Subsystem dimensions

## Returns

Inner product  $\langle \phi_{subsys} | \psi \rangle$ , as a scalar or column vector over the remaining Hilbert space

## 6.1.3.63 isprime()

```
bool qpp::isprime (
    bigint p,
    idx k = 80 ) [inline]
```

Primality test based on the Miller-Rabin's algorithm.

## Parameters

<i>p</i>	Integer different from 0, 1 or -1
<i>k</i>	Number of iterations. The probability of a false positive is $2^{-k}$ .

## Returns

True if the number is (most-likely) prime, false otherwise

## 6.1.3.64 kraus2choi()

```
cmat qpp::kraus2choi (
    const std::vector< cmat > & Ks ) [inline]
```

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

<i>Ks</i>	Set of Kraus operators
-----------	------------------------

## Returns

Choi matrix

## 6.1.3.65 kraus2super()

```
cmat qpp::kraus2super (
    const std::vector< cmat > & Ks ) [inline]
```

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

<i>Ks</i>	Set of Kraus operators
-----------	------------------------

## Returns

Superoperator matrix

## 6.1.3.66 kron() [1/4]

```
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*

6.1.3.67 `kron()` [2/4]

```
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

6.1.3.68 `kron()` [3/4]

```
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

**6.1.3.69 kron()** [ 4 / 4 ]

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

Kronecker product.

**See also**

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

**Parameters**

$As$	std::initializer_list of Eigen expressions, such as $\{A1, A2, \dots, Ak\}$
------	---

**Returns**

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

**6.1.3.70 kronpow()**

```
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  $A$

**6.1.3.71 lcm()** [1/2]

```
bigint qpp::lcm (
    bigint a,
    bigint b ) [inline]
```

Least common multiple of two integers.

**See also**

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

**Parameters**

$a$	Integer
$b$	Integer

**Returns**

Least common multiple of  $a$  and  $b$

**6.1.3.72 lcm()** [2/2]

```
bigint qpp::lcm (
    const std::vector< bigint > & as ) [inline]
```

Least common multiple of a list of integers.

**See also**

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

**Parameters**

$as$	List of integers
------	------------------

**Returns**

Least common multiple of all numbers in  $as$

### 6.1.3.73 load()

```
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"
cmat mat = load<cmat>("input.bin");
```

Parameters

<i>fname</i>	Output file name
--------------	------------------

### 6.1.3.74 loadMATLAB() [1/2]

```
template<typename Derived >
std::enable_if<std::is_same<typename Derived::Scalar, cplx>::value, dyn_mat < cplx> >::type
qpp::loadMATLAB (
    const std::string & mat_file,
    const std::string & var_name )
```

Loads a complex Eigen dynamic matrix from a MATLAB .mat file,.

See also

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

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

Example:

```
// loads a previously saved Eigen ket
// from the MATLAB file "input.mat"
ket psi = loadMATLAB<ket>("input.mat");
```

Template Parameters

<i>Derived</i>	Complex Eigen type
----------------	--------------------

## 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 dynamic matrix

## 6.1.3.75 loadMATLAB() [2/2]

```
template<typename Derived >
std::enable_if<!std::is_same<typename Derived::Scalar, cplx>::value, dyn_mat < typename Derived↵
::Scalar> >::type qpp::loadMATLAB (
    const std::string & mat_file,
    const std::string & var_name )
```

Loads a non-complex Eigen dynamic matrix from a MATLAB .mat file,.

## See also

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

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"
dmat mat = loadMATLAB<dmat>("input.mat");
```

## Template Parameters

<i>Derived</i>	Non-complex Eigen type
----------------	------------------------

## 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 dynamic matrix

**6.1.3.76 logdet()**

```
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 over the same scalar field as *A*

**6.1.3.77 logm()**

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

Matrix logarithm.

**Parameters**

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

**Returns**

Matrix logarithm of *A*

**6.1.3.78 lognegativity()** <sup>[1/2]</sup>

```
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

**6.1.3.79 lognegativity()** [2/2]

```
template<typename Derived >
double qpp::lognegativity (
    const Eigen::MatrixBase< Derived > & A,
    idx d = 2 )
```

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

**Parameters**

$A$	Eigen expression
$d$	Subsystem dimensions

**Returns**

Logarithmic negativity, with the logarithm in base 2

**6.1.3.80 marginalX()**

```
std::vector<double> qpp::marginalX (
    const dmat & probXY ) [inline]
```

Marginal distribution.

**Parameters**

$probXY$	Real matrix representing the joint probability distribution of $X$ and $Y$ in lexicographical order ( $X$ labels the rows, $Y$ labels the columns)
----------	--

**Returns**

Real vector consisting of the marginal distribution of  $X$

**6.1.3.81 marginalY()**

```
std::vector<double> qpp::marginalY (
    const dmat & probXY ) [inline]
```

Marginal distribution.

## Parameters

<i>probXY</i>	Real matrix representing the joint probability distribution of $X$ and $Y$ in lexicographical order ( $X$ labels the rows, $Y$ labels the columns)
---------------	--

## Returns

Real vector consisting of the marginal distribution of  $Y$

6.1.3.82 `measure()` [1/9]

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

6.1.3.83 `measure()` [2/9]

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

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

## Parameters

$A$	Eigen expression
$Ks$	Set of Kraus operators

## Returns

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

6.1.3.84 `measure()` [3/9]

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

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

## Parameters

$A$	Eigen expression
$U$	Unitary matrix whose columns represent the measurement basis vectors

## Returns

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

6.1.3.85 `measure()` [4/9]

```
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  $Ks$ .

## See also

[qpp::measure\\_seq\(\)](#)

## Note

The dimension of all  $Ks$  must match the dimension of *subsys*. The measurement is destructive, i.e. the measured subsystems are traced away.

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

6.1.3.86 `measure()` [5/9]

```
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*.

## See also

[qpp::measure\\_seq\(\)](#)

## Note

The dimension of all *Ks* must match the dimension of *subsys*. The measurement is destructive, i.e. the measured subsystems are traced away.

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



**6.1.3.87** `measure()` [6/9]

```
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,
    idx d = 2 )
```

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

See also

[qpp::measure\\_seq\(\)](#)

Note

The dimension of all *Ks* must match the dimension of *subsys*. The measurement is destructive, i.e. the measured subsystems are traced away.

Parameters

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

Returns

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

**6.1.3.88** `measure()` [7/9]

```
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,
    idx d = 2 )
```

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

See also

[qpp::measure\\_seq\(\)](#)

Note

The dimension of all *Ks* must match the dimension of *subsys*. The measurement is destructive, i.e. the measured subsystems are traced away.

## Parameters

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

## Returns

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

6.1.3.89 `measure()` [8/9]

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

Measures the part *subsys* of the multi-partite state vector or density matrix *A* in the orthonormal basis or rank-1 POVM specified by the matrix *V*.

## See also

[qpp::measure\\_seq\(\)](#)

## Note

The dimension of *V* must match the dimension of *subsys*. The measurement is destructive, i.e. the measured subsystems are traced away.

## Parameters

<i>A</i>	Eigen expression
<i>V</i>	Matrix whose columns represent the measurement basis vectors or the bra parts of the rank-1 POVM
<i>subsys</i>	Subsystem indexes that are measured
<i>dims</i>	Dimensions of the multi-partite system

## Returns

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

**6.1.3.90** `measure()` [9/9]

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

Measures the part *subsys* of the multi-partite state vector or density matrix *A* in the orthonormal basis or rank-1 POVM specified by the matrix *V*.

See also

[qpp::measure\\_seq\(\)](#)

Note

The dimension of *V* must match the dimension of *subsys*. The measurement is destructive, i.e. the measured subsystems are traced away.

Parameters

<i>A</i>	Eigen expression
<i>V</i>	Matrix whose columns represent the measurement basis vectors or the bra parts of the rank-1 POVM
<i>subsys</i>	Subsystem indexes that are measured
<i>d</i>	Subsystem dimensions

Returns

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

**6.1.3.91** `measure_seq()` [1/2]

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

Sequentially measures the part *subsys* of the multi-partite state vector or density matrix *A* in the computational basis.

See also

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

## Parameters

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

## Returns

Tuple of: 1. Vector of outcome results of the measurement (ordered in increasing order with respect to *subsys*, i.e. first measurement result corresponds to the subsystem with the smallest index), 2. Outcome probability, and 3. Post-measurement normalized state

6.1.3.92 `measure_seq()` [2/2]

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

Sequentially measures the part *subsys* of the multi-partite state vector or density matrix *A* in the computational basis.

## See also

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

## Parameters

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

## Returns

Tuple of: 1. Vector of outcome results of the measurement (ordered in increasing order with respect to *subsys*, i.e. first measurement result corresponds to the subsystem with the smallest index), 2. Outcome probability, and 3. Post-measurement normalized state

6.1.3.93 `mket()` [1/2]

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

Multi-partite qudit ket.

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

## Parameters

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

## Returns

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

6.1.3.94 `mket()` [2/2]

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

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

## Returns

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

6.1.3.95 `modinv()`

```
bigint qpp::modinv (
    bigint a,
    bigint p ) [inline]
```

Modular inverse of  $a$  mod  $p$ .

## See also

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

## Note

$a$  and  $p$  must be co-prime

## Parameters

$a$	Non-negative integer
$p$	Non-negative integer

## Returns

Modular inverse  $a^{-1} \bmod p$

## 6.1.3.96 modmul()

```
bigint qpp::modmul (
    bigint a,
    bigint b,
    bigint p ) [inline]
```

Modular multiplication without overflow.

Computes  $ab \bmod p$  without overflow

## Parameters

$a$	Integer
$b$	Integer
$p$	Positive integer

## Returns

$ab \bmod p$  avoiding overflow

## 6.1.3.97 modpow()

```
bigint qpp::modpow (
    bigint a,
    bigint n,
    bigint p ) [inline]
```

Fast integer power modulo  $p$  based on the SQUARE-AND-MULTIPLY algorithm.

## Note

Uses [qpp::modmul\(\)](#) that avoids overflows

Computes  $a^n \bmod p$

## Parameters

$a$	Non-negative integer
$n$	Non-negative integer
$p$	Strictly positive integer

## Returns

$$a^n \bmod p$$

6.1.3.98 `mprj()` [1/2]

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

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

6.1.3.99 `mprj()` [2/2]

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

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

**6.1.3.100 multiidx2n()**

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

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

**6.1.3.101 n2multiidx()**

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

Non-negative integer index to multi-index.

**See also**

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

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

**Parameters**

<i>n</i>	Non-negative integer index
<i>dims</i>	Dimensions of the multi-partite system

**Returns**

Multi-index of the same size as *dims*

**6.1.3.102 negativity()** [1/2]

```
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**

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

**Returns**

Negativity

**6.1.3.103 negativity()** [2/2]

```
template<typename Derived >
double qpp::negativity (
    const Eigen::MatrixBase< Derived > & A,
    idx d = 2 )
```

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

**Parameters**

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

**Returns**

Negativity

**6.1.3.104 norm()**

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

Frobenius norm.

#### Parameters

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

#### Returns

Frobenius norm of  $A$

#### 6.1.3.105 `omega()`

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

D-th root of unity.

#### Parameters

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

#### Returns

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

#### 6.1.3.106 `operator""_i()` [1/2]

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

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

Example:

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

#### 6.1.3.107 `operator""_i()` [2/2]

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

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

Example:

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

## 6.1.3.108 powm()

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

Fast matrix power based on the SQUARE-AND-MULTIPLY algorithm.

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  $A$

## 6.1.3.109 prj()

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

Projector.

Normalized projector onto state vector

Parameters

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

Returns

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

**6.1.3.110** `prod()` [1/3]

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

Element-wise product of *A*.

**Parameters**

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

**Returns**

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

**6.1.3.111** `prod()` [2/3]

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

Element-wise product of an STL-like 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 over the same scalar field as the range

**6.1.3.112** `prod()` [3/3]

```
template<typename Container >
Container::value_type qpp::prod (
    const Container & c,
    typename std::enable_if< is\_iterable< Container >::value >::type * = nullptr )
```

Element-wise product of the elements of an STL-like container.

**Parameters**

<i>c</i>	STL-like container
----------	--------------------

**Returns**

Element-wise product of the elements of the container, as a scalar over the same scalar field as the container

**6.1.3.113 ptrace()** [1/2]

```
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 state vector or 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*

**6.1.3.114 ptrace()** [2/2]

```
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 state vector or density matrix over a list of subsystems

## Parameters

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

6.1.3.115 `ptrace1()` [1/2]

```
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 over the first subsystem of bi-partite state vector or density matrix

## Parameters

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

## 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  $A$

6.1.3.116 `ptrace1()` [2/2]

```
template<typename Derived >
dyn_mat<typename Derived::Scalar> qpp::ptrace1 (
    const Eigen::MatrixBase< Derived > & A,
    idx d = 2 )
```

Partial trace.

See also

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

Partial trace over the first subsystem of bi-partite state vector or density matrix



## Parameters

$A$	Eigen expression
$d$	Subsystem dimensions

## 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  $A$

## 6.1.3.117 ptrace2() [1/2]

```
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\(\)](#)

Partial trace over the second subsystem of bi-partite state vector or density matrix

## Parameters

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

## 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  $A$

## 6.1.3.118 ptrace2() [2/2]

```
template<typename Derived >
dyn_mat<typename Derived::Scalar> qpp::ptrace2 (
    const Eigen::MatrixBase< Derived > & A,
    idx d = 2 )
```

Partial trace.

## See also

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

Partial trace over the second subsystem of bi-partite state vector or density matrix

## Parameters

$A$	Eigen expression
$d$	Subsystem dimensions

## 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  $A$

## 6.1.3.119 ptranspose() [1/2]

```
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.

Partial transpose of the multi-partite state vector or 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  $A$

## 6.1.3.120 ptranspose() [2/2]

```
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.

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

## 6.1.3.121 qmutualinfo() [1/2]

```
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

<i>A</i>	Eigen expression
<i>subsysA</i>	Indexes of the first subsystem
<i>subsysB</i>	Indexes of the second subsystem
<i>dims</i>	Dimensions of the multi-partite system

## Returns

Mutual information between the 2 subsystems

## 6.1.3.122 qmutualinfo() [2/2]

```
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**

<i>A</i>	Eigen expression
<i>subsysA</i>	Indexes of the first subsystem
<i>subsysB</i>	Indexes of the second subsystem
<i>d</i>	Subsystem dimensions

**Returns**

Mutual information between the 2 subsystems

**6.1.3.123 rand()** [1/5]

```
double qpp::rand (
    double a,
    double b ) [inline]
```

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)

**6.1.3.124 rand()** [2/5]

```
bigint qpp::rand (
    bigint a,
    bigint b ) [inline]
```

Generates a random big integer uniformly distributed in the interval [a, b].

**Note**

To avoid ambiguity with double [qpp::rand\(double, double\)](#) cast at least one of the arguments to [qpp::bigint](#)

**Parameters**

<i>a</i>	Beginning of the interval, belongs to it
<i>b</i>	End of the interval, belongs to it

**Returns**

Random big integer uniformly distributed in the interval [a, b]

**6.1.3.125 rand()** [3/5]

```
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`

**6.1.3.126 rand()** [4/5]

```
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)
dmat 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

**6.1.3.127 rand()** [5/5]

```
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)
cmat 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

**6.1.3.128 randH()**

```
cmat qpp::randH (
    idx D = 2 ) [inline]
```

Generates a random Hermitian matrix.

**Parameters**

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

**Returns**

Random Hermitian matrix

**6.1.3.129 randidx()**

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

Generates a random index (idx) 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, belongs to it

**Returns**

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

**6.1.3.130 randket()**

```
ket qpp::randket (
    idx D = 2 ) [inline]
```

Generates a random normalized ket (pure state vector)

**Parameters**

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

**Returns**

Random normalized ket

**6.1.3.131 randkraus()**

```
std::vector<cmat> qpp::randkraus (
    idx N,
    idx D = 2 ) [inline]
```

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**

<i>N</i>	Number of Kraus operators
<i>D</i>	Dimension of the Hilbert space

**Returns**

Set of *N* Kraus operators satisfying the closure condition

**6.1.3.132 randn()** [1/4]

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

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

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

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

**6.1.3.133 randn()** [2/4]

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

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

## 6.1.3.134 randn() [3/4]

```
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)
cmat 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

## 6.1.3.135 randn() [4/4]

```
double qpp::randn (
    double mean = 0,
    double sigma = 1 ) [inline]
```

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

#### 6.1.3.136 randperm()

```
std::vector<idx> qpp::randperm (
    idx N ) [inline]
```

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*

#### 6.1.3.137 randprime()

```
bigint qpp::randprime (
    bigint a,
    bigint b,
    idx N = 1000 ) [inline]
```

Generates a random big prime 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, belongs to it
<i>N</i>	Maximum number of candidates

**Returns**

Random big integer uniformly distributed in the interval [a, b]

**6.1.3.138 randprob()**

```
std::vector<double> qpp::randprob (
    idx N ) [inline]
```

Generates a random probability vector uniformly distributed over the probability simplex.

**Parameters**

<i>N</i>	Size of the probability vector
----------	--------------------------------

**Returns**

Random probability vector

**6.1.3.139 randrho()**

```
cmat qpp::randrho (
    idx D = 2 ) [inline]
```

Generates a random density matrix.

**Parameters**

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

**Returns**

Random density matrix

**6.1.3.140 randU()**

```
cmat qpp::randU (
    idx D = 2 ) [inline]
```

Generates a random unitary matrix.

**Parameters**

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

**Returns**

Random unitary

**6.1.3.141 randV()**

```
cmat qpp::randV (
    idx Din,
    idx Dout ) [inline]
```

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

**6.1.3.142 renyi()** [1/2]

```
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

**6.1.3.143** `renyi()` [2/2]

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

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 <code>qpp::infy</code> for $\alpha = \infty$

**Returns**

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

**6.1.3.144** `reshape()`

```
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*

**6.1.3.145 rho2bloch()**

```
template<typename Derived >
std::vector<double> qpp::rho2bloch (
    const Eigen::MatrixBase< Derived > & A )
```

Computes the 3-dimensional real Bloch vector corresponding to the qubit density matrix *A*.

**See also**

[qpp::bloch2rho\(\)](#)

**Note**

It is implicitly assumed that the density matrix is Hermitian

**Parameters**

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

**Returns**

3-dimensional Bloch vector

**6.1.3.146 rho2pure()**

```
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  $A$  (up to a phase), as a dynamic column vector over the same scalar field as  $A$

6.1.3.147 `save()`

```
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

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

6.1.3.148 `saveMATLAB()` [1/2]

```
template<typename Derived >
std::enable_if<std::is_same<typename Derived::Scalar, cplx>::value>::type qpp::saveMATLAB (
    const Eigen::MatrixBase< Derived > & A,
    const std::string & mat_file,
    const std::string & var_name,
    const std::string & mode )
```

Saves a complex Eigen dynamic matrix to a MATLAB .mat file,.

## See also

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

## Template Parameters

<i>Complex</i>	Eigen type
----------------	------------

## Parameters

$A$	Eigen expression over the complex field
-----	---

## Parameters

<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

6.1.3.149 `saveMATLAB()` [2/2]

```
template<typename Derived >
std::enable_if<!std::is_same<typename Derived::Scalar, cplx>::value>::type qpp::saveMATLAB (
    const Eigen::MatrixBase< Derived > & A,
    const std::string & mat_file,
    const std::string & var_name,
    const std::string & mode )
```

Saves a non-complex Eigen dynamic matrix to a MATLAB .mat file,.

## See also

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

## Template Parameters

<i>Npn-complex</i>	Eigen type
--------------------	------------

## Parameters

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

6.1.3.150 `schatten()`

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

Schatten matrix norm.

## Parameters

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



**Returns**

Schatten- $p$  matrix norm of  $A$

**6.1.3.151 schmidtA()** [1/2]

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

Schmidt basis on Alice side.

**Parameters**

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

**Returns**

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

**6.1.3.152 schmidtA()** [2/2]

```
template<typename Derived >
cmat qpp::schmidtA (
    const Eigen::MatrixBase< Derived > & A,
    idx d = 2 )
```

Schmidt basis on Alice side.

**Parameters**

$A$	Eigen expression
$d$	Subsystem dimensions

**Returns**

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

**6.1.3.153 schmidtB()** [1/2]

```
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.

#### 6.1.3.154 `schmidtB()` [2/2]

```
template<typename Derived >
cmat qpp::schmidtB (
    const Eigen::MatrixBase< Derived > & A,
    idx d = 2 )
```

Schmidt basis on Bob side.

#### Parameters

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

#### Returns

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

#### 6.1.3.155 `schmidtcoeffs()` [1/2]

```
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*, ordered in decreasing order, as a real dynamic column vector

6.1.3.156 `schmidtcoeffs()` [2/2]

```
template<typename Derived >
dyn_col_vect<double> qpp::schmidtcoeffs (
    const Eigen::MatrixBase< Derived > & A,
    idx d = 2 )
```

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>d</i>	Subsystem dimensions

## Returns

Schmidt coefficients of *A*, ordered in decreasing order, as a real dynamic column vector

6.1.3.157 `schmidtprobs()` [1/2]

```
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

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

Returns

Real vector consisting of the Schmidt probabilities of *A*, ordered in decreasing order

#### 6.1.3.158 `schmidtprobs()` [2/2]

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

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

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

Returns

Real vector consisting of the Schmidt probabilities of *A*, ordered in decreasing order

#### 6.1.3.159 `sigma()`

```
template<typename Container >
double qpp::sigma (
    const std::vector< double > & prob,
    const Container & X,
    typename std::enable_if< is_iterable< Container >::value >::type * = nullptr )
```

Standard deviation.

## Parameters

<i>prob</i>	Real probability vector representing the probability distribution of $X$
$X$	Real random variable values represented by an STL-like container

## Returns

Standard deviation of  $X$

6.1.3.160 `sinm()`

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

Matrix sin.

## Parameters

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

## Returns

Matrix sine of  $A$

6.1.3.161 `spectralpowm()`

```
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  $A^z$

**6.1.3.162 sqrtm()**

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

Matrix square root.

**Parameters**

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

**Returns**

Matrix square root of  $A$

**6.1.3.163 sum()** [1/3]

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

Element-wise sum of  $A$ .

**Parameters**

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

**Returns**

Element-wise sum of  $A$ , as a scalar over the same scalar field as  $A$

**6.1.3.164 sum()** [2/3]

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

Element-wise sum of an STL-like 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 over the same scalar field as the range

6.1.3.165 `sum()` [3/3]

```
template<typename Container >
Container::value_type qpp::sum (
    const Container & c,
    typename std::enable_if< is\_iterable< Container >::value >::type * = nullptr )
```

Element-wise sum of the elements of an STL-like container.

## Parameters

<i>c</i>	STL-like container
----------	--------------------

## Returns

Element-wise sum of the elements of the container, as a scalar over the same scalar field as the container

6.1.3.166 `super2choi()`

```
cmat qpp::super2choi (
    const cmat & A ) [inline]
```

Converts superoperator matrix to Choi matrix.

## See also

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

## Parameters

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

**Returns**

Choi matrix

**6.1.3.167 svals()**

```
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

**6.1.3.168 svd()**

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

Full singular value decomposition.

**Parameters**

<i>A</i>	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

**6.1.3.169 svdU()**

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

Left singular vectors.



## Parameters

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

## Returns

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

6.1.3.170 `svdV()`

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

Right singular vectors.

## Parameters

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

## Returns

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

6.1.3.171 `syspermute()` [1/2]

```
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 of a state vector or density matrix. The qubit *perm*[*i*] is permuted to the location *i*.

## Parameters

<i>A</i>	Eigen expression
<i>perm</i>	Permutation
<i>dims</i>	Dimensions of the multi-partite system

**Returns**

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

**6.1.3.172 syspermute()** [2/2]

```
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 of 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  $A$

**6.1.3.173 trace()**

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

Trace.

**Parameters**

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

**Returns**

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

## 6.1.3.174 transpose()

```
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  $A$

## 6.1.3.175 tsallis() [1/2]

```
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

## 6.1.3.176 tsallis() [2/2]

```
double qpp::tsallis (
    const std::vector< double > & prob,
    double  $q$  ) [inline]
```

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

**6.1.3.177 uniform()**

```
std::vector<double> qpp::uniform (
    idx N ) [inline]
```

Uniform probability distribution vector.

**Parameters**

<i>N</i>	Size of the alphabet
----------	----------------------

**Returns**

Real vector consisting of a uniform distribution of size  $N$

**6.1.3.178 var()**

```
template<typename Container >
double qpp::var (
    const std::vector< double > & prob,
    const Container & X,
    typename std::enable_if< is_iterable< Container >::value >::type * = nullptr )
```

Variance.

**Parameters**

<i>prob</i>	Real probability vector representing the probability distribution of $X$
$X$	Real random variable values represented by an STL-like container

**Returns**

Variance of  $X$

**6.1.3.179 x2contfrac()**

```
std::vector<int> qpp::x2contfrac (
    double x,
    idx N,
    idx cut = 1e5 ) [inline]
```

Simple continued fraction expansion.

**See also**

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

**Parameters**

$x$	Real number
$N$	Maximum number of terms in the expansion
$cut$	Stop the expansion when the next term is greater than $cut$

**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 chop**

```
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 ee**

```
constexpr double qpp::ee = 2.718281828459045235360287471352662497
```

Base of natural logarithm,  $e$ .

#### 6.1.4.3 eps

```
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
```

#### 6.1.4.4 infty

```
constexpr double qpp::infty = std::numeric_limits<double>::max()
```

Used to denote infinity in double precision.

#### 6.1.4.5 maxn

```
constexpr idx qpp::maxn = 64
```

Maximum number of allowed qubits/qudits (subsystems)

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

#### 6.1.4.6 pi

```
constexpr double qpp::pi = 3.141592653589793238462643383279502884
```

$\pi$

## 6.2 qpp::exception Namespace Reference

Quantum++ exception hierarchy namespace.

## Classes

- class [CustomException](#)  
*Custom exception.*
- class [DimsInvalid](#)  
*Invalid dimension(s) exception.*
- class [DimsMismatchCvector](#)  
*Dimension(s) mismatch column vector size exception.*
- class [DimsMismatchMatrix](#)  
*Dimension(s) mismatch matrix size exception.*
- class [DimsMismatchRvector](#)  
*Dimension(s) mismatch row vector size exception.*
- class [DimsMismatchVector](#)  
*Dimension(s) mismatch vector size exception.*
- class [DimsNotEqual](#)  
*Dimensions not equal exception.*
- class [Exception](#)  
*Base class for generating Quantum++ custom exceptions.*
- class [MatrixMismatchSubsys](#)  
*Matrix mismatch subsystems exception.*
- class [MatrixNotCvector](#)  
*Matrix is not a column vector exception.*
- class [MatrixNotRvector](#)  
*Matrix is not a row vector exception.*
- class [MatrixNotSquare](#)  
*Matrix is not square exception.*
- class [MatrixNotSquareNorCvector](#)  
*Matrix is not square nor column vector exception.*
- class [MatrixNotSquareNorRvector](#)  
*Matrix is not square nor row vector exception.*
- class [MatrixNotSquareNorVector](#)  
*Matrix is not square nor vector exception.*
- class [MatrixNotVector](#)  
*Matrix is not a vector exception.*
- class [NoCodeword](#)  
*Codeword does not exist exception.*
- class [NotBipartite](#)  
*Not bi-partite exception.*
- class [NotQubitCvector](#)  
*Column vector is not 2 x 1 exception.*
- class [NotQubitMatrix](#)  
*Matrix is not 2 x 2 exception.*
- class [NotQubitRvector](#)  
*Row vector is not 1 x 2 exception.*
- class [NotQubitSubsys](#)  
*Subsystems are not qubits exception.*
- class [NotQubitVector](#)  
*Vector is not 2 x 1 nor 1 x 2 exception.*
- class [OutOfRange](#)  
*Parameter out of range exception.*
- class [PermInvalid](#)

- Invalid permutation exception.*
- class [PermMismatchDims](#)
  - Permutation mismatch dimensions exception.*
- class [SizeMismatch](#)
  - Size mismatch exception.*
- class [SubsysMismatchDims](#)
  - Subsystems mismatch dimensions exception.*
- class [TypeMismatch](#)
  - Type mismatch exception.*
- class [UndefinedType](#)
  - Not defined for this type exception.*
- class [Unknown](#)
  - Unknown exception.*
- class [ZeroSize](#)
  - Object has zero size exception.*

### 6.2.1 Detailed Description

Quantum++ exception hierarchy namespace.

## 6.3 qpp::experimental Namespace Reference

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

### 6.3.1 Detailed Description

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

## 6.4 qpp::internal Namespace Reference

Internal utility functions, do not use them directly or modify them.

### Classes

- struct [Display\\_Impl\\_](#)
- 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 \*const dims, idx \*result) noexcept
- idx [multiidx2n](#) (const idx \*const midx, idx numdims, const idx \*const dims) noexcept
- 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\\_rvector](#) (const Eigen::MatrixBase< Derived > &A)
- template<typename Derived >  
bool [check\\_cvector](#) (const Eigen::MatrixBase< Derived > &A)
- template<typename T >  
bool [check\\_nonzero\\_size](#) (const T &x) noexcept
- template<typename T1 , typename T2 >  
bool [check\\_matching\\_sizes](#) (const T1 &lhs, const T2 &rhs) noexcept
- 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 > &A)
- template<typename Derived >  
bool [check\\_dims\\_match\\_rvect](#) (const std::vector< idx > &dims, const Eigen::MatrixBase< Derived > &A)
- bool [check\\_eq\\_dims](#) (const std::vector< idx > &dims, idx dim) noexcept
- bool [check\\_subsys\\_match\\_dims](#) (const std::vector< idx > &subsys, const std::vector< idx > &dims)
- template<typename Derived >  
bool [check\\_qubit\\_matrix](#) (const Eigen::MatrixBase< Derived > &A) noexcept
- template<typename Derived >  
bool [check\\_qubit\\_cvector](#) (const Eigen::MatrixBase< Derived > &A) noexcept
- template<typename Derived >  
bool [check\\_qubit\\_rvector](#) (const Eigen::MatrixBase< Derived > &A) noexcept
- template<typename Derived >  
bool [check\\_qubit\\_vector](#) (const Eigen::MatrixBase< Derived > &A) noexcept
- 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< Derived2 > &B)
- template<typename T >  
void [variadic\\_vector\\_emplace](#) (std::vector< T > &)
- template<typename T , typename First , typename ... Args>  
void [variadic\\_vector\\_emplace](#) (std::vector< T > &v, First &&first, Args &&... args)
- idx [get\\_num\\_subsys](#) (idx sz, idx d)
- idx [get\\_dim\\_subsys](#) (idx sz, idx N)

### 6.4.1 Detailed Description

Internal utility functions, do not use them directly or modify them.

### 6.4.2 Function Documentation

#### 6.4.2.1 check\_cvector()

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

#### 6.4.2.2 check\_dims()

```
bool qpp::internal::check_dims (
    const std::vector< idx > & dims ) [inline]
```

#### 6.4.2.3 check\_dims\_match\_cvect()

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

#### 6.4.2.4 check\_dims\_match\_mat()

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

#### 6.4.2.5 check\_dims\_match\_rvect()

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

#### 6.4.2.6 check\_eq\_dims()

```
bool qpp::internal::check_eq_dims (
    const std::vector< idx > & dims,
    idx dim ) [inline], [noexcept]
```

#### 6.4.2.7 check\_matching\_sizes()

```
template<typename T1 , typename T2 >
bool qpp::internal::check_matching_sizes (
    const T1 & lhs,
    const T2 & rhs ) [noexcept]
```

#### 6.4.2.8 check\_nonzero\_size()

```
template<typename T >
bool qpp::internal::check_nonzero_size (
    const T & x ) [noexcept]
```

#### 6.4.2.9 check\_perm()

```
bool qpp::internal::check_perm (
    const std::vector< idx > & perm ) [inline]
```

#### 6.4.2.10 check\_qubit\_cvector()

```
template<typename Derived >
bool qpp::internal::check_qubit_cvector (
    const Eigen::MatrixBase< Derived > & A ) [noexcept]
```

#### 6.4.2.11 check\_qubit\_matrix()

```
template<typename Derived >
bool qpp::internal::check_qubit_matrix (
    const Eigen::MatrixBase< Derived > & A ) [noexcept]
```

#### 6.4.2.12 check\_qubit\_rvector()

```
template<typename Derived >
bool qpp::internal::check_qubit_rvector (
    const Eigen::MatrixBase< Derived > & A ) [noexcept]
```

**6.4.2.13 check\_qubit\_vector()**

```
template<typename Derived >
bool qpp::internal::check_qubit_vector (
    const Eigen::MatrixBase< Derived > & A ) [noexcept]
```

**6.4.2.14 check\_rvector()**

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

**6.4.2.15 check\_square\_mat()**

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

**6.4.2.16 check\_subsys\_match\_dims()**

```
bool qpp::internal::check_subsys_match_dims (
    const std::vector< idx > & subsys,
    const std::vector< idx > & dims ) [inline]
```

**6.4.2.17 check\_vector()**

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

**6.4.2.18 dirsum2()**

```
template<typename Derived1 , typename Derived2 >
dyn_mat<typename Derived1::Scalar> qpp::internal::dirsum2 (
    const Eigen::MatrixBase< Derived1 > & A,
    const Eigen::MatrixBase< Derived2 > & B )
```

## 6.4.2.19 get\_dim\_subsys()

```
idx qpp::internal::get_dim_subsys (
    idx sz,
    idx N ) [inline]
```

## 6.4.2.20 get\_num\_subsys()

```
idx qpp::internal::get_num_subsys (
    idx sz,
    idx d ) [inline]
```

## 6.4.2.21 kron2()

```
template<typename Derived1 , typename Derived2 >
dyn_mat<typename Derived1::Scalar> qpp::internal::kron2 (
    const Eigen::MatrixBase< Derived1 > & A,
    const Eigen::MatrixBase< Derived2 > & B )
```

## 6.4.2.22 multiidx2n()

```
idx qpp::internal::multiidx2n (
    const idx *const midx,
    idx numdims,
    const idx *const dims ) [inline], [noexcept]
```

## 6.4.2.23 n2multiidx()

```
void qpp::internal::n2multiidx (
    idx n,
    idx numdims,
    const idx *const dims,
    idx * result ) [inline], [noexcept]
```

## 6.4.2.24 variadic\_vector\_emplace() [1/2]

```
template<typename T >
void qpp::internal::variadic_vector_emplace (
    std::vector< T > & )
```

## 6.4.2.25 variadic\_vector\_emplace() [2/2]

```
template<typename T , typename First , typename ... Args>
void qpp::internal::variadic_vector_emplace (
    std::vector< T > & v,
    First && first,
    Args &&... args )
```



## Chapter 7

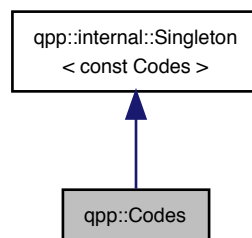
# Class Documentation

### 7.1 qpp::Codes Class Reference

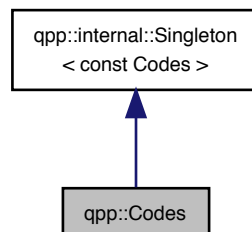
const Singleton class that defines quantum error correcting codes

```
#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.*
- [~Codes](#) ()=default  
*Default destructor.*

## 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 Type

```
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 Codes()

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

Default constructor.

#### 7.1.3.2 ~Codes()

```
qpp::Codes::~~Codes ( ) [private], [default]
```

Default destructor.

### 7.1.4 Member Function Documentation

#### 7.1.4.1 codeword()

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

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

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

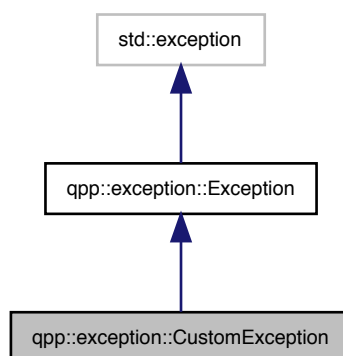
- `classes/codes.h`

## 7.2 `qpp::exception::CustomException` Class Reference

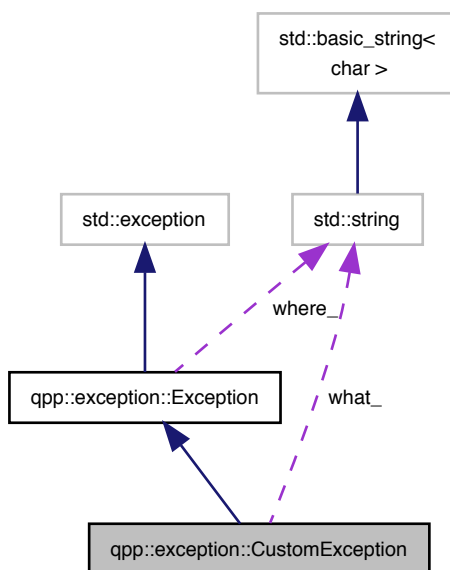
Custom exception.

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

Inheritance diagram for `qpp::exception::CustomException`:



Collaboration diagram for qpp::exception::CustomException:



### Public Member Functions

- [CustomException](#) (const std::string &where, const std::string &[what](#))

### Private Member Functions

- std::string [type\\_description](#) () const override  
*[Exception](#) type description.*

### Private Attributes

- std::string [what\\_](#) {}

#### 7.2.1 Detailed Description

Custom exception.

Custom exception, the user must provide a custom message

#### 7.2.2 Constructor & Destructor Documentation

#### 7.2.2.1 CustomException()

```
qpp::exception::CustomException::CustomException (
    const std::string & where,
    const std::string & what ) [inline]
```

### 7.2.3 Member Function Documentation

#### 7.2.3.1 type\_description()

```
std::string qpp::exception::CustomException::type_description ( ) const [inline], [override],
[private], [virtual]
```

[Exception](#) type description.

#### Returns

[Exception](#) type description

Implements [qpp::exception::Exception](#).

### 7.2.4 Member Data Documentation

#### 7.2.4.1 what\_

```
std::string qpp::exception::CustomException::what_ {} [private]
```

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

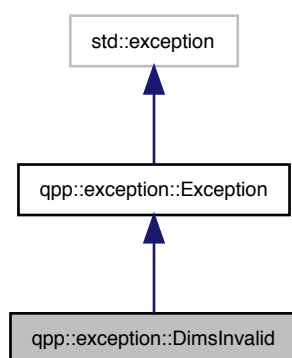
- [classes/exception.h](#)

## 7.3 qpp::exception::DimsInvalid Class Reference

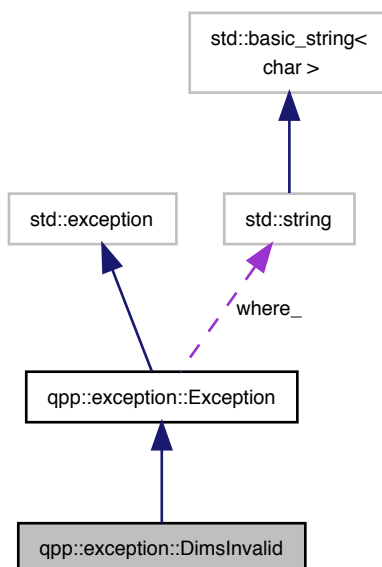
Invalid dimension(s) exception.

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

Inheritance diagram for qpp::exception::DimsInvalid:



Collaboration diagram for qpp::exception::DimsInvalid:



## Public Member Functions

- `std::string type\_description ()` const override  
*[Exception](#) type description.*

### 7.3.1 Detailed Description

Invalid dimension(s) exception.

`std::vector<idx>` of dimensions has zero size or contains zeros

### 7.3.2 Member Function Documentation

#### 7.3.2.1 `type_description()`

```
std::string qpp::exception::DimsInvalid::type_description ( ) const [inline], [override],  
[virtual]
```

[Exception](#) type description.

#### Returns

[Exception](#) type description

Implements [qpp::exception::Exception](#).

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

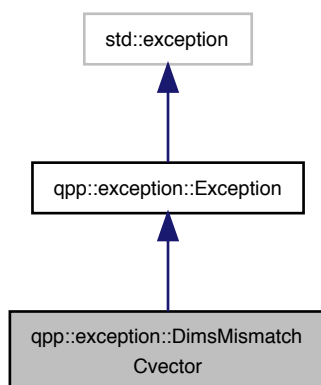
- `classes/exception.h`

## 7.4 `qpp::exception::DimsMismatchCvector` Class Reference

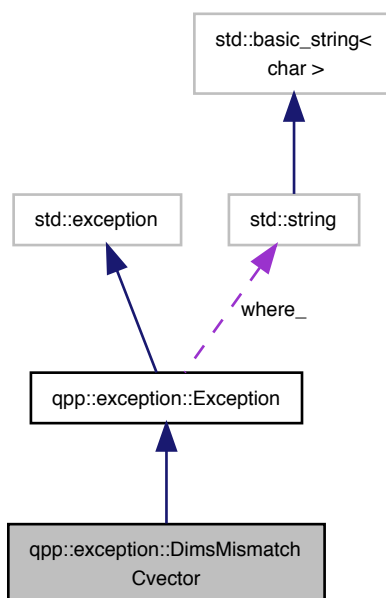
Dimension(s) mismatch column vector size exception.

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

Inheritance diagram for qpp::exception::DimsMismatchCvector:



Collaboration diagram for qpp::exception::DimsMismatchCvector:



## Public Member Functions

- `std::string type\_description ()` const override  
*[Exception](#) type description.*

### 7.4.1 Detailed Description

Dimension(s) mismatch column vector size exception.

Product of the elements of `std::vector<idx>` of dimensions is not equal to the number of elements of the `Eigen::Matrix` (assumed to be a column vector)

### 7.4.2 Member Function Documentation

#### 7.4.2.1 `type_description()`

```
std::string qpp::exception::DimsMismatchCvector::type_description ( ) const [inline], [override], [virtual]
```

[Exception](#) type description.

#### Returns

[Exception](#) type description

Implements [qpp::exception::Exception](#).

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

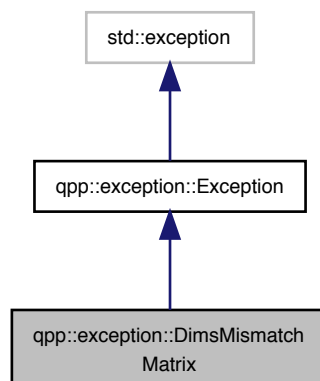
- [classes/exception.h](#)

## 7.5 `qpp::exception::DimsMismatchMatrix` Class Reference

Dimension(s) mismatch matrix size exception.

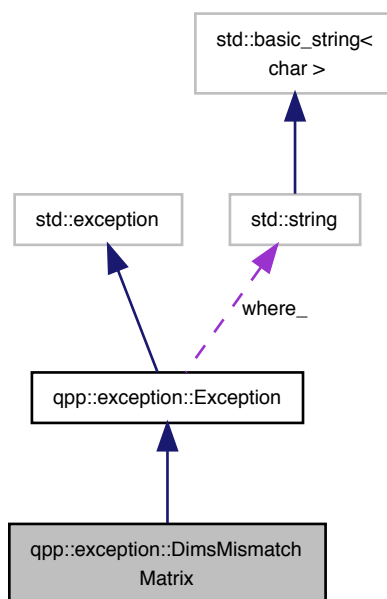
```
#include <classes/exception.h>
```

Inheritance diagram for `qpp::exception::DimsMismatchMatrix`:





Collaboration diagram for qpp::exception::DimsMismatchMatrix:



## Public Member Functions

- `std::string type_description ()` const override  
*Exception type description.*

### 7.5.1 Detailed Description

Dimension(s) mismatch matrix size exception.

Product of the elements of `std::vector<idx>` of dimensions is not equal to the number of rows of the `Eigen::Matrix` (assumed to be a square matrix)

### 7.5.2 Member Function Documentation

### 7.5.2.1 type\_description()

```
std::string qpp::exception::DimsMismatchMatrix::type_description ( ) const [inline], [override],  
[virtual]
```

[Exception](#) type description.

#### Returns

[Exception](#) type description

Implements [qpp::exception::Exception](#).

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

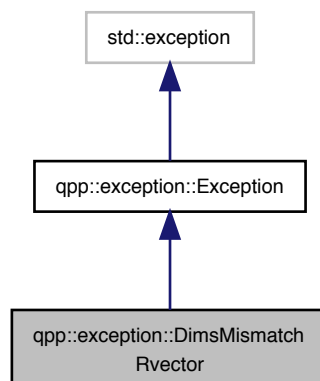
- [classes/exception.h](#)

## 7.6 qpp::exception::DimsMismatchRvector Class Reference

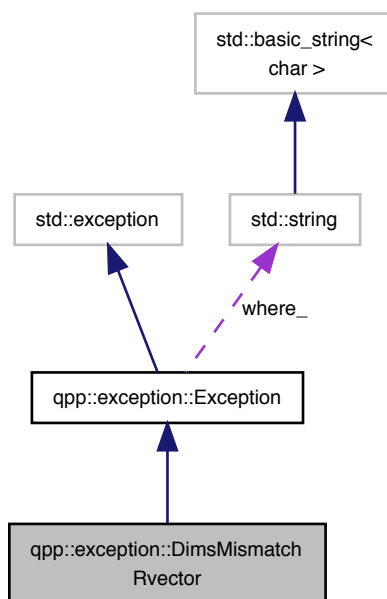
Dimension(s) mismatch row vector size exception.

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

Inheritance diagram for qpp::exception::DimsMismatchRvector:



Collaboration diagram for qpp::exception::DimsMismatchRvector:



## Public Member Functions

- `std::string type_description ()` const override  
*Exception type description.*

### 7.6.1 Detailed Description

Dimension(s) mismatch row vector size exception.

Product of the elements of `std::vector<idx>` of dimensions is not equal to the number of elements of the Eigen::↵ Matrix (assumed to be a row vector)

### 7.6.2 Member Function Documentation

### 7.6.2.1 type\_description()

```
std::string qpp::exception::DimsMismatchRvector::type_description ( ) const [inline], [override],  
[virtual]
```

[Exception](#) type description.

#### Returns

[Exception](#) type description

Implements [qpp::exception::Exception](#).

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

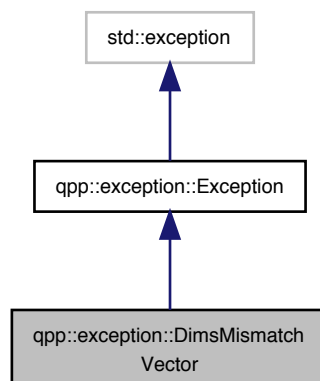
- [classes/exception.h](#)

## 7.7 qpp::exception::DimsMismatchVector Class Reference

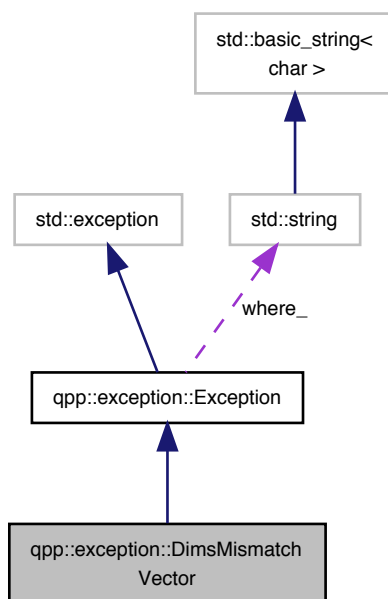
Dimension(s) mismatch vector size exception.

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

Inheritance diagram for qpp::exception::DimsMismatchVector:



Collaboration diagram for qpp::exception::DimsMismatchVector:



## Public Member Functions

- `std::string type_description ()` const override  
*Exception type description.*

### 7.7.1 Detailed Description

Dimension(s) mismatch vector size exception.

Product of the elements of `std::vector<idx>` of dimensions is not equal to the number of elements of the Eigen::↵ Matrix (assumed to be a row/column vector)

### 7.7.2 Member Function Documentation

### 7.7.2.1 type\_description()

```
std::string qpp::exception::DimsMismatchVector::type_description ( ) const [inline], [override],  
[virtual]
```

Exception type description.

#### Returns

Exception type description

Implements [qpp::exception::Exception](#).

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

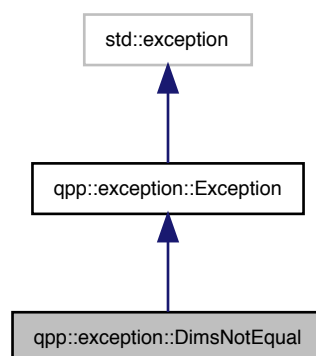
- [classes/exception.h](#)

## 7.8 qpp::exception::DimsNotEqual Class Reference

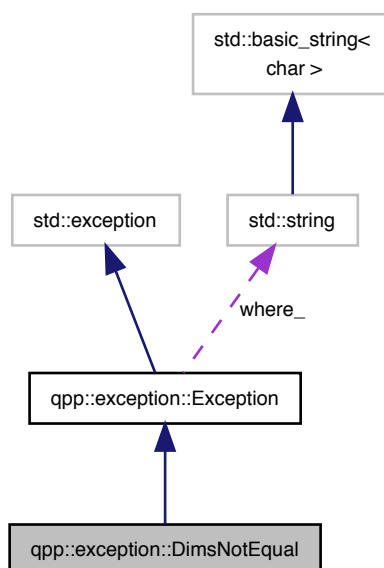
Dimensions not equal exception.

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

Inheritance diagram for `qpp::exception::DimsNotEqual`:



Collaboration diagram for qpp::exception::DimsNotEqual:



## Public Member Functions

- `std::string type_description () const` override  
*Exception type description.*

### 7.8.1 Detailed Description

Dimensions not equal exception.

Local/global dimensions are not equal

### 7.8.2 Member Function Documentation

#### 7.8.2.1 type\_description()

```
std::string qpp::exception::DimsNotEqual::type_description ( ) const [inline], [override], [virtual]
```

*Exception* type description.

Returns

*Exception* type description

Implements `qpp::exception::Exception`.

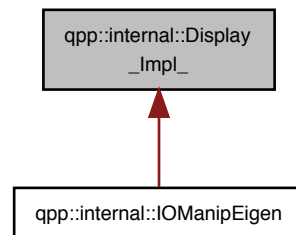
The documentation for this class was generated from the following file:

- `classes/exception.h`

## 7.9 qpp::internal::Display\_Impl\_ Struct Reference

```
#include <internal/util.h>
```

Inheritance diagram for qpp::internal::Display\_Impl\_:



### Public Member Functions

- `template<typename T >`  
`std::ostream & display\_impl\_ (const T &A, std::ostream &os, double chop=qpp::chop) const`

### 7.9.1 Member Function Documentation

#### 7.9.1.1 `display_impl_()`

```
template<typename T >
std::ostream& qpp::internal::Display_Impl_::display_impl_ (
    const T & A,
    std::ostream & os,
    double chop = qpp::chop ) const [inline]
```

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

- [internal/util.h](#)

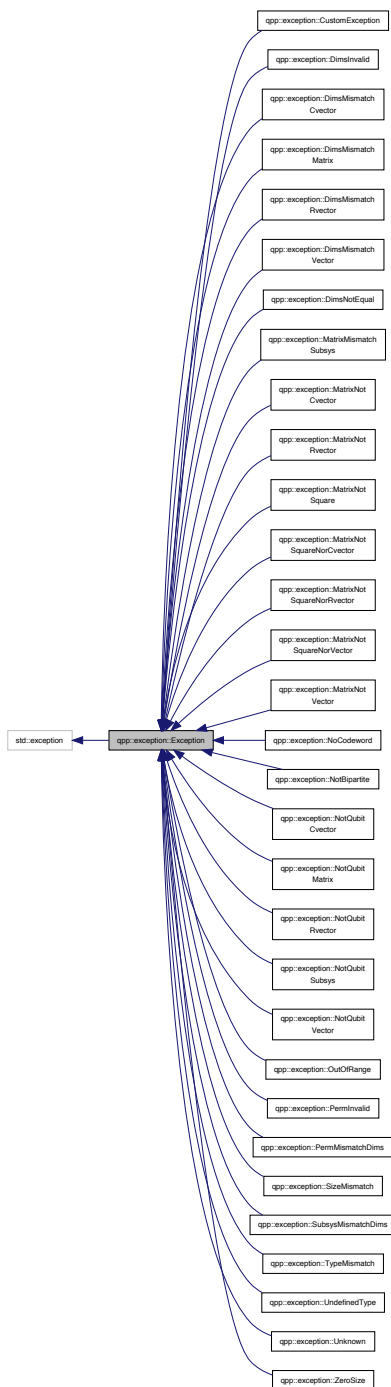


## 7.10 qpp::exception::Exception Class Reference

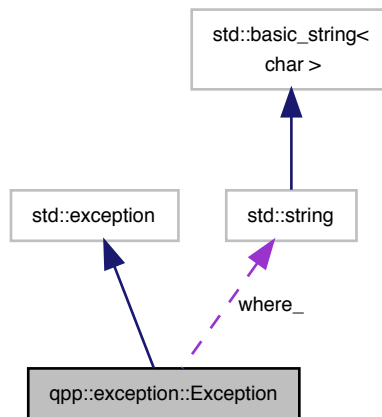
Base class for generating Quantum++ custom exceptions.

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

Inheritance diagram for qpp::exception::Exception:



Collaboration diagram for `qpp::exception::Exception`:



## Public Member Functions

- [Exception](#) (const std::string &where)  
*Constructs an exception.*
- virtual const char \* [what](#) () const noexcept override  
*Overrides std::exception::what()*
- virtual std::string [type\\_description](#) () const =0  
*Exception type description.*

## Private Attributes

- std::string [where\\_](#)

### 7.10.1 Detailed Description

Base class for generating Quantum++ custom exceptions.

Derive from this class if more exceptions are needed, making sure to override [qpp::exception::Exception::type\\_description\(\)](#) in the derived class and to inherit the constructor [qpp::exception::Exception::Exception\(\)](#). Preferably keep your newly defined exception classes in the namespace [qpp::exception](#).

Example:

```

namespace qpp
{
namespace exception
{
    class ZeroSize : public Exception
    {
    public:
        std::string type_description() const override
        {
            return "Object has zero size";
        }

        // inherit the base class' qpp::exception::Exception constructor
        using Exception::Exception;
    };
} // namespace exception
} // namespace qpp
  
```

## 7.10.2 Constructor & Destructor Documentation

### 7.10.2.1 Exception()

```
qpp::exception::Exception::Exception (
    const std::string & where ) [inline]
```

Constructs an exception.

#### Parameters

<i>where</i>	Text representing where the exception occurred
--------------	--

## 7.10.3 Member Function Documentation

### 7.10.3.1 type\_description()

```
std::string qpp::exception::Exception::type_description ( ) const [inline], [pure virtual]
```

[Exception](#) type description.

#### Returns

[Exception](#) type description

Implemented in [qpp::exception::CustomException](#), [qpp::exception::UndefinedType](#), [qpp::exception::SizeMismatch](#), [qpp::exception::TypeMismatch](#), [qpp::exception::OutOfRange](#), [qpp::exception::NoCodeword](#), [qpp::exception::NotBipartite](#), [qpp::exception::NotQubitSubsys](#), [qpp::exception::NotQubitVector](#), [qpp::exception::NotQubitRvector](#), [qpp::exception::NotQubitCvector](#), [qpp::exception::NotQubitMatrix](#), [qpp::exception::PermMismatchDims](#), [qpp::exception::PermInvalid](#), [qpp::exception::SubsysMismatchDims](#), [qpp::exception::DimsMismatchVector](#), [qpp::exception::DimsMismatchRvector](#), [qpp::exception::DimsMismatchCvector](#), [qpp::exception::DimsMismatchMatrix](#), [qpp::exception::DimsNotEqual](#), [qpp::exception::DimsInvalid](#), [qpp::exception::MatrixMismatchSubsys](#), [qpp::exception::MatrixNotSquareNorVector](#), [qpp::exception::MatrixNotSquareNorRvector](#), [qpp::exception::MatrixNotSquareNorCvector](#), [qpp::exception::MatrixNotVector](#), [qpp::exception::MatrixNotRvector](#), [qpp::exception::MatrixNotCvector](#), [qpp::exception::MatrixNotSquare](#), [qpp::exception::ZeroSize](#), and [qpp::exception::Unknown](#).

### 7.10.3.2 what()

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

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

#### Returns

[Exception](#) description

## 7.10.4 Member Data Documentation

### 7.10.4.1 where\_

```
std::string qpp::exception::Exception::where_ [private]
```

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

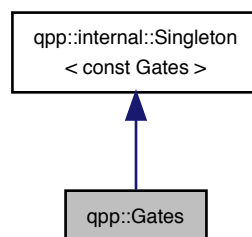
- [classes/exception.h](#)

## 7.11 qpp::Gates Class Reference

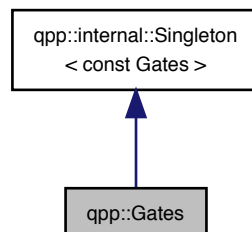
const Singleton class that implements most commonly used gates

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

Inheritance diagram for qpp::Gates:



Collaboration diagram for qpp::Gates:



## Public Member Functions

- [cmat Rn](#) (double theta, const std::vector< double > &n) const  
*Qubit rotation of theta about the 3-dimensional real (unit) vector n.*
- [cmat Zd](#) (idx D=2) const  
*Generalized Z gate for qudits.*
- [cmat Fd](#) (idx D=2) const  
*Fourier transform gate for qudits.*
- [cmat Xd](#) (idx D=2) const  
*Generalized X gate for qudits.*
- template<typename Derived = Eigen::MatrixXcd>  
Derived [Id](#) (idx D=2) 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.*
- template<typename Derived >  
[dyn\\_mat](#)< typename Derived::Scalar > [expandout](#) (const Eigen::MatrixBase< Derived > &A, idx pos, const std::initializer\_list< idx > &dims) const  
*Expands out.*
- template<typename Derived >  
[dyn\\_mat](#)< typename Derived::Scalar > [expandout](#) (const Eigen::MatrixBase< Derived > &A, idx pos, idx N, idx d=2) 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.*

- [~Gates](#) ()=default

*Default destructor.*

## Friends

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

## Additional Inherited Members

### 7.11.1 Detailed Description

const Singleton class that implements most commonly used gates

### 7.11.2 Constructor & Destructor Documentation

#### 7.11.2.1 Gates()

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

Initializes the gates.

#### 7.11.2.2 ~Gates()

```
qpp::Gates::~Gates ( ) [private], [default]
```

Default destructor.

### 7.11.3 Member Function Documentation

#### 7.11.3.1 CTRL()

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

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

See also

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

Note

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

Parameters

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

Returns

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

#### 7.11.3.2 expandout() [1/3]

```
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](#)( $I, I, \dots, I, A, I, \dots, I$ ).

## Parameters

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

## Returns

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

7.11.3.3 `expandout()` [2/3]

```
template<typename Derived >
dyn_mat<typename Derived::Scalar> qpp::Gates::expandout (
    const Eigen::MatrixBase< Derived > & A,
    idx pos,
    const std::initializer_list< 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\(I, I, ..., I, A, I, ..., I\)](#).

## Note

The `std::initializer_list` overload exists because otherwise, in the degenerate case when *dims* has only one element, the one element list is implicitly converted to the element's underlying type, i.e. [qpp::idx](#), which has the net effect of picking the wrong (non-vector) `qpp::expandout()` overload

## Parameters

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

## Returns

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



## 7.11.3.4 expandout() [3/3]

```
template<typename Derived >
dyn_mat<typename Derived::Scalar> qpp::Gates::expandout (
    const Eigen::MatrixBase< Derived > & A,
    idx pos,
    idx N,
    idx d = 2 ) 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
$N$	Number of subsystems
$d$	Subsystem dimension

## Returns

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

## 7.11.3.5 Fd()

```
cmat qpp::Gates::Fd (
    idx D = 2 ) const [inline]
```

Fourier transform gate for qudits.

## Note

Defined as  $F = \sum_{j,k=0}^{D-1} \exp(2\pi i j k / D) |j\rangle \langle k|$

## Parameters

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

## Returns

Fourier transform gate for qudits

### 7.11.3.6 Id()

```
template<typename Derived = Eigen::MatrixXcd>
Derived qpp::Gates::Id (
    idx  $D = 2$  ) 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 on a Hilbert space of dimension  $D$

### 7.11.3.7 Rn()

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

Qubit rotation of  $\theta$  about the 3-dimensional real (unit) vector  $n$ .

#### Parameters

$\theta$	Rotation angle
$n$	3-dimensional real (unit) vector

#### Returns

Rotation gate

### 7.11.3.8 Xd()

```
cmat qpp::Gates::Xd (
    idx  $D = 2$  ) const [inline]
```

Generalized X gate for qudits.

**Note**

Defined as  $X = \sum_{j=0}^{D-1} |j \oplus 1\rangle\langle j|$ , i.e. raising operator  $X|j\rangle = |j \oplus 1\rangle$

**Parameters**

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

**Returns**

Generalized X gate for qudits

**7.11.3.9 Zd()**

```
cmat qpp::Gates::Zd (
    idx D = 2 ) const [inline]
```

Generalized Z gate for qudits.

**Note**

Defined as  $Z = \sum_{j=0}^{D-1} \exp(2\pi i j/D) |j\rangle\langle j|$

**Parameters**

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

**Returns**

Generalized Z gate for qudits

**7.11.4 Friends And Related Function Documentation****7.11.4.1 internal::Singleton< const Gates >**

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

**7.11.5 Member Data Documentation**

#### 7.11.5.1 CNOT

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

Controlled-NOT control target gate.

#### 7.11.5.2 CNOTba

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

Controlled-NOT target control gate.

#### 7.11.5.3 CZ

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

Controlled-Phase gate.

#### 7.11.5.4 FRED

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

Fredkin gate.

#### 7.11.5.5 H

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

Hadamard gate.

#### 7.11.5.6 Id2

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

Identity gate.

#### 7.11.5.7 S

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

S gate.

#### 7.11.5.8 SWAP

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

SWAP gate.

#### 7.11.5.9 T

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

T gate.

#### 7.11.5.10 TOF

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

Toffoli gate.

#### 7.11.5.11 X

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

Pauli Sigma-X gate.

#### 7.11.5.12 Y

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

Pauli Sigma-Y gate.

## 7.11.5.13 Z

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

Pauli Sigma-Z gate.

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

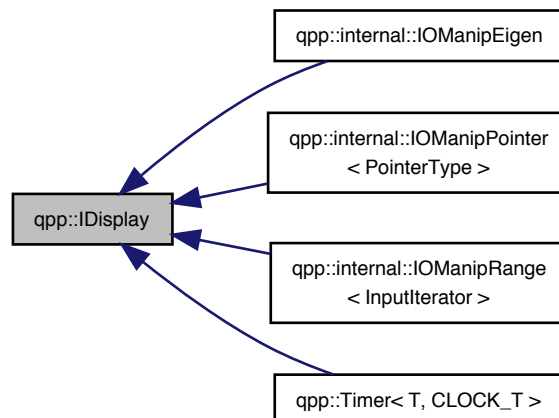
- [classes/gates.h](#)

## 7.12 qpp::IDisplay Class Reference

Abstract class (interface) that mandates the definition of virtual `std::ostream& display(std::ostream& os) const`.

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

Inheritance diagram for qpp::IDisplay:



## Public Member Functions

- `IDisplay()`=default  
*Default constructor.*
- `IDisplay(const IDisplay &)=default`  
*Default copy constructor.*
- `IDisplay(IDisplay &&)=default`  
*Default move constructor.*
- `IDisplay & operator= (const IDisplay &)=default`  
*Default copy assignment operator.*
- `IDisplay & operator= (IDisplay &&)=default`  
*Default move assignment operator.*
- `virtual ~IDisplay()`=default  
*Default virtual destructor.*

## Private Member Functions

- virtual std::ostream & [display](#) (std::ostream &os) const =0  
*Must be overridden by all derived classes.*

## Friends

- std::ostream & [operator<<](#) (std::ostream &os, const [IDisplay](#) &rhs)  
*Overloads the extraction operator.*

### 7.12.1 Detailed Description

Abstract class (interface) that mandates the definition of virtual std::ostream& [display](#)(std::ostream& os) const.

This class defines friend inline std::ostream& operator<< (std::ostream& os, const [qpp::IDisplay](#)& rhs). The latter delegates the work to the pure private virtual function [qpp::IDisplay::display\(\)](#) which has to be overridden by all derived classes.

### 7.12.2 Constructor & Destructor Documentation

#### 7.12.2.1 IDisplay() [1/3]

```
qpp::IDisplay::IDisplay ( ) [default]
```

Default constructor.

#### 7.12.2.2 IDisplay() [2/3]

```
qpp::IDisplay::IDisplay (
    const IDisplay & ) [default]
```

Default copy constructor.

#### 7.12.2.3 IDisplay() [3/3]

```
qpp::IDisplay::IDisplay (
    IDisplay && ) [default]
```

Default move constructor.

#### 7.12.2.4 ~IDisplay()

```
virtual qpp::IDisplay::~~IDisplay ( ) [virtual], [default]
```

Default virtual destructor.

### 7.12.3 Member Function Documentation

#### 7.12.3.1 display()

```
virtual std::ostream& qpp::IDisplay::display (
    std::ostream & os ) const [private], [pure virtual]
```

Must be overridden by all derived classes.

The actual stream extraction processing is performed by the overridden member function in the derived class. This function is automatically invoked by friend inline `std::ostream& operator<<(std::ostream& os, const IDisplay& rhs)`.

Implemented in [qpp::internal::IOManipEigen](#), [qpp::Timer< T, CLOCK\\_T >](#), [qpp::internal::IOManipPointer< PointerType >](#), and [qpp::internal::IOManipRange< InputIterator >](#).

#### 7.12.3.2 operator=() [1/2]

```
IDisplay& qpp::IDisplay::operator= (
    const IDisplay & ) [default]
```

Default copy assignment operator.

#### 7.12.3.3 operator=() [2/2]

```
IDisplay& qpp::IDisplay::operator= (
    IDisplay && ) [default]
```

Default move assignment operator.

### 7.12.4 Friends And Related Function Documentation



## 7.12.4.1 operator&lt;&lt;

```
std::ostream& operator<< (
    std::ostream & os,
    const IDisplay & rhs ) [friend]
```

Overloads the extraction operator.

Delegates the work to the virtual function [qpp::IDisplay::display\(\)](#)

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

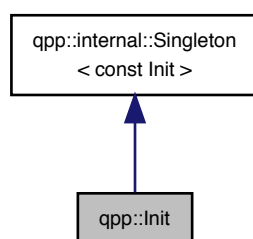
- [classes/ideplay.h](#)

## 7.13 qpp::Init Class Reference

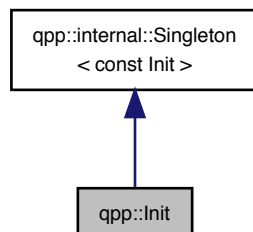
const Singleton class that performs additional initializations/cleanups

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

Inheritance diagram for qpp::Init:



Collaboration diagram for qpp::Init:



## Private Member Functions

- [Init](#) ()  
*Additional initializations.*
- [~Init](#) ()  
*Cleanups.*

## Friends

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

## Additional Inherited Members

### 7.13.1 Detailed Description

const Singleton class that performs additional initializations/cleanups

### 7.13.2 Constructor & Destructor Documentation

#### 7.13.2.1 Init()

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

Additional initializations.

#### 7.13.2.2 ~Init()

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

Cleanups.

### 7.13.3 Friends And Related Function Documentation

#### 7.13.3.1 internal::Singleton< const Init >

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

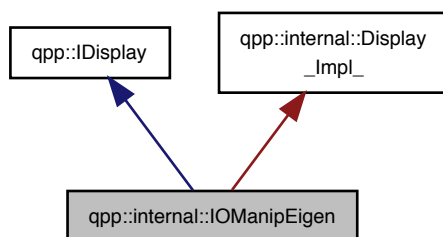
The documentation for this class was generated from the following file:

- [classes/init.h](#)

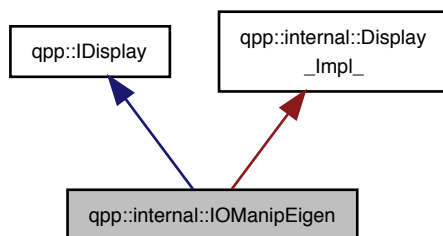
## 7.14 qpp::internal::IOManipEigen Class Reference

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

Inheritance diagram for qpp::internal::IOManipEigen:



Collaboration diagram for qpp::internal::IOManipEigen:



### 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 Member Functions

- `std::ostream & display` (`std::ostream &os`) const override  
*Must be overridden by all derived classes.*

## Private Attributes

- [cmat A\\_](#)
- double [chop\\_](#)

## 7.14.1 Constructor & Destructor Documentation

### 7.14.1.1 IManipEigen() [1/2]

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

### 7.14.1.2 IManipEigen() [2/2]

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

## 7.14.2 Member Function Documentation

### 7.14.2.1 display()

```
std::ostream& qpp::internal::IManipEigen::display (
    std::ostream & os ) const [inline], [override], [private], [virtual]
```

Must be overridden by all derived classes.

The actual stream extraction processing is performed by the overridden member function in the derived class. This function is automatically invoked by friend inline `std::ostream& operator<<(std::ostream& os, const IDisplay& rhs)`.

Implements [qpp::IDisplay](#).

## 7.14.3 Member Data Documentation

## 7.14.3.1 A\_

```
cmat qpp::internal::IOManipEigen::A_ [private]
```

## 7.14.3.2 chop\_

```
double qpp::internal::IOManipEigen::chop_ [private]
```

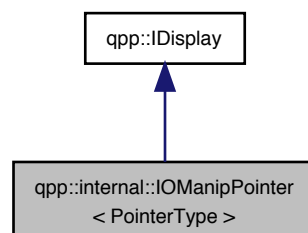
The documentation for this class was generated from the following file:

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

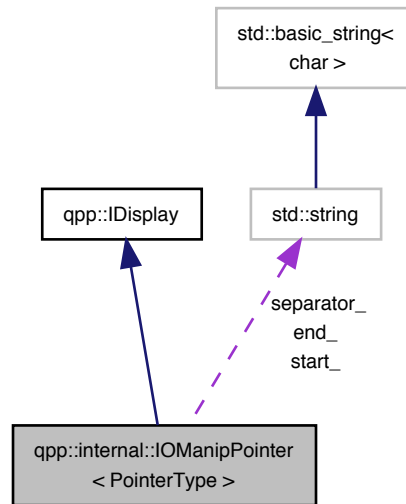
## 7.15 qpp::internal::IOManipPointer&lt; PointerType &gt; Class Template Reference

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

Inheritance diagram for qpp::internal::IOManipPointer< PointerType >:



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



## Public Member Functions

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

## Private Member Functions

- `std::ostream & display` (std::ostream &os) const override  
*Must be overridden by all derived classes.*

## Private Attributes

- const PointerType \* `p_`
- idx `N_`
- std::string `separator_`
- std::string `start_`
- std::string `end_`

### 7.15.1 Constructor & Destructor Documentation

## 7.15.1.1 IOManipPointer() [1/2]

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

## 7.15.1.2 IOManipPointer() [2/2]

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

## 7.15.2 Member Function Documentation

## 7.15.2.1 display()

```
template<typename PointerType>
std::ostream& qpp::internal::IOManipPointer< PointerType >::display (
    std::ostream & os ) const [inline], [override], [private], [virtual]
```

Must be overridden by all derived classes.

The actual stream extraction processing is performed by the overridden member function in the derived class. This function is automatically invoked by friend inline `std::ostream& operator<<(std::ostream& os, const IDisplay& rhs)`.

Implements [qpp::IDisplay](#).

## 7.15.2.2 operator=()

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

## 7.15.3 Member Data Documentation

#### 7.15.3.1 end\_

```
template<typename PointerType>
std::string qpp::internal::IManipPointer< PointerType >::end_ [private]
```

#### 7.15.3.2 N\_

```
template<typename PointerType>
idx qpp::internal::IManipPointer< PointerType >::N_ [private]
```

#### 7.15.3.3 p\_

```
template<typename PointerType>
const PointerType* qpp::internal::IManipPointer< PointerType >::p_ [private]
```

#### 7.15.3.4 separator\_

```
template<typename PointerType>
std::string qpp::internal::IManipPointer< PointerType >::separator_ [private]
```

#### 7.15.3.5 start\_

```
template<typename PointerType>
std::string qpp::internal::IManipPointer< PointerType >::start_ [private]
```

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

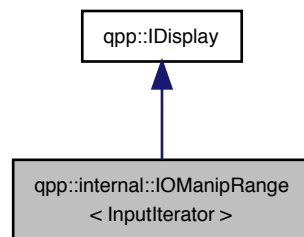
- [internal/classes/iomanip.h](#)



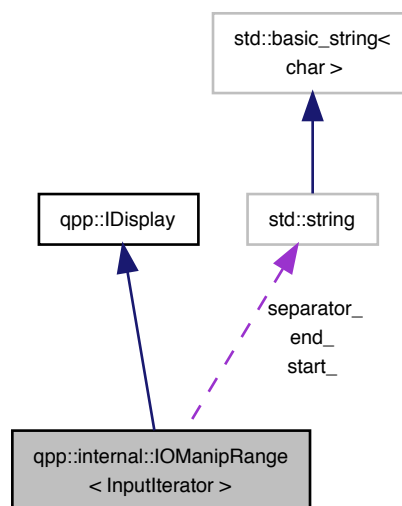
## 7.16 qpp::internal::IOManipRange< InputIterator > Class Template Reference

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

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



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="]")
- [IOManipRange](#) (const [IOManipRange](#) &)=default
- [IOManipRange](#) & [operator=](#) (const [IOManipRange](#) &)=default

## Private Member Functions

- `std::ostream & display (std::ostream &os)` const override  
*Must be overridden by all derived classes.*

## Private Attributes

- InputIterator `first_`
- InputIterator `last_`
- `std::string` `separator_`
- `std::string` `start_`
- `std::string` `end_`

## 7.16.1 Constructor & Destructor Documentation

### 7.16.1.1 IOManipRange() [1/2]

```
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]
```

### 7.16.1.2 IOManipRange() [2/2]

```
template<typename InputIterator>
qpp::internal::IOManipRange< InputIterator >::IOManipRange (
    const IOManipRange< InputIterator > & ) [default]
```

## 7.16.2 Member Function Documentation

### 7.16.2.1 display()

```
template<typename InputIterator>
std::ostream& qpp::internal::IOManipRange< InputIterator >::display (
    std::ostream & os ) const [inline], [override], [private], [virtual]
```

Must be overridden by all derived classes.

The actual stream extraction processing is performed by the overridden member function in the derived class. This function is automatically invoked by friend inline `std::ostream& operator<<(std::ostream& os, const IDisplay& rhs)`.

Implements `qpp::IDisplay`.

### 7.16.2.2 operator=()

```
template<typename InputIterator>
IOManipRange& qpp::internal::IOManipRange< InputIterator >::operator= (
    const IOManipRange< InputIterator > & ) [default]
```

## 7.16.3 Member Data Documentation

### 7.16.3.1 end\_

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

### 7.16.3.2 first\_

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

### 7.16.3.3 last\_

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

### 7.16.3.4 separator\_

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

### 7.16.3.5 start\_

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

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

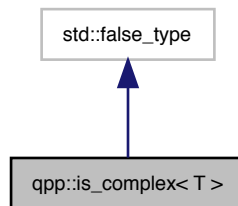
- [internal/classes/iomanip.h](#)

## 7.17 qpp::is\_complex< T > Struct Template Reference

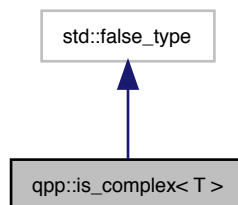
Checks whether the type is a complex type.

```
#include <traits.h>
```

Inheritance diagram for qpp::is\_complex< T >:



Collaboration diagram for qpp::is\_complex< T >:



### 7.17.1 Detailed Description

```
template<typename T>  
struct qpp::is_complex< T >
```

Checks whether the type is a complex type.

Provides the constant member *value* which is equal to *true*, if the type is a complex type, i.e. *std::complex< T >*

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

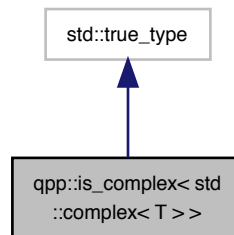
- [traits.h](#)

## 7.18 qpp::is\_complex< std::complex< T > > Struct Template Reference

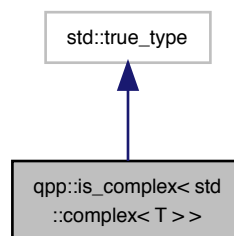
Checks whether the type is a complex number type, specialization for complex types.

```
#include <traits.h>
```

Inheritance diagram for qpp::is\_complex< std::complex< T > >:



Collaboration diagram for qpp::is\_complex< std::complex< T > >:



### 7.18.1 Detailed Description

```
template<typename T>  
struct qpp::is_complex< std::complex< T > >
```

Checks whether the type is a complex number type, specialization for complex types.

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

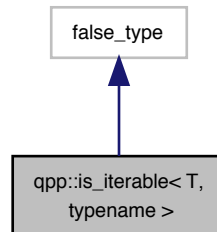
- [traits.h](#)

## 7.19 qpp::is\_iterable< T, typename > Struct Template Reference

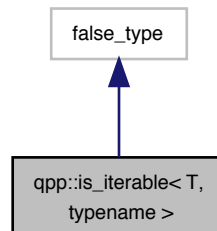
Checks whether *T* is compatible with an STL-like iterable container.

```
#include <traits.h>
```

Inheritance diagram for `qpp::is_iterable< T, typename >`:



Collaboration diagram for `qpp::is_iterable< T, typename >`:



### 7.19.1 Detailed Description

```
template<typename T, typename = void>  
struct qpp::is_iterable< T, typename >
```

Checks whether *T* is compatible with an STL-like iterable container.

Provides the constant member *value* which is equal to *true*, if *T* is compatible with an iterable container, i.e. provides at least *begin()* and *end()* member functions. Otherwise, *value* is equal to *false*.

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

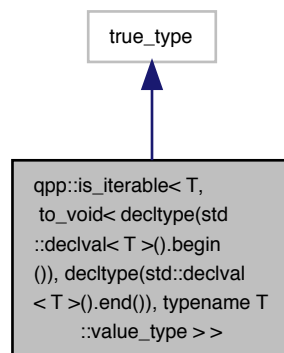
- [traits.h](#)

## 7.20 `qpp::is_iterable< T, to_void< decltype(std::declval< T >().begin()), decltype(std::declval< T >().end()), typename T::value_type > >` Struct Template Reference

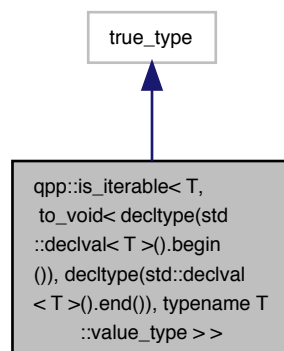
Checks whether *T* is compatible with an STL-like iterable container, specialization for STL-like iterable containers.

```
#include <traits.h>
```

Inheritance diagram for `qpp::is_iterable< T, to_void< decltype(std::declval< T >().begin()), decltype(std::declval< T >().end()), typename T::value_type > >`:



Collaboration diagram for `qpp::is_iterable< T, to_void< decltype(std::declval< T >().begin()), decltype(std::declval< T >().end()), typename T::value_type > >`:



### 7.20.1 Detailed Description

```
template<typename T>
struct qpp::is_iterable< T, to_void< decltype(std::declval< T >().begin()), decltype(std::declval< T >().end()), typename T::value_type > >
```

Checks whether *T* is compatible with an STL-like iterable container, specialization for STL-like iterable containers.

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

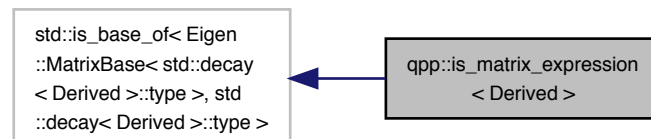
- [traits.h](#)

## 7.21 qpp::is\_matrix\_expression< Derived > Struct Template Reference

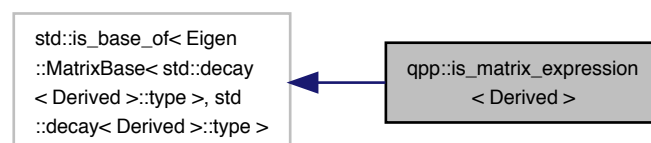
Checks whether the type is an Eigen matrix expression.

```
#include <traits.h>
```

Inheritance diagram for qpp::is\_matrix\_expression< Derived >:



Collaboration diagram for qpp::is\_matrix\_expression< Derived >:





### 7.21.1 Detailed Description

```
template<typename Derived>
struct qpp::is_matrix_expression< Derived >
```

Checks whether the type is an Eigen matrix expression.

Provides the constant member *value* which is equal to *true*, if the type is an Eigen matrix expression of type *EigenMatrixBase<Derived>*. Otherwise, *value* is equal to *false*.

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

- [traits.h](#)

## 7.22 qpp::make\_void< Ts > Struct Template Reference

Helper for [qpp::to\\_void<>](#) alias template.

```
#include <traits.h>
```

### Public Types

- typedef void [type](#)

### 7.22.1 Detailed Description

```
template<typename... Ts>
struct qpp::make_void< Ts >
```

Helper for [qpp::to\\_void<>](#) alias template.

See also

[qpp::to\\_void<>](#)

### 7.22.2 Member Typedef Documentation

#### 7.22.2.1 type

```
template<typename... Ts>
typedef void qpp::make\_void< Ts >::type
```

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

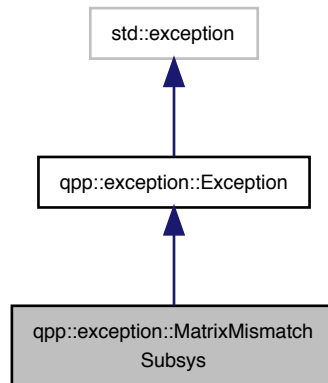
- [traits.h](#)

## 7.23 qpp::exception::MatrixMismatchSubsys Class Reference

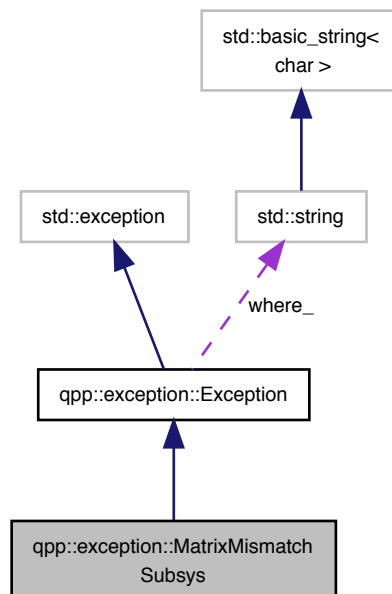
Matrix mismatch subsystems exception.

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

Inheritance diagram for qpp::exception::MatrixMismatchSubsys:



Collaboration diagram for qpp::exception::MatrixMismatchSubsys:



## Public Member Functions

- `std::string type_description ()` const override  
*Exception type description.*

### 7.23.1 Detailed Description

Matrix mismatch subsystems exception.

Matrix size mismatch subsystem sizes (e.g. in `qpp::apply()`)

### 7.23.2 Member Function Documentation

#### 7.23.2.1 `type_description()`

```
std::string qpp::exception::MatrixMismatchSubsys::type_description ( ) const [inline], [override],  
[virtual]
```

*Exception type description.*

#### Returns

*Exception type description*

Implements `qpp::exception::Exception`.

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

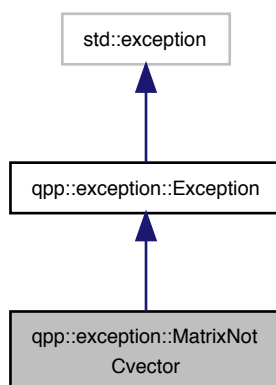
- `classes/exception.h`

## 7.24 `qpp::exception::MatrixNotCvector` Class Reference

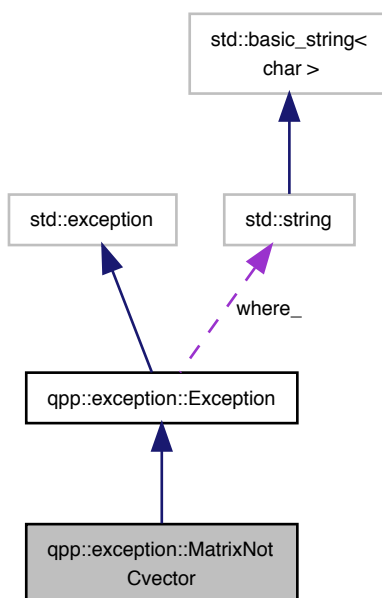
Matrix is not a column vector exception.

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

Inheritance diagram for qpp::exception::MatrixNotCvector:



Collaboration diagram for qpp::exception::MatrixNotCvector:



## Public Member Functions

- `std::string type\_description () const` override  
*[Exception](#) type description.*

### 7.24.1 Detailed Description

Matrix is not a column vector exception.

Eigen::Matrix is not a column vector

### 7.24.2 Member Function Documentation

#### 7.24.2.1 type\_description()

```
std::string qpp::exception::MatrixNotCvector::type_description ( ) const [inline], [override],  
[virtual]
```

Exception type description.

#### Returns

Exception type description

Implements [qpp::exception::Exception](#).

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

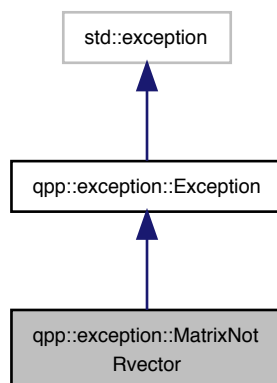
- [classes/exception.h](#)

## 7.25 qpp::exception::MatrixNotRvector Class Reference

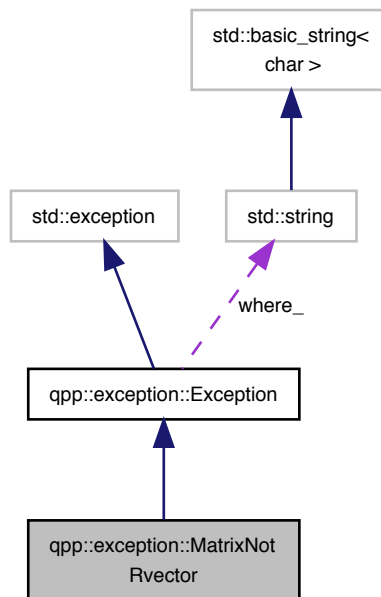
Matrix is not a row vector exception.

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

Inheritance diagram for `qpp::exception::MatrixNotRvector`:



Collaboration diagram for `qpp::exception::MatrixNotRvector`:



## Public Member Functions

- `std::string type_description () const` override  
*Exception type description.*

### 7.25.1 Detailed Description

Matrix is not a row vector exception.

Eigen::Matrix is not a row vector

### 7.25.2 Member Function Documentation

#### 7.25.2.1 type\_description()

```
std::string qpp::exception::MatrixNotRvector::type_description ( ) const [inline], [override], [virtual]
```

*Exception type description.*

## Returns

[Exception](#) type description

Implements [qpp::exception::Exception](#).

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

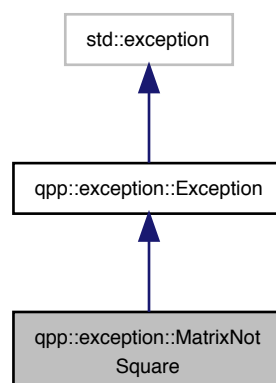
- [classes/exception.h](#)

## 7.26 qpp::exception::MatrixNotSquare Class Reference

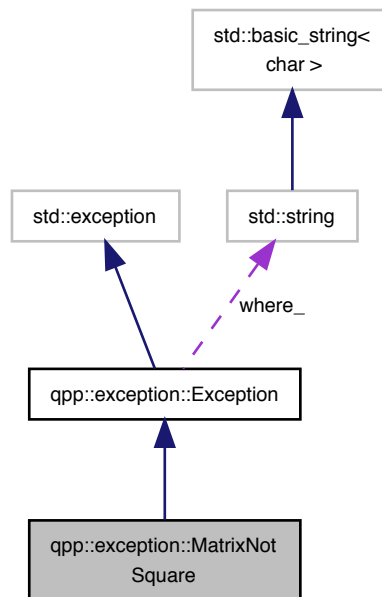
Matrix is not square exception.

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

Inheritance diagram for qpp::exception::MatrixNotSquare:



Collaboration diagram for qpp::exception::MatrixNotSquare:



## Public Member Functions

- `std::string type_description () const` override  
*Exception type description.*

### 7.26.1 Detailed Description

Matrix is not square exception.

Eigen::Matrix is not a square matrix

### 7.26.2 Member Function Documentation

#### 7.26.2.1 type\_description()

```
std::string qpp::exception::MatrixNotSquare::type_description ( ) const [inline], [override], [virtual]
```

*Exception type description.*



## Returns

[Exception](#) type description

Implements [qpp::exception::Exception](#).

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

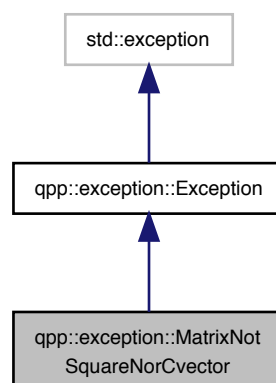
- [classes/exception.h](#)

## 7.27 qpp::exception::MatrixNotSquareNorCvector Class Reference

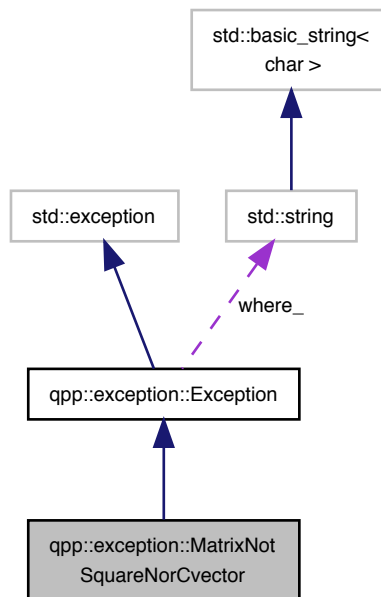
Matrix is not square nor column vector exception.

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

Inheritance diagram for qpp::exception::MatrixNotSquareNorCvector:



Collaboration diagram for `qpp::exception::MatrixNotSquareNorCvector`:



## Public Member Functions

- `std::string type_description () const` override  
*Exception type description.*

### 7.27.1 Detailed Description

Matrix is not square nor column vector exception.

Eigen::Matrix is not a square matrix nor a column vector

### 7.27.2 Member Function Documentation

#### 7.27.2.1 type\_description()

```
std::string qpp::exception::MatrixNotSquareNorCvector::type_description ( ) const [inline],
[override], [virtual]
```

*Exception type description.*

## Returns

[Exception](#) type description

Implements [qpp::exception::Exception](#).

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

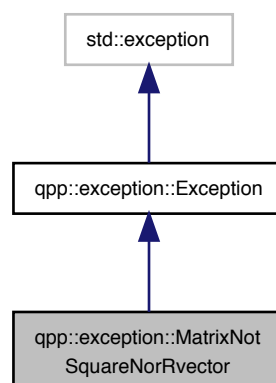
- [classes/exception.h](#)

## 7.28 qpp::exception::MatrixNotSquareNorRvector Class Reference

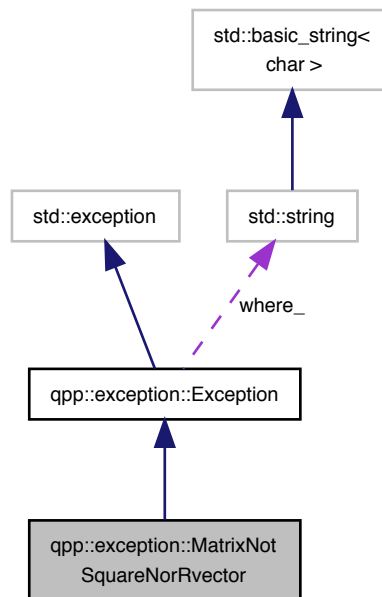
Matrix is not square nor row vector exception.

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

Inheritance diagram for qpp::exception::MatrixNotSquareNorRvector:



Collaboration diagram for `qpp::exception::MatrixNotSquareNorRvector`:



## Public Member Functions

- `std::string type_description () const` override  
*Exception type description.*

### 7.28.1 Detailed Description

Matrix is not square nor row vector exception.

Eigen::Matrix is not a square matrix nor a row vector

### 7.28.2 Member Function Documentation

#### 7.28.2.1 type\_description()

```
std::string qpp::exception::MatrixNotSquareNorRvector::type_description ( ) const [inline],
[override], [virtual]
```

*Exception type description.*

## Returns

[Exception](#) type description

Implements [qpp::exception::Exception](#).

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

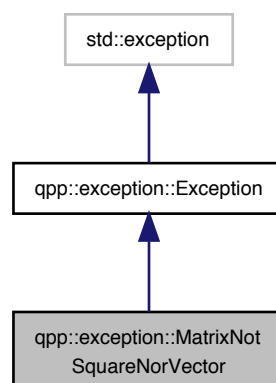
- [classes/exception.h](#)

## 7.29 qpp::exception::MatrixNotSquareNorVector Class Reference

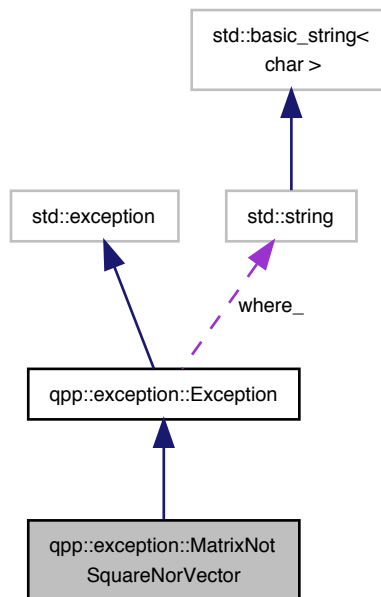
Matrix is not square nor vector exception.

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

Inheritance diagram for qpp::exception::MatrixNotSquareNorVector:



Collaboration diagram for `qpp::exception::MatrixNotSquareNorVector`:



## Public Member Functions

- `std::string type_description () const` override  
*Exception type description.*

### 7.29.1 Detailed Description

Matrix is not square nor vector exception.

Eigen::Matrix is not a square matrix nor a row/column vector

### 7.29.2 Member Function Documentation

#### 7.29.2.1 type\_description()

```
std::string qpp::exception::MatrixNotSquareNorVector::type_description ( ) const [inline],
[override], [virtual]
```

*Exception type description.*

## Returns

[Exception](#) type description

Implements [qpp::exception::Exception](#).

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

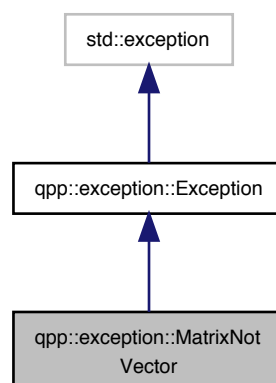
- [classes/exception.h](#)

## 7.30 qpp::exception::MatrixNotVector Class Reference

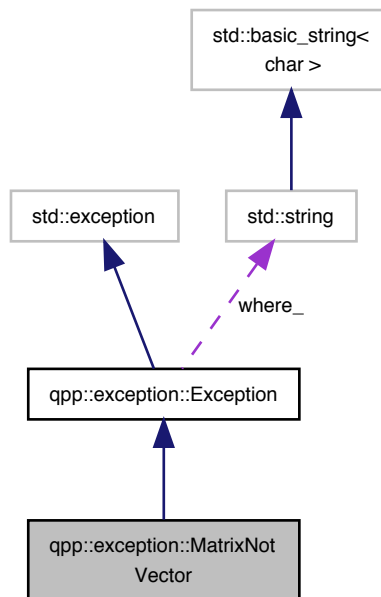
Matrix is not a vector exception.

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

Inheritance diagram for qpp::exception::MatrixNotVector:



Collaboration diagram for qpp::exception::MatrixNotVector:



## Public Member Functions

- `std::string type_description () const` override  
*Exception type description.*

### 7.30.1 Detailed Description

Matrix is not a vector exception.

Eigen::Matrix is not a row or column vector

### 7.30.2 Member Function Documentation

#### 7.30.2.1 type\_description()

```
std::string qpp::exception::MatrixNotVector::type_description ( ) const [inline], [override], [virtual]
```

*Exception type description.*



## Returns

[Exception](#) type description

Implements [qpp::exception::Exception](#).

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

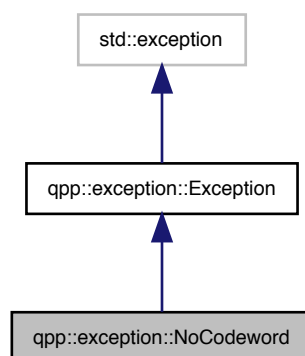
- [classes/exception.h](#)

## 7.31 qpp::exception::NoCodeword Class Reference

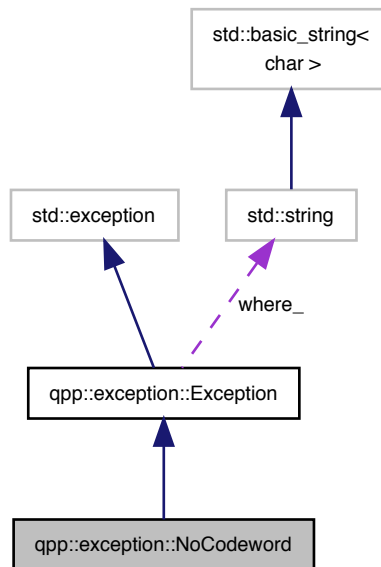
Codeword does not exist exception.

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

Inheritance diagram for qpp::exception::NoCodeword:



Collaboration diagram for `qpp::exception::NoCodeword`:



## Public Member Functions

- `std::string type_description ()` const override  
*Exception type description.*

### 7.31.1 Detailed Description

Codeword does not exist exception.

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

### 7.31.2 Member Function Documentation

#### 7.31.2.1 type\_description()

```
std::string qpp::exception::NoCodeword::type_description ( ) const [inline], [override],
[virtual]
```

*Exception type description.*

#### Returns

*Exception type description*

Implements `qpp::exception::Exception`.

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

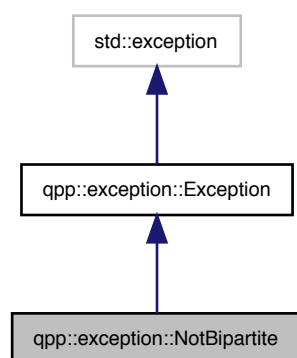
- `classes/exception.h`

## 7.32 qpp::exception::NotBipartite Class Reference

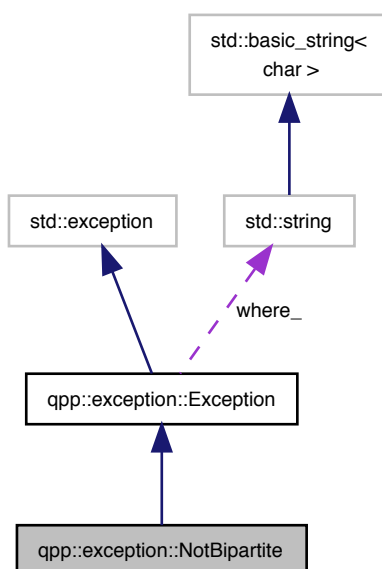
Not bi-partite exception.

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

Inheritance diagram for qpp::exception::NotBipartite:



Collaboration diagram for qpp::exception::NotBipartite:



## Public Member Functions

- `std::string type\_description () const` override  
*[Exception](#) type description.*

### 7.32.1 Detailed Description

Not bi-partite exception.

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

### 7.32.2 Member Function Documentation

#### 7.32.2.1 `type_description()`

```
std::string qpp::exception::NotBipartite::type_description ( ) const [inline], [override],
[virtual]
```

[Exception](#) type description.

#### Returns

[Exception](#) type description

Implements [qpp::exception::Exception](#).

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

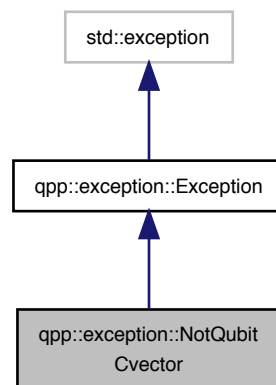
- `classes/exception.h`

## 7.33 `qpp::exception::NotQubitCvector` Class Reference

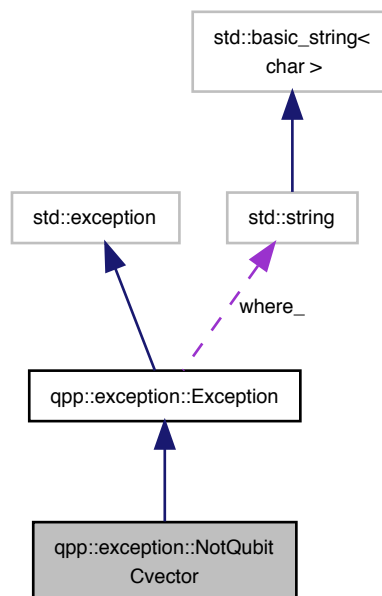
Column vector is not 2 x 1 exception.

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

Inheritance diagram for qpp::exception::NotQubitCvector:



Collaboration diagram for qpp::exception::NotQubitCvector:



## Public Member Functions

- `std::string` [type\\_description](#) () const override  
*[Exception](#) type description.*

### 7.33.1 Detailed Description

Column vector is not 2 x 1 exception.

Eigen::Matrix is not 2 x 1

### 7.33.2 Member Function Documentation

#### 7.33.2.1 type\_description()

```
std::string qpp::exception::NotQubitCvector::type_description ( ) const [inline], [override],  
[virtual]
```

[Exception](#) type description.

#### Returns

[Exception](#) type description

Implements [qpp::exception::Exception](#).

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

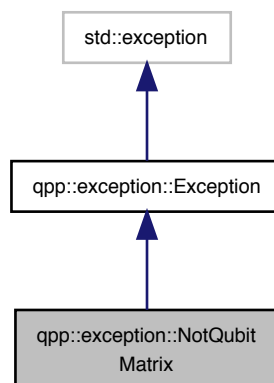
- [classes/exception.h](#)

## 7.34 qpp::exception::NotQubitMatrix Class Reference

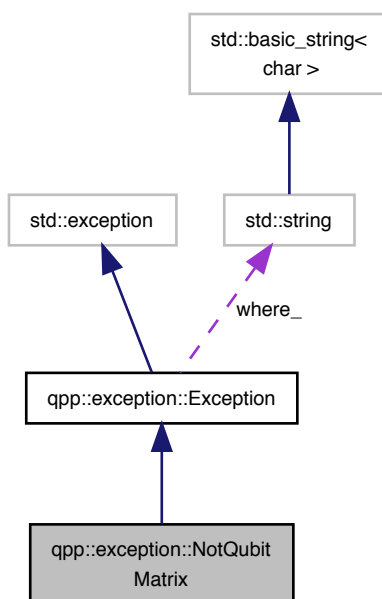
Matrix is not 2 x 2 exception.

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

Inheritance diagram for qpp::exception::NotQubitMatrix:



Collaboration diagram for qpp::exception::NotQubitMatrix:



## Public Member Functions

- `std::string type_description () const` override  
*Exception type description.*

### 7.34.1 Detailed Description

Matrix is not 2 x 2 exception.

Eigen::Matrix is not 2 x 2

### 7.34.2 Member Function Documentation

#### 7.34.2.1 type\_description()

```
std::string qpp::exception::NotQubitMatrix::type_description ( ) const [inline], [override], [virtual]
```

*Exception type description.*

**Returns**

[Exception](#) type description

Implements [qpp::exception::Exception](#).

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

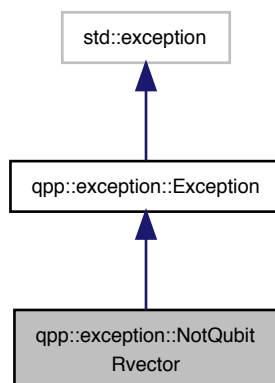
- [classes/exception.h](#)

## 7.35 qpp::exception::NotQubitRvector Class Reference

Row vector is not 1 x 2 exception.

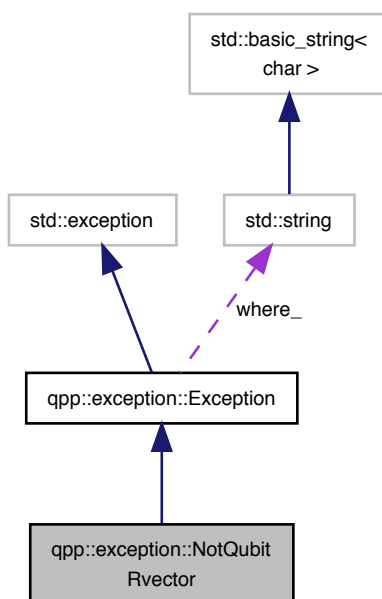
```
#include <classes/exception.h>
```

Inheritance diagram for qpp::exception::NotQubitRvector:





Collaboration diagram for qpp::exception::NotQubitRvector:



## Public Member Functions

- `std::string type_description () const` override  
*Exception type description.*

### 7.35.1 Detailed Description

Row vector is not 1 x 2 exception.

Eigen::Matrix is not 1 x 2

### 7.35.2 Member Function Documentation

#### 7.35.2.1 type\_description()

```
std::string qpp::exception::NotQubitRvector::type_description ( ) const [inline], [override], [virtual]
```

*Exception type description.*

**Returns**

[Exception](#) type description

Implements [qpp::exception::Exception](#).

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

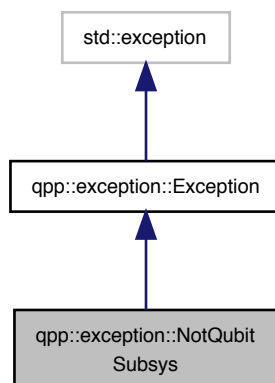
- [classes/exception.h](#)

## 7.36 qpp::exception::NotQubitSubsys Class Reference

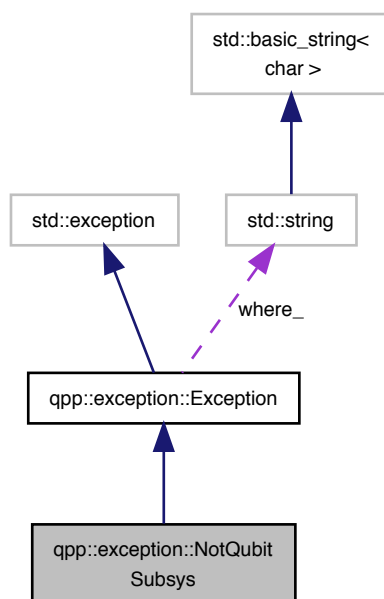
Subsystems are not qubits exception.

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

Inheritance diagram for qpp::exception::NotQubitSubsys:



Collaboration diagram for qpp::exception::NotQubitSubsys:



## Public Member Functions

- `std::string type_description () const` override  
*Exception type description.*

### 7.36.1 Detailed Description

Subsystems are not qubits exception.

Subsystems are not 2-dimensional (qubits)

### 7.36.2 Member Function Documentation

#### 7.36.2.1 type\_description()

```
std::string qpp::exception::NotQubitSubsys::type_description ( ) const [inline], [override], [virtual]
```

*Exception type description.*

## Returns

[Exception](#) type description

Implements [qpp::exception::Exception](#).

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

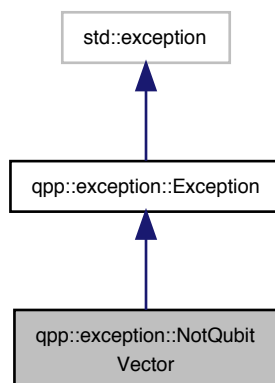
- [classes/exception.h](#)

### 7.37 qpp::exception::NotQubitVector Class Reference

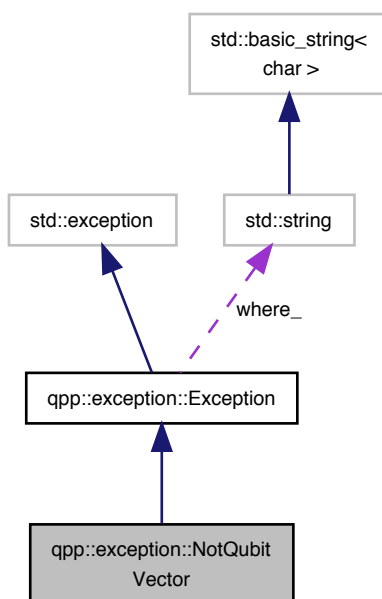
Vector is not 2 x 1 nor 1 x 2 exception.

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

Inheritance diagram for qpp::exception::NotQubitVector:



Collaboration diagram for qpp::exception::NotQubitVector:



## Public Member Functions

- `std::string type_description () const` override  
*Exception type description.*

### 7.37.1 Detailed Description

Vector is not 2 x 1 nor 1 x 2 exception.

Eigen::Matrix is not 2 x 1 nor 1 x 2

### 7.37.2 Member Function Documentation

#### 7.37.2.1 type\_description()

```
std::string qpp::exception::NotQubitVector::type_description ( ) const [inline], [override], [virtual]
```

*Exception type description.*

## Returns

[Exception](#) type description

Implements [qpp::exception::Exception](#).

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

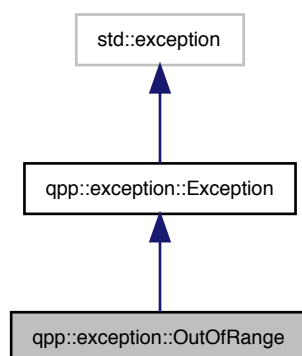
- [classes/exception.h](#)

## 7.38 qpp::exception::OutOfRange Class Reference

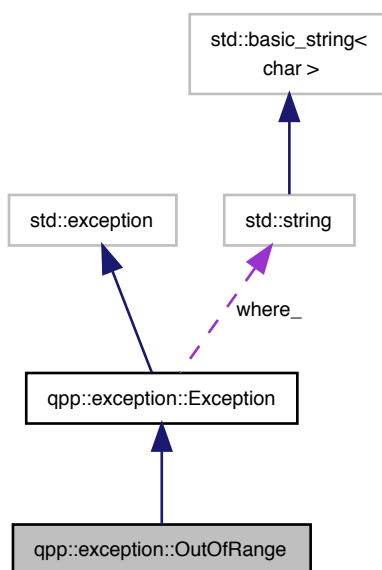
Parameter out of range exception.

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

Inheritance diagram for qpp::exception::OutOfRange:



Collaboration diagram for qpp::exception::OutOfRange:



## Public Member Functions

- `std::string type_description () const` override  
*Exception type description.*

### 7.38.1 Detailed Description

Parameter out of range exception.

Parameter out of range

### 7.38.2 Member Function Documentation

#### 7.38.2.1 type\_description()

```
std::string qpp::exception::OutOfRange::type_description ( ) const [inline], [override],
[virtual]
```

*Exception type description.*

#### Returns

*Exception type description*

Implements `qpp::exception::Exception`.

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

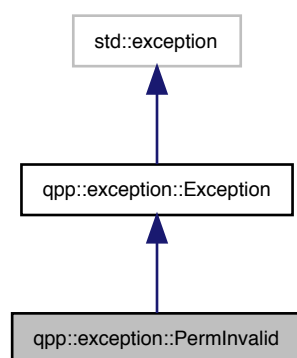
- `classes/exception.h`

### 7.39 qpp::exception::PermlInvalid Class Reference

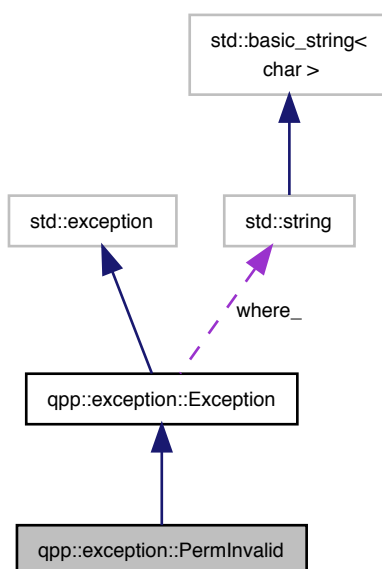
Invalid permutation exception.

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

Inheritance diagram for qpp::exception::PermlInvalid:



Collaboration diagram for qpp::exception::PermlInvalid:





## Public Member Functions

- `std::string type_description ()` const override  
*Exception type description.*

### 7.39.1 Detailed Description

Invalid permutation exception.

`std::vector<idx>` does not represent a valid permutation

### 7.39.2 Member Function Documentation

#### 7.39.2.1 type\_description()

```
std::string qpp::exception::PermInvalid::type_description ( ) const [inline], [override],  
[virtual]
```

*Exception type description.*

#### Returns

*Exception type description*

Implements `qpp::exception::Exception`.

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

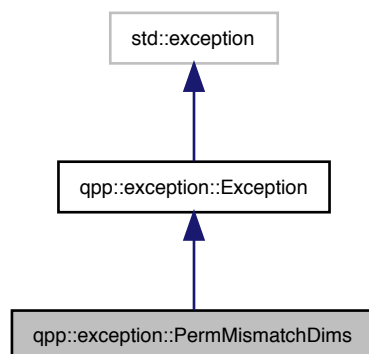
- `classes/exception.h`

## 7.40 qpp::exception::PermMismatchDims Class Reference

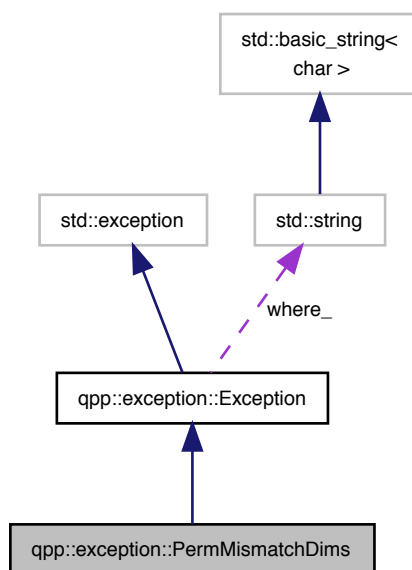
Permutation mismatch dimensions exception.

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

Inheritance diagram for qpp::exception::PermMismatchDims:



Collaboration diagram for qpp::exception::PermMismatchDims:



## Public Member Functions

- `std::string type\_description ()` const override  
*[Exception](#) type description.*

### 7.40.1 Detailed Description

Permutation mismatch dimensions exception.

Size of the `std::vector<idx>` representing the permutation is different from the size of the `std::vector<idx>` of dimensions

### 7.40.2 Member Function Documentation

#### 7.40.2.1 `type_description()`

```
std::string qpp::exception::PermMismatchDims::type_description ( ) const [inline], [override], [virtual]
```

[Exception](#) type description.

Returns

[Exception](#) type description

Implements [qpp::exception::Exception](#).

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

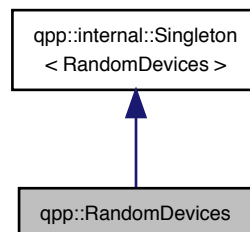
- [classes/exception.h](#)

## 7.41 qpp::RandomDevices Class Reference

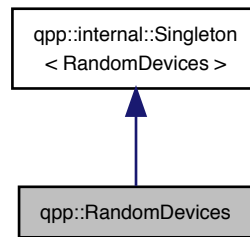
Singleton class that manages the source of randomness in the library.

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

Inheritance diagram for `qpp::RandomDevices`:



Collaboration diagram for `qpp::RandomDevices`:



## Public Member Functions

- `std::mt19937 & get_prng ()`  
*Returns a reference to the internal PRNG object.*
- `std::istream & load (std::istream &is)`  
*Loads the state of the PRNG from an input stream.*
- `std::ostream & save (std::ostream &os) const`  
*Saves the state of the PRNG to an output stream.*

## Private Member Functions

- `RandomDevices ()`  
*Initializes and seeds the random number generators.*
- `~RandomDevices ()=default`  
*Default destructor.*

## Private Attributes

- `std::random_device rd_`  
*used to seed std::mt19937 prng\_*
- `std::mt19937 prng_`  
*Mersenne twister random number generator.*

## Friends

- class `internal::Singleton< RandomDevices >`

## Additional Inherited Members

### 7.41.1 Detailed Description

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

Consists of a wrapper around an `std::mt19937` Mersenne twister random number generator engine and an `std::random_device` engine. The latter is used to seed the Mersenne twister.

#### Warning

This class DOES NOT seed the standard C number generator used by `Eigen::Matrix::Random()`, since it is not thread safe. Do not use `Eigen::Matrix::Random()` or functions that depend on the C style random number engine, but use `qpp::rand()` instead!

### 7.41.2 Constructor & Destructor Documentation

#### 7.41.2.1 RandomDevices()

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

Initializes and seeds the random number generators.

#### 7.41.2.2 ~RandomDevices()

```
qpp::RandomDevices::~~RandomDevices ( ) [private], [default]
```

Default destructor.

### 7.41.3 Member Function Documentation

#### 7.41.3.1 get\_prng()

```
std::mt19937& qpp::RandomDevices::get_prng ( ) [inline]
```

Returns a reference to the internal PRNG object.

#### Returns

Reference to the internal PRNG object

#### 7.41.3.2 load()

```
std::istream& qpp::RandomDevices::load (
    std::istream & is ) [inline]
```

Loads the state of the PRNG from an input stream.

**Parameters**

<i>is</i>	Input stream
-----------	--------------

**Returns**

The input stream

**7.41.3.3 save()**

```
std::ostream& qpp::RandomDevices::save (  
    std::ostream & os ) const [inline]
```

Saves the state of the PRNG to an output stream.

**Parameters**

<i>os</i>	Output stream
-----------	---------------

**Returns**

The output stream

**7.41.4 Friends And Related Function Documentation****7.41.4.1 internal::Singleton< RandomDevices >**

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

**7.41.5 Member Data Documentation****7.41.5.1 prng\_**

```
std::mt19937 qpp::RandomDevices::prng_ [private]
```

Mersenne twister random number generator.

## 7.41.5.2 rd\_

```
std::random_device qpp::RandomDevices::rd_ [private]
```

used to seed std::mt19937 prng\_

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

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

## 7.42 qpp::internal::Singleton&lt; T &gt; Class Template Reference

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

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

## Static Public Member Functions

- static T & [get\\_instance](#) () noexcept(std::is\_nothrow\_constructible< T >::value)
- static T & [get\\_thread\\_local\\_instance](#) () noexcept(std::is\_nothrow\_constructible< T >::value)

## Protected Member Functions

- [Singleton](#) () noexcept=default
- [Singleton](#) (const [Singleton](#) &)=delete
- [Singleton](#) & [operator=](#) (const [Singleton](#) &)=delete
- virtual [~Singleton](#) ()=default

## 7.42.1 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 and destructor of your class as private. To get an instance, use the static member function [qpp::internal::Singleton::get\\_instance\(\)](#) ([qpp::internal::Singleton::get\\_thread\\_local\\_instance\(\)](#)), which returns a reference (thread\_local reference) to your newly created singleton (thread-safe in C++11).

Example:

```

class MySingleton: public qpp::internal::Singleton<MySingleton>
{
    friend class qpp::internal::Singleton<MySingleton>;
public:
    // Declare all public members here
private:
    MySingleton()
    {
        // Implement the constructor here
    }
    ~MySingleton()
    {
        // Implement the destructor here
    }
};

MySingleton& mySingleton = MySingleton::get_instance(); // Get an instance
thread_local MySingleton& tls = MySingleton::get_thread_local_instance();
// Get a thread_local instance

```

### See also

Code of [qpp::Codes](#), [qpp::Gates](#), [qpp::Init](#), [qpp::RandomDevices](#), [qpp::States](#) or [qpp.h](#) for real world examples of usage.

## 7.42.2 Constructor & Destructor Documentation

### 7.42.2.1 Singleton() [1/2]

```

template<typename T>
qpp::internal::Singleton< T >::Singleton ( ) [protected], [default], [noexcept]

```

### 7.42.2.2 Singleton() [2/2]

```

template<typename T>
qpp::internal::Singleton< T >::Singleton (
    const Singleton< T > & ) [protected], [delete]

```

### 7.42.2.3 ~Singleton()

```

template<typename T>
virtual qpp::internal::Singleton< T >::~~Singleton ( ) [protected], [virtual], [default]

```

## 7.42.3 Member Function Documentation



## 7.42.3.1 get\_instance()

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

## 7.42.3.2 get\_thread\_local\_instance()

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

## 7.42.3.3 operator=()

```
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:

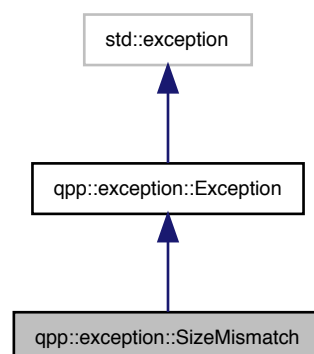
- [internal/classes/singleton.h](#)

## 7.43 qpp::exception::SizeMismatch Class Reference

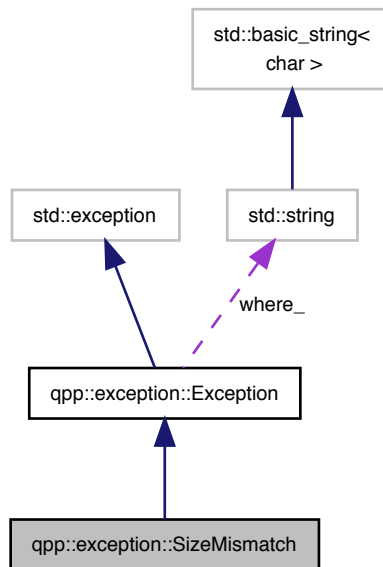
Size mismatch exception.

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

Inheritance diagram for qpp::exception::SizeMismatch:



Collaboration diagram for `qpp::exception::SizeMismatch`:



## Public Member Functions

- `std::string type_description ()` const override  
*Exception type description.*

### 7.43.1 Detailed Description

Size mismatch exception.

Sizes do not match

### 7.43.2 Member Function Documentation

#### 7.43.2.1 type\_description()

```
std::string qpp::exception::SizeMismatch::type_description ( ) const [inline], [override],
[virtual]
```

*Exception type description.*

**Returns**

*Exception type description*

Implements `qpp::exception::Exception`.

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

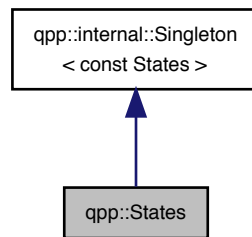
- `classes/exception.h`

## 7.44 qpp::States Class Reference

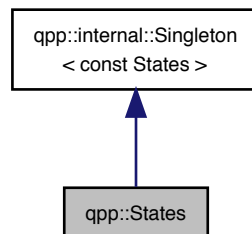
const Singleton class that implements most commonly used states

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

Inheritance diagram for qpp::States:



Collaboration diagram for qpp::States:



### Public Member Functions

- `ket mes (idx d=2) const`  
*Maximally entangled state of 2 qudits.*
- `ket zero (idx n, idx d=2) const`  
*Zero state of n qudits.*
- `ket one (idx n, idx d=2) const`  
*One state of n qudits.*
- `ket jn (idx j, idx n, idx d=2) const`  
 $|j\rangle^{\otimes n}$  *state of n qudits*
- `ket plus (idx n) const`  
*Plus state of n qubits.*
- `ket minus (idx n) const`  
*Minus state of n qubits.*

## 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](#) ()
- [~States](#) ()=default  
*Default destructor.*

## Friends

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

## Additional Inherited Members

### 7.44.1 Detailed Description

const Singleton class that implements most commonly used states

### 7.44.2 Constructor & Destructor Documentation

#### 7.44.2.1 States()

```
qpp::States::States ( ) [inline], [private]
```

Initialize the states

#### 7.44.2.2 ~States()

```
qpp::States::~~States ( ) [private], [default]
```

Default destructor.

### 7.44.3 Member Function Documentation

#### 7.44.3.1 jn()

```
ket qpp::States::jn (
    idx j,
    idx n,
    idx d = 2 ) const [inline]
```

$|j\rangle^{\otimes n}$  state of  $n$  qudits

**Parameters**

$j$	Non-negative integer
$n$	Non-negative integer
$d$	Subsystem dimensions

**Returns**

$|j\rangle^{\otimes n}$  state of  $n$  qudits

**7.44.3.2 mes()**

```
ket qpp::States::mes (
    idx d = 2 ) const [inline]
```

Maximally entangled state of 2 qudits.

**Parameters**

$d$	Subsystem dimensions
-----	----------------------

**Returns**

Maximally entangled state  $\frac{1}{\sqrt{d}} \sum_{j=0}^{d-1} |jj\rangle$  of 2 qudits

**7.44.3.3 minus()**

```
ket qpp::States::minus (
    idx n ) const [inline]
```

Minus state of  $n$  qubits.

**Parameters**

$n$	Non-negative integer
-----	----------------------

**Returns**

Minus state  $|-\rangle^{\otimes n}$  of  $n$  qubits

## 7.44.3.4 one()

```
ket qpp::States::one (
    idx n,
    idx d = 2 ) const [inline]
```

One state of  $n$  qudits.

## Parameters

$n$	Non-negative integer
$d$	Subsystem dimensions

## Returns

One state  $|1\rangle^{\otimes n}$  of  $n$  qudits

## 7.44.3.5 plus()

```
ket qpp::States::plus (
    idx n ) const [inline]
```

Plus state of  $n$  qubits.

## Parameters

$n$	Non-negative integer
-----	----------------------

## Returns

Plus state  $|+\rangle^{\otimes n}$  of  $n$  qubits

## 7.44.3.6 zero()

```
ket qpp::States::zero (
    idx n,
    idx d = 2 ) const [inline]
```

Zero state of  $n$  qudits.

## Parameters

$n$	Non-negative integer
$d$	Subsystem dimensions

**Returns**

Zero state  $|0\rangle^{\otimes n}$  of  $n$  qudits

**7.44.4 Friends And Related Function Documentation****7.44.4.1 internal::Singleton< const States >**

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

**7.44.5 Member Data Documentation****7.44.5.1 b00**

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

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

**7.44.5.2 b01**

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

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

**7.44.5.3 b10**

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

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

**7.44.5.4 b11**

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

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



#### 7.44.5.5 GHZ

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

GHZ state.

#### 7.44.5.6 pb00

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

Projector onto the Bell-00 state.

#### 7.44.5.7 pb01

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

Projector onto the Bell-01 state.

#### 7.44.5.8 pb10

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

Projector onto the Bell-10 state.

#### 7.44.5.9 pb11

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

Projector onto the Bell-11 state.

#### 7.44.5.10 pGHZ

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

Projector onto the GHZ state.

#### 7.44.5.11 pW

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

Projector onto the W state.

#### 7.44.5.12 px0

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

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

#### 7.44.5.13 px1

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

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

#### 7.44.5.14 py0

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

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

#### 7.44.5.15 py1

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

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

#### 7.44.5.16 pz0

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

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

#### 7.44.5.17 pz1

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

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

#### 7.44.5.18 W

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

W state.

#### 7.44.5.19 x0

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

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

#### 7.44.5.20 x1

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

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

#### 7.44.5.21 y0

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

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

#### 7.44.5.22 y1

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

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

#### 7.44.5.23 z0

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

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

#### 7.44.5.24 z1

```
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:

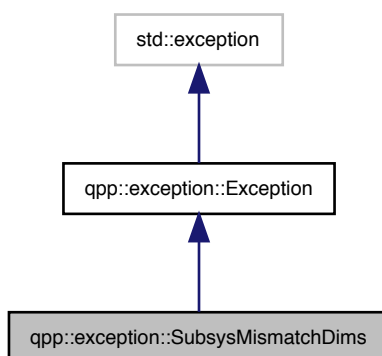
- [classes/states.h](#)

## 7.45 qpp::exception::SubsysMismatchDims Class Reference

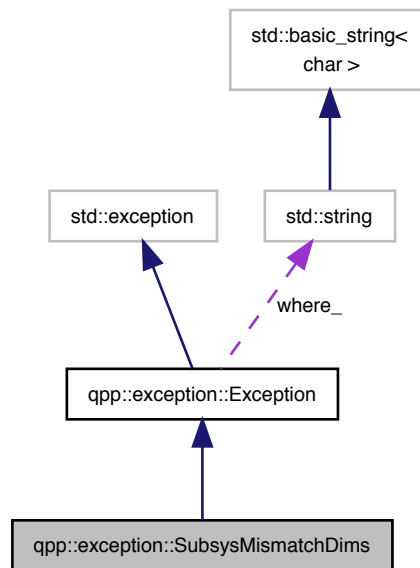
Subsystems mismatch dimensions exception.

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

Inheritance diagram for qpp::exception::SubsysMismatchDims:



Collaboration diagram for qpp::exception::SubsysMismatchDims:



## Public Member Functions

- `std::string type_description ()` const override  
*Exception type description.*

### 7.45.1 Detailed Description

Subsystems mismatch dimensions exception.

`std::vector<idx>` of subsystem labels has duplicates, or has entries that are larger than the size of the `std::vector<idx>` of dimensions

### 7.45.2 Member Function Documentation

#### 7.45.2.1 type\_description()

```
std::string qpp::exception::SubsysMismatchDims::type_description ( ) const [inline], [override], [virtual]
```

*Exception type description.*

## Returns

[Exception](#) type description

Implements [qpp::exception::Exception](#).

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

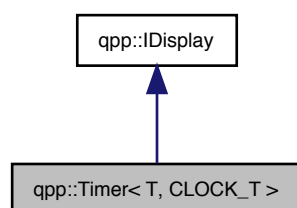
- [classes/exception.h](#)

## 7.46 qpp::Timer< T, CLOCK\_T > Class Template Reference

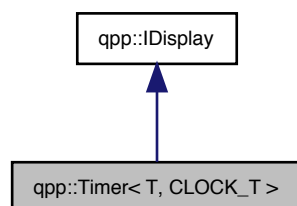
Chronometer.

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

Inheritance diagram for qpp::Timer< T, CLOCK\_T >:



Collaboration diagram for qpp::Timer< T, CLOCK\_T >:



## Public Member Functions

- [Timer](#) () noexcept  
*Constructs an instance with the current time as the starting point.*
- void [tic](#) () noexcept  
*Resets the chronometer.*
- const [Timer](#) & [toc](#) () noexcept  
*Stops the chronometer.*
- double [tics](#) () const noexcept  
*Time passed in the duration specified by T.*
- template<typename U = T>  
U [get\\_duration](#) () const noexcept  
*Duration specified by U.*
- [Timer](#) (const [Timer](#) &)=default  
*Default copy constructor.*
- [Timer](#) ([Timer](#) &&)=default  
*Default move constructor.*
- [Timer](#) & [operator=](#) (const [Timer](#) &)=default  
*Default copy assignment operator.*
- [Timer](#) & [operator=](#) ([Timer](#) &&)=default  
*Default move assignment operator.*
- virtual [~Timer](#) ()=default  
*Default virtual destructor.*

## Protected Attributes

- CLOCK\_T::time\_point [start\\_](#)
- CLOCK\_T::time\_point [end\\_](#)

## Private Member Functions

- std::ostream & [display](#) (std::ostream &os) const override  
*qpp::!Display::display() override*

### 7.46.1 Detailed Description

```
template<typename T = std::chrono::duration<double>, typename CLOCK_T = std::chrono::steady_clock>
class qpp::Timer< T, CLOCK_T >
```

Chronometer.

#### Template Parameters

<i>T</i>	Tics duration, default is std::chrono::duration<double, 1>, i.e. seconds in double precision
<i>CLOCK_T</i>	Clock's type, default is std::chrono::steady_clock, not affected by wall clock changes during runtime

## 7.46.2 Constructor & Destructor Documentation

### 7.46.2.1 Timer() [1/3]

```
template<typename T = std::chrono::duration<double>, typename CLOCK_T = std::chrono::steady↵
_clock>
qpp::Timer< T, CLOCK_T >::Timer ( ) [inline], [noexcept]
```

Constructs an instance with the current time as the starting point.

### 7.46.2.2 Timer() [2/3]

```
template<typename T = std::chrono::duration<double>, typename CLOCK_T = std::chrono::steady↵
_clock>
qpp::Timer< T, CLOCK_T >::Timer (
    const Timer< T, CLOCK_T > & ) [default]
```

Default copy constructor.

### 7.46.2.3 Timer() [3/3]

```
template<typename T = std::chrono::duration<double>, typename CLOCK_T = std::chrono::steady↵
_clock>
qpp::Timer< T, CLOCK_T >::Timer (
    Timer< T, CLOCK_T > && ) [default]
```

Default move constructor.

### 7.46.2.4 ~Timer()

```
template<typename T = std::chrono::duration<double>, typename CLOCK_T = std::chrono::steady↵
_clock>
virtual qpp::Timer< T, CLOCK_T >::~~Timer ( ) [virtual], [default]
```

Default virtual destructor.

## 7.46.3 Member Function Documentation

### 7.46.3.1 display()

```
template<typename T = std::chrono::duration<double>, typename CLOCK_T = std::chrono::steady↵
_clock>
std::ostream& qpp::Timer< T, CLOCK_T >::display (
    std::ostream & os ) const [inline], [override], [private], [virtual]
```

qpp::IDisplay::display() override



## Parameters

<code>os</code>	Output stream
-----------------	---------------

## Returns

Writes to the output stream the number of tics (specified by `T`) that passed between the instantiation/reset and invocation of `qpp::Timer::toc()`.

Implements `qpp::IDisplay`.

7.46.3.2 `get_duration()`

```
template<typename T = std::chrono::duration<double>, typename CLOCK_T = std::chrono::steady_
_clock>
template<typename U = T>
U qpp::Timer< T, CLOCK_T >::get_duration ( ) const [inline], [noexcept]
```

Duration specified by `U`.

## Template Parameters

<code>U</code>	Duration, default is <code>T</code> , which defaults to <code>std::chrono::duration&lt;double, 1&gt;</code> , i.e. seconds in double precision
----------------	--

## Returns

Duration that passed between the instantiation/reset and invocation of `qpp::Timer::toc()`

7.46.3.3 `operator=()` [1/2]

```
template<typename T = std::chrono::duration<double>, typename CLOCK_T = std::chrono::steady_
_clock>
Timer& qpp::Timer< T, CLOCK_T >::operator= (
    const Timer< T, CLOCK_T > & ) [default]
```

Default copy assignment operator.

7.46.3.4 `operator=()` [2/2]

```
template<typename T = std::chrono::duration<double>, typename CLOCK_T = std::chrono::steady_
_clock>
Timer& qpp::Timer< T, CLOCK_T >::operator= (
    Timer< T, CLOCK_T > && ) [default]
```

Default move assignment operator.

#### 7.46.3.5 tic()

```
template<typename T = std::chrono::duration<double>, typename CLOCK_T = std::chrono::steady↵
_clock>
void qpp::Timer< T, CLOCK_T >::tic ( ) [inline], [noexcept]
```

Resets the chronometer.

Resets the starting/ending point to the current time

#### 7.46.3.6 tics()

```
template<typename T = std::chrono::duration<double>, typename CLOCK_T = std::chrono::steady↵
_clock>
double qpp::Timer< T, CLOCK_T >::tics ( ) const [inline], [noexcept]
```

Time passed in the duration specified by T.

##### Returns

Number of tics (specified by T) that passed between the instantiation/reset and invocation of `qpp::Timer::toc()`

#### 7.46.3.7 toc()

```
template<typename T = std::chrono::duration<double>, typename CLOCK_T = std::chrono::steady↵
_clock>
const Timer& qpp::Timer< T, CLOCK_T >::toc ( ) [inline], [noexcept]
```

Stops the chronometer.

Set the current time as the ending point

##### Returns

Current instance

### 7.46.4 Member Data Documentation

#### 7.46.4.1 end\_

```
template<typename T = std::chrono::duration<double>, typename CLOCK_T = std::chrono::steady↵
_clock>
CLOCK_T::time_point qpp::Timer< T, CLOCK_T >::end_ [protected]
```

## 7.46.4.2 start\_

```
template<typename T = std::chrono::duration<double>, typename CLOCK_T = std::chrono::steady↵_clock>
CLOCK_T::time_point qpp::Timer< T, CLOCK_T >::start_ [protected]
```

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

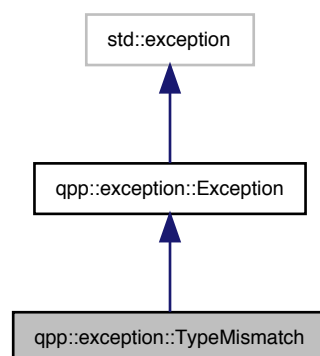
- [classes/timer.h](#)

## 7.47 qpp::exception::TypeMismatch Class Reference

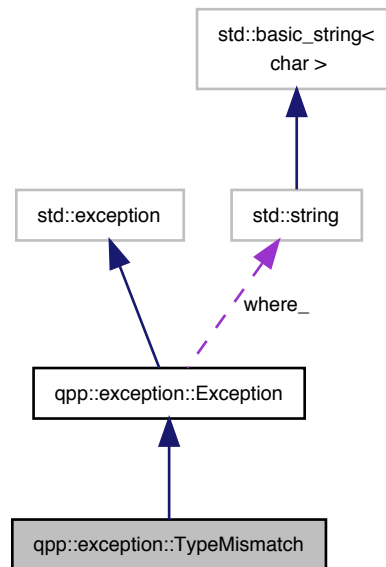
Type mismatch exception.

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

Inheritance diagram for qpp::exception::TypeMismatch:



Collaboration diagram for `qpp::exception::TypeMismatch`:



## Public Member Functions

- `std::string type_description ()` const override  
*Exception type description.*

### 7.47.1 Detailed Description

Type mismatch exception.

Scalar types do not match

### 7.47.2 Member Function Documentation

#### 7.47.2.1 type\_description()

```
std::string qpp::exception::TypeMismatch::type_description ( ) const [inline], [override],
[virtual]
```

*Exception type description.*

#### Returns

*Exception type description*

Implements `qpp::exception::Exception`.

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

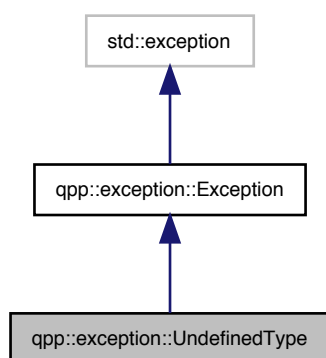
- `classes/exception.h`

## 7.48 qpp::exception::UndefinedType Class Reference

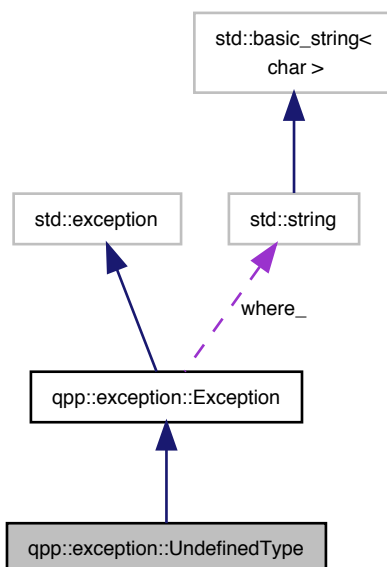
Not defined for this type exception.

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

Inheritance diagram for qpp::exception::UndefinedType:



Collaboration diagram for qpp::exception::UndefinedType:



## Public Member Functions

- `std::string type\_description () const` override  
*[Exception](#) type description.*

### 7.48.1 Detailed Description

Not defined for this type exception.

Templated specialization is not defined for this type

### 7.48.2 Member Function Documentation

#### 7.48.2.1 `type_description()`

```
std::string qpp::exception::UndefinedType::type_description ( ) const [inline], [override],  
[virtual]
```

[Exception](#) type description.

#### Returns

[Exception](#) type description

Implements [qpp::exception::Exception](#).

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

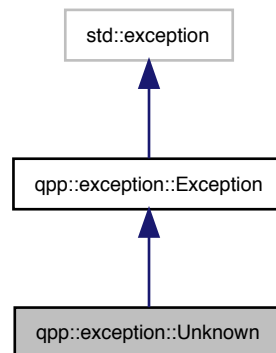
- `classes/exception.h`

## 7.49 `qpp::exception::Unknown` Class Reference

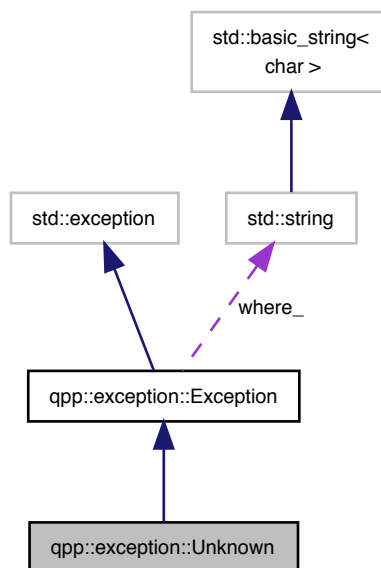
[Unknown](#) exception.

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

Inheritance diagram for qpp::exception::Unknown:



Collaboration diagram for qpp::exception::Unknown:



## Public Member Functions

- `std::string type\_description () const` override  
*[Exception](#) type description.*

### 7.49.1 Detailed Description

[Unknown](#) exception.

Thrown when no other exception is suitable (not recommended, it is better to define another suitable exception type)

### 7.49.2 Member Function Documentation

#### 7.49.2.1 `type_description()`

```
std::string qpp::exception::Unknown::type_description ( ) const [inline], [override], [virtual]
```

[Exception](#) type description.

#### Returns

[Exception](#) type description

Implements [qpp::exception::Exception](#).

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

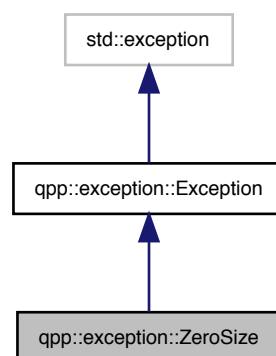
- [classes/exception.h](#)

## 7.50 `qpp::exception::ZeroSize` Class Reference

Object has zero size exception.

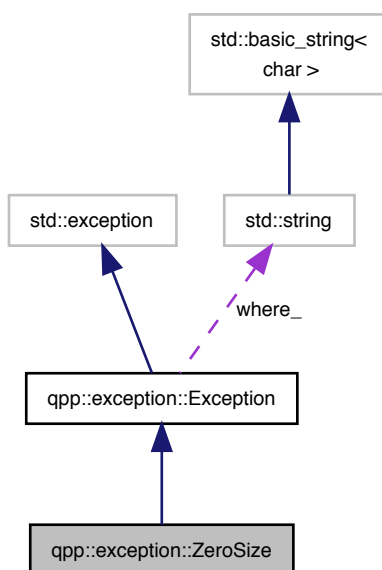
```
#include <classes/exception.h>
```

Inheritance diagram for `qpp::exception::ZeroSize`:





Collaboration diagram for qpp::exception::ZeroSize:



## Public Member Functions

- `std::string type_description () const` override  
*Exception type description.*

### 7.50.1 Detailed Description

Object has zero size exception.

Zero sized object, e.g. empty Eigen::Matrix or std::vector with no elements

### 7.50.2 Member Function Documentation

#### 7.50.2.1 type\_description()

```
std::string qpp::exception::ZeroSize::type_description ( ) const [inline], [override], [virtual]
```

*Exception type description.*

Returns

*Exception type description*

Implements `qpp::exception::Exception`.

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

- `classes/exception.h`



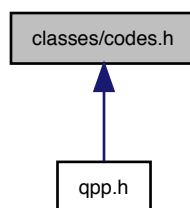
## Chapter 8

# 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.*

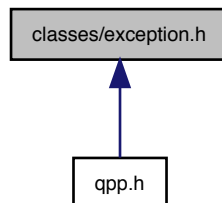
#### 8.1.1 Detailed Description

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::Exception](#)  
*Base class for generating Quantum++ custom exceptions.*
- class [qpp::exception::Unknown](#)  
*Unknown exception.*
- class [qpp::exception::ZeroSize](#)  
*Object has zero size exception.*
- class [qpp::exception::MatrixNotSquare](#)  
*Matrix is not square exception.*
- class [qpp::exception::MatrixNotCvector](#)  
*Matrix is not a column vector exception.*
- class [qpp::exception::MatrixNotRvector](#)  
*Matrix is not a row vector exception.*
- class [qpp::exception::MatrixNotVector](#)  
*Matrix is not a vector exception.*
- class [qpp::exception::MatrixNotSquareNorCvector](#)  
*Matrix is not square nor column vector exception.*
- class [qpp::exception::MatrixNotSquareNorRvector](#)  
*Matrix is not square nor row vector exception.*
- class [qpp::exception::MatrixNotSquareNorVector](#)  
*Matrix is not square nor vector exception.*
- class [qpp::exception::MatrixMismatchSubsys](#)  
*Matrix mismatch subsystems exception.*
- class [qpp::exception::DimsInvalid](#)  
*Invalid dimension(s) exception.*
- class [qpp::exception::DimsNotEqual](#)  
*Dimensions not equal exception.*
- class [qpp::exception::DimsMismatchMatrix](#)  
*Dimension(s) mismatch matrix size exception.*
- class [qpp::exception::DimsMismatchCvector](#)

- Dimension(s) mismatch column vector size exception.*
- class [qpp::exception::DimsMismatchRvector](#)
- Dimension(s) mismatch row vector size exception.*
- class [qpp::exception::DimsMismatchVector](#)
- Dimension(s) mismatch vector size exception.*
- class [qpp::exception::SubsysMismatchDims](#)
- Subsystems mismatch dimensions exception.*
- class [qpp::exception::PermInvalid](#)
- Invalid permutation exception.*
- class [qpp::exception::PermMismatchDims](#)
- Permutation mismatch dimensions exception.*
- class [qpp::exception::NotQubitMatrix](#)
- Matrix is not 2 x 2 exception.*
- class [qpp::exception::NotQubitCvector](#)
- Column vector is not 2 x 1 exception.*
- class [qpp::exception::NotQubitRvector](#)
- Row vector is not 1 x 2 exception.*
- class [qpp::exception::NotQubitVector](#)
- Vector is not 2 x 1 nor 1 x 2 exception.*
- class [qpp::exception::NotQubitSubsys](#)
- Subsystems are not qubits exception.*
- class [qpp::exception::NotBipartite](#)
- Not bi-partite exception.*
- class [qpp::exception::NoCodeword](#)
- Codeword does not exist exception.*
- class [qpp::exception::OutOfRange](#)
- Parameter out of range exception.*
- class [qpp::exception::TypeMismatch](#)
- Type mismatch exception.*
- class [qpp::exception::SizeMismatch](#)
- Size mismatch exception.*
- class [qpp::exception::UndefinedType](#)
- Not defined for this type exception.*
- class [qpp::exception::CustomException](#)
- Custom exception.*

## Namespaces

- [qpp](#)
- Quantum++ main namespace.*
- [qpp::exception](#)
- Quantum++ exception hierarchy namespace.*

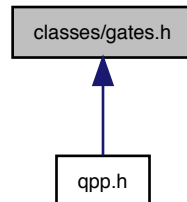
### 8.2.1 Detailed Description

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.*

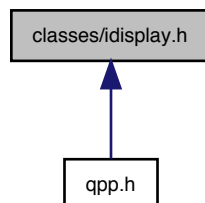
#### 8.3.1 Detailed Description

Quantum gates.

## 8.4 classes/ideisplay.h File Reference

Display interface via the non-virtual interface (NVI)

This graph shows which files directly or indirectly include this file:



## Classes

- class [qpp::IDisplay](#)

*Abstract class (interface) that mandates the definition of virtual `std::ostream& display(std::ostream& os) const`.*

## Namespaces

- [qpp](#)

*Quantum++ main namespace.*

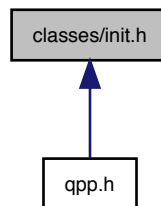
### 8.4.1 Detailed Description

Display interface via the non-virtual interface (NVI)

## 8.5 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.*

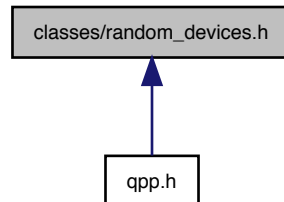
### 8.5.1 Detailed Description

Initialization.

## 8.6 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.*

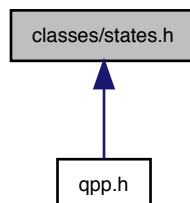
### 8.6.1 Detailed Description

Random devices.

## 8.7 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.*

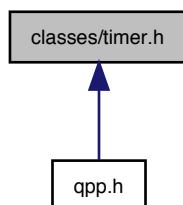
### 8.7.1 Detailed Description

Quantum states.

## 8.8 classes/timer.h File Reference

Timing.

This graph shows which files directly or indirectly include this file:



## Classes

- class [qpp::Timer< T, CLOCK\\_T >](#)  
*Chronometer.*

## Namespaces

- [qpp](#)  
*Quantum++ main namespace.*

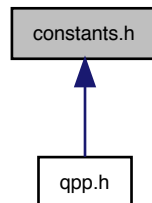
### 8.8.1 Detailed Description

Timing.

## 8.9 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) noexcept  
*User-defined literal for complex  $i = \sqrt{-1}$  (integer overload)*
- constexpr cplx [qpp::operator"" \\_i](#) (long double x) noexcept  
*User-defined literal for complex  $i = \sqrt{-1}$  (real overload)*
- cplx [qpp::omega](#) (idx D)  
*D-th root of unity.*

### Variables

- constexpr double [qpp::chop](#) = 1e-10  
*Used in [qpp::disp\(\)](#) for setting to zero numbers that have their absolute value smaller than [qpp::chop](#).*
- constexpr double [qpp::eps](#) = 1e-12  
*Used to decide whether a number or expression in double precision is zero or not.*
- constexpr idx [qpp::maxn](#) = 64  
*Maximum number of allowed qubits/qudits (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>::max()  
*Used to denote infinity in double precision.*

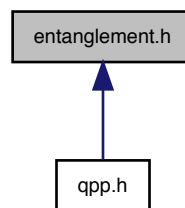
### 8.9.1 Detailed Description

Constants.

## 8.10 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 >`  
`dyn_col_vect< double > qpp::schmidtcoeffs (const Eigen::MatrixBase< Derived > &A, idx d=2)`  
*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::schmidtA (const Eigen::MatrixBase< Derived > &A, idx d=2)`  
*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 >`  
`cmat qpp::schmidtB (const Eigen::MatrixBase< Derived > &A, idx d=2)`

*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 >`  
`std::vector< double > qpp::schmidtprobs (const Eigen::MatrixBase< Derived > &A, idx d=2)`

*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::entanglement (const Eigen::MatrixBase< Derived > &A, idx d=2)`

*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::negativity (const Eigen::MatrixBase< Derived > &A, idx d=2)`

*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::lognegativity (const Eigen::MatrixBase< Derived > &A, idx d=2)`

*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.*

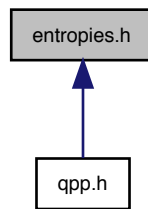
### 8.10.1 Detailed Description

Entanglement functions.

## 8.11 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.*

### 8.11.1 Detailed Description

Entropy functions.

## 8.12 experimental/experimental.h File Reference

Experimental/test functions/classes.

### Namespaces

- [qpp](#)  
*Quantum++ main namespace.*
- [qpp::experimental](#)  
*Experimental/test functions/classes, do not use or modify.*

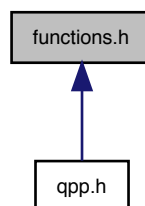
### 8.12.1 Detailed Description

Experimental/test functions/classes.

## 8.13 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::hevecs (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 absolute 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)`  
*Fast matrix power based on the SQUARE-AND-MULTIPLY algorithm.*
- `template<typename Derived >`  
`double qpp::schatten (const Eigen::MatrixBase< Derived > &A, double p)`  
*Schatten matrix norm.*
- `template<typename OutputScalar, typename Derived >`  
`dyn_mat< OutputScalar > qpp::cwise (const Eigen::MatrixBase< Derived > &A, OutputScalar(*f)(const typename Derived::Scalar &))`  
*Functor.*
- `template<typename T >`  
`dyn_mat< typename T::Scalar > qpp::kron (const T &head)`  
*Kronecker product.*
- `template<typename T, typename ... Args>`  
`dyn_mat< typename T::Scalar > qpp::kron (const T &head, const Args &... tail)`  
*Kronecker product.*
- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::kron (const std::vector< Derived > &As)`  
*Kronecker product.*



- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::kron (const std::initializer_list< Derived > &As)`  
*Kronecker product.*
- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::kronpow (const Eigen::MatrixBase< Derived > &A, idx n)`  
*Kronecker power.*
- `template<typename T >`  
`dyn_mat< typename T::Scalar > qpp::dirsum (const T &head)`  
*Direct sum.*
- `template<typename T , typename ... Args>`  
`dyn_mat< typename T::Scalar > qpp::dirsum (const T &head, const Args &... tail)`  
*Direct sum.*
- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::dirsum (const std::vector< Derived > &As)`  
*Direct sum.*
- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::dirsum (const std::initializer_list< Derived > &As)`  
*Direct sum.*
- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::dirsumpow (const Eigen::MatrixBase< Derived > &A, idx n)`  
*Direct sum power.*
- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::reshape (const Eigen::MatrixBase< Derived > &A, idx rows, idx cols)`  
*Reshape.*
- `template<typename Derived1 , typename Derived2 >`  
`dyn_mat< typename Derived1::Scalar > qpp::comm (const Eigen::MatrixBase< Derived1 > &A, const Eigen::MatrixBase< Derived2 > &B)`  
*Commutator.*
- `template<typename Derived1 , typename Derived2 >`  
`dyn_mat< typename Derived1::Scalar > qpp::anticomm (const Eigen::MatrixBase< Derived1 > &A, const Eigen::MatrixBase< Derived2 > &B)`  
*Anti-commutator.*
- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::prj (const Eigen::MatrixBase< Derived > &A)`  
*Projector.*
- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::grams (const std::vector< Derived > &As)`  
*Gram-Schmidt orthogonalization.*
- `template<typename Derived >`  
`dyn_mat< typename Derived::Scalar > qpp::grams (const std::initializer_list< Derived > &As)`  
*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 absolute values squared of an STL-like range of complex numbers.*
- `template<typename Container >`  
`std::vector< double > qpp::abssq (const Container &c, typename std::enable_if< is_iterable< Container >::value >::type *==nullptr)`  
*Computes the absolute values squared of an STL-like container.*
- `template<typename Derived >`  
`std::vector< double > qpp::abssq (const Eigen::MatrixBase< Derived > &A)`  
*Computes the absolute values squared of an Eigen expression.*
- `template<typename InputIterator >`  
`std::iterator_traits< InputIterator >::value_type qpp::sum (InputIterator first, InputIterator last)`  
*Element-wise sum of an STL-like range.*
- `template<typename Container >`  
`Container::value_type qpp::sum (const Container &c, typename std::enable_if< is_iterable< Container >::value >::type *==nullptr)`  
*Element-wise sum of the elements of an STL-like container.*
- `template<typename InputIterator >`  
`std::iterator_traits< InputIterator >::value_type qpp::prod (InputIterator first, InputIterator last)`  
*Element-wise product of an STL-like range.*
- `template<typename Container >`  
`Container::value_type qpp::prod (const Container &c, typename std::enable_if< is_iterable< Container >::value >::type *==nullptr)`  
*Element-wise product of the elements of an STL-like container.*
- `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.*
- `template<typename T >`  
`std::vector< T > qpp::complement (std::vector< T > subsys, idx N)`  
*Constructs the complement of a subsystem vector.*
- `template<typename Derived >`  
`std::vector< double > qpp::rho2bloch (const Eigen::MatrixBase< Derived > &A)`  
*Computes the 3-dimensional real Bloch vector corresponding to the qubit density matrix A.*
- `cmat qpp::bloch2rho (const std::vector< double > &r)`  
*Computes the density matrix corresponding to the 3-dimensional real Bloch vector r.*

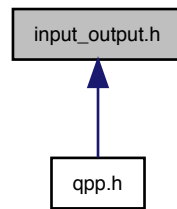
### 8.13.1 Detailed Description

Generic quantum computing functions.

## 8.14 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 (InputIterator first, 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="]", typename std::enable_if< is_iterable< Container >::value >::type !=nullptr)`  
*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.*

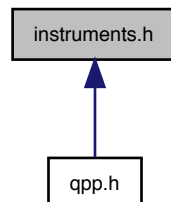
### 8.14.1 Detailed Description

Input/output functions.

## 8.15 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 >`  
`dyn_col_vect< typename Derived::Scalar > qpp::ip (const Eigen::MatrixBase< Derived > &phi, const Eigen::MatrixBase< Derived > &psi, const std::vector< idx > &subsys, const std::vector< idx > &dims)`  
*Generalized inner product.*
- `template<typename Derived >`  
`dyn_col_vect< typename Derived::Scalar > qpp::ip (const Eigen::MatrixBase< Derived > &phi, const Eigen::MatrixBase< Derived > &psi, const std::vector< idx > &subsys, idx d=2)`  
*Generalized inner product.*
- `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.*
- `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, 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, 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 &V, const std::vector< idx > &subsys, const std::vector< idx > &dims)  
*Measures the part subsys of the multi-partite state vector or density matrix A in the orthonormal basis or rank-1 POVM specified by the matrix V.*
- `template<typename Derived >`  
`std::tuple< idx, std::vector< double >, std::vector< cmat > > qpp::measure` (const Eigen::MatrixBase< Derived > &A, const cmat &V, const std::vector< idx > &subsys, idx d=2)  
*Measures the part subsys of the multi-partite state vector or density matrix A in the orthonormal basis or rank-1 POVM specified by the matrix V.*
- `template<typename Derived >`  
`std::tuple< std::vector< idx >, double, cmat > qpp::measure_seq` (const Eigen::MatrixBase< Derived > &A, std::vector< idx > subsys, std::vector< idx > dims)  
*Sequentially measures the part subsys of the multi-partite state vector or density matrix A in the computational basis.*
- `template<typename Derived >`  
`std::tuple< std::vector< idx >, double, cmat > qpp::measure_seq` (const Eigen::MatrixBase< Derived > &A, std::vector< idx > subsys, idx d=2)  
*Sequentially measures the part subsys of the multi-partite state vector or density matrix A in the computational basis.*

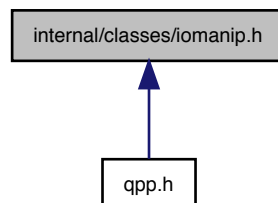
### 8.15.1 Detailed Description

Measurement functions.

## 8.16 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 them directly or modify them.*

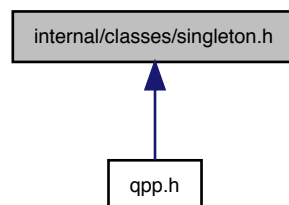
### 8.16.1 Detailed Description

Input/output manipulators.

## 8.17 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 them directly or modify them.*

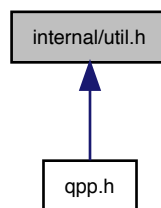
### 8.17.1 Detailed Description

Singleton pattern via CRTP.

## 8.18 internal/util.h File Reference

Internal utility functions.

This graph shows which files directly or indirectly include this file:



### Classes

- struct [qpp::internal::Display\\_Impl\\_](#)

### Namespaces

- [qpp](#)  
*Quantum++ main namespace.*
- [qpp::internal](#)  
*Internal utility functions, do not use them directly or modify them.*

### Functions

- void [qpp::internal::n2multiidx](#) (idx n, idx numdims, const idx \*const dims, idx \*result) noexcept
- idx [qpp::internal::multiidx2n](#) (const idx \*const midx, idx numdims, const idx \*const dims) noexcept
- 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\\_rvector](#) (const Eigen::MatrixBase< Derived > &A)
- template<typename Derived >  
bool [qpp::internal::check\\_cvector](#) (const Eigen::MatrixBase< Derived > &A)
- template<typename T >  
bool [qpp::internal::check\\_nonzero\\_size](#) (const T &x) noexcept

- `template<typename T1 , typename T2 >`  
`bool qpp::internal::check_matching_sizes (const T1 &lhs, const T2 &rhs) noexcept`
- `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 > &A)`
- `template<typename Derived >`  
`bool qpp::internal::check_dims_match_rvect (const std::vector< idx > &dims, const Eigen::MatrixBase< Derived > &A)`
- `bool qpp::internal::check_eq_dims (const std::vector< idx > &dims, idx dim) noexcept`
- `bool qpp::internal::check_subsys_match_dims (const std::vector< idx > &subsys, const std::vector< idx > &dims)`
- `template<typename Derived >`  
`bool qpp::internal::check_qubit_matrix (const Eigen::MatrixBase< Derived > &A) noexcept`
- `template<typename Derived >`  
`bool qpp::internal::check_qubit_cvector (const Eigen::MatrixBase< Derived > &A) noexcept`
- `template<typename Derived >`  
`bool qpp::internal::check_qubit_rvector (const Eigen::MatrixBase< Derived > &A) noexcept`
- `template<typename Derived >`  
`bool qpp::internal::check_qubit_vector (const Eigen::MatrixBase< Derived > &A) noexcept`
- `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)`
- `idx qpp::internal::get_num_subsys (idx sz, idx d)`
- `idx qpp::internal::get_dim_subsys (idx sz, idx N)`

### 8.18.1 Detailed Description

Internal utility functions.

## 8.19 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 >`  
`std::enable_if< std::is_same< typename Derived::Scalar, cplx >::value, dyn_mat< cplx > >::type` [qpp::loadMATLAB](#) (const std::string &mat\_file, const std::string &var\_name)  
*Loads a complex Eigen dynamic matrix from a MATLAB .mat file,.*
- `template<typename Derived >`  
`std::enable_if<!std::is_same< typename Derived::Scalar, cplx >::value, dyn_mat< typename Derived::Scalar > >::type` [qpp::loadMATLAB](#) (const std::string &mat\_file, const std::string &var\_name)  
*Loads a non-complex Eigen dynamic matrix from a MATLAB .mat file,.*
- `template<typename Derived >`  
`std::enable_if< std::is_same< typename Derived::Scalar, cplx >::value >::type` [qpp::saveMATLAB](#) (const Eigen::MatrixBase< Derived > &A, const std::string &mat\_file, const std::string &var\_name, const std::string &mode)  
*Saves a complex Eigen dynamic matrix to a MATLAB .mat file,.*
- `template<typename Derived >`  
`std::enable_if<!std::is_same< typename Derived::Scalar, cplx >::value >::type` [qpp::saveMATLAB](#) (const Eigen::MatrixBase< Derived > &A, const std::string &mat\_file, const std::string &var\_name, const std::string &mode)  
*Saves a non-complex Eigen dynamic matrix to a MATLAB .mat file,.*

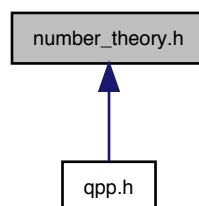
### 8.19.1 Detailed Description

Input/output interfacing with MATLAB.

## 8.20 number\_theory.h File Reference

Number theory functions.

This graph shows which files directly or indirectly include this file:



## Namespaces

- [qpp](#)  
*Quantum++ main namespace.*

## Functions

- `std::vector< int > qpp::x2contfrac` (double x, idx N, idx cut=1e5)  
*Simple continued fraction expansion.*
- `double qpp::contfrac2x` (const `std::vector< int >` &cf, idx N=idx(-1))  
*Real representation of a simple continued fraction.*
- `bigint qpp::gcd` (bigint a, bigint b)  
*Greatest common divisor of two integers.*
- `bigint qpp::gcd` (const `std::vector< bigint >` &as)  
*Greatest common divisor of a list of integers.*
- `bigint qpp::lcm` (bigint a, bigint b)  
*Least common multiple of two integers.*
- `bigint qpp::lcm` (const `std::vector< bigint >` &as)  
*Least common multiple of a list of integers.*
- `std::vector< idx > qpp::invperm` (const `std::vector< idx >` &perm)  
*Inverse permutation.*
- `std::vector< idx > qpp::compperm` (const `std::vector< idx >` &perm, const `std::vector< idx >` &sigma)  
*Compose permutations.*
- `std::vector< bigint > qpp::factors` (bigint a)  
*Prime factor decomposition.*
- `bigint qpp::modmul` (bigint a, bigint b, bigint p)  
*Modular multiplication without overflow.*
- `bigint qpp::modpow` (bigint a, bigint n, bigint p)  
*Fast integer power modulo p based on the SQUARE-AND-MULTIPLY algorithm.*
- `std::tuple< bigint, bigint, bigint > qpp::egcd` (bigint a, bigint b)  
*Extended greatest common divisor of two integers.*
- `bigint qpp::modinv` (bigint a, bigint p)  
*Modular inverse of a mod p.*
- `bool qpp::isprime` (bigint p, idx k=80)  
*Primality test based on the Miller-Rabin's algorithm.*
- `bigint qpp::randprime` (bigint a, bigint b, idx N=1000)  
*Generates a random big prime uniformly distributed in the interval [a, b].*

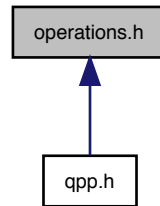
### 8.20.1 Detailed Description

Number theory functions.

## 8.21 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 > &A, const std::vector< cmat > &Ks)`  
*Applies the channel specified by the set of Kraus operators Ks to the density matrix A.*
- `template<typename Derived >`  
`cmat qpp::apply (const Eigen::MatrixBase< Derived > &A, 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 A.*
- `template<typename Derived >`  
`cmat qpp::apply (const Eigen::MatrixBase< Derived > &A, 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 A.*

- `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::ptrace1` (const Eigen::MatrixBase< Derived > &A, idx d=2)  
*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::ptrace2` (const Eigen::MatrixBase< Derived > &A, idx d=2)  
*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.*

## 8.21.1 Detailed Description

Quantum operation functions.

## 8.22 qpp.h File Reference

Quantum++ main header file, includes all other necessary headers.

```
#include <algorithm>
#include <cassert>
#include <chrono>
#include <cmath>
#include <complex>
#include <cstdlib>
#include <cstring>
#include <exception>
#include <fstream>
#include <functional>
#include <initializer_list>
#include <iomanip>
#include <iterator>
#include <limits>
#include <memory>
#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 "classes/exception.h"
#include "constants.h"
#include "traits.h"
#include "classes/idevice.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 "statistics.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.*

## Macros

- `#define` [QPP\\_UNUSED\\_](#)

### 8.22.1 Detailed Description

Quantum++ main header file, includes all other necessary headers.

### 8.22.2 Macro Definition Documentation

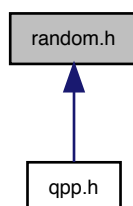
#### 8.22.2.1 QPP\_UNUSED\_

```
#define QPP_UNUSED_
```

## 8.23 random.h File Reference

Randomness-related functions.

This graph shows which files directly or indirectly include this file:



## Namespaces

- [qpp](#)  
*Quantum++ main namespace.*

## Functions

- double `qpp::rand` (double a, double b)  
*Generates a random real number uniformly distributed in the interval [a, b]*
- bigint `qpp::rand` (bigint a, bigint b)  
*Generates a random big integer 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::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`)*
- 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=2)  
*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=2)  
*Generates a set of random Kraus operators.*
- cmat `qpp::randH` (idx D=2)  
*Generates a random Hermitian matrix.*
- ket `qpp::randket` (idx D=2)  
*Generates a random normalized ket (pure state vector)*
- cmat `qpp::randrho` (idx D=2)  
*Generates a random density matrix.*
- std::vector< idx > `qpp::randperm` (idx N)  
*Generates a random uniformly distributed permutation.*
- std::vector< double > `qpp::randprob` (idx N)  
*Generates a random probability vector uniformly distributed over the probability simplex.*

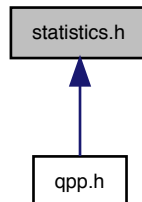
### 8.23.1 Detailed Description

Randomness-related functions.

## 8.24 statistics.h File Reference

Statistics functions.

This graph shows which files directly or indirectly include this file:



### Namespaces

- [qpp](#)  
*Quantum++ main namespace.*

### Functions

- `std::vector< double > qpp::uniform (idx N)`  
*Uniform probability distribution vector.*
- `std::vector< double > qpp::marginalX (const dmat &probXY)`  
*Marginal distribution.*
- `std::vector< double > qpp::marginalY (const dmat &probXY)`  
*Marginal distribution.*
- `template<typename Container >`  
`double qpp::avg (const std::vector< double > &prob, const Container &X, typename std::enable_if< is_↔`  
`iterable< Container >::value >::type !=nullptr)`  
*Average.*
- `template<typename Container >`  
`double qpp::cov (const dmat &probXY, const Container &X, const Container &Y, typename std::enable_if<`  
`is_iterable< Container >::value >::type !=nullptr)`  
*Covariance.*
- `template<typename Container >`  
`double qpp::var (const std::vector< double > &prob, const Container &X, typename std::enable_if< is_↔`  
`iterable< Container >::value >::type !=nullptr)`  
*Variance.*
- `template<typename Container >`  
`double qpp::sigma (const std::vector< double > &prob, const Container &X, typename std::enable_if< is_↔`  
`iterable< Container >::value >::type !=nullptr)`  
*Standard deviation.*
- `template<typename Container >`  
`double qpp::cor (const dmat &probXY, const Container &X, const Container &Y, typename std::enable_if<`  
`is_iterable< Container >::value >::type !=nullptr)`  
*Correlation.*



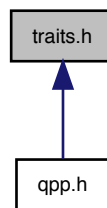
### 8.24.1 Detailed Description

Statistics functions.

## 8.25 traits.h File Reference

Type traits.

This graph shows which files directly or indirectly include this file:



### Classes

- struct `qpp::make_void< Ts >`  
*Helper for `qpp::to_void<>` alias template.*
- struct `qpp::is_iterable< T, typename >`  
*Checks whether `T` is compatible with an STL-like iterable container.*
- struct `qpp::is_iterable< T, to_void< decltype(std::declval< T >().begin()), decltype(std::declval< T >().end()), typename T::value_type >>`  
*Checks whether `T` is compatible with an STL-like iterable container, specialization for STL-like iterable containers.*
- struct `qpp::is_matrix_expression< Derived >`  
*Checks whether the type is an Eigen matrix expression.*
- struct `qpp::is_complex< T >`  
*Checks whether the type is a complex type.*
- struct `qpp::is_complex< std::complex< T > >`  
*Checks whether the type is a complex number type, specialization for complex types.*

### Namespaces

- `qpp`  
*Quantum++ main namespace.*

### Typedefs

- `template<typename... Ts>`  
`using qpp::to_void = typename make_void< Ts... >::type`  
*Alias template that implements the proposal for `void_t`.*

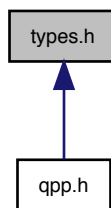
### 8.25.1 Detailed Description

Type traits.

## 8.26 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::bigint](#) = long long int  
*Big integer.*
- 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.*

### 8.26.1 Detailed Description

Type aliases.

## 8.27 /Users/vlad/Dropbox/programming/cpp/qpp/README.md File Reference



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