quantum++ 0.1

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quantum++ - A C++11 quantum computing library

Version

0.1

Author

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A simple example:

```
#include "qpp.h"
//#include "matlab.h" // support for MATLAB
using namespace std;
using namespace qpp;
cplx pow3(const cplx& z) // a test function
    return std::pow(z, 3);
int main()
    cout << "Starting qpp..." << endl;</pre>
     // output format
     //cout << std::scientific;</pre>
    cout << std::fixed; // use fixed format for nice formatting</pre>
    cout << std::setprecision(4); // only for fixed or scientific modes</pre>
     // TESTING
     // testing channel and Gates::apply
     cout << endl << "Testing channel(...) and Gates::apply(...)." << endl;</pre>
     cmat rho = randrho(16);
cmat K = kron(gt.Id2, gt.X, gt.Y, gt.Z);
    vector<std::size_t> p = randperm(4); // permutation
cout << "Permutation: ";</pre>
     displn(p, ", ");
    vector<std::size_t> invp = invperm(p); // inverse permutation
cout << "Inverse permutation: ";
displn(invp, ", ");</pre>
     cmat r1 = channel(rho, { K }, p, { 2, 2, 2, 2 });
     cmat r2 = syspermute(channel(syspermute(rho, p, { 2, 2, 2 }), { K },
      { 0,
    1, 2, 3 }, { 2, 2, 2, 2 }), invp, { 2, 2, 2, 2 }); cout << norm(r1 - r2) << endl << endl;
     r1 = gt.apply(rho, K, p, { 2, 2, 2, 2 });
     gt.apply(syspermute(rho, p, { 2, 2, 2, 2 }), K, { 0, 1, 2, 3 }, { 2, 2, 2, 2 }), invp, { 2, 2, 2, 2 });
cout << norm(r1 - r2) << endl << endl;
```

```
displn(channel(prj(mket( { 0, 1 })), { gt.CNOTab }, { 1, 0 }, { 2, 2 }));
displn(gt.apply(mket( { 0, 0 }), gt.CNOTab, { 0, 1 }, { 2, 2 }));
// quantum teleportation
cout << endl << "Qudit teleportation." << endl;</pre>
ket psi = randket(2); // a random state;
cout << "|psi><psi|:" << endl;</pre>
ket psiout = telecircuit * psiin; // output state before measurement
// measure Alice's qubits, measurement results are 1 0
psiout = kron(prj(st.z1), prj(st.z0), gt.Id2) * psiout;
// apply correction
psiout = expandout(powm(gt.Z, 1) * powm(gt.X, 0), { 2 }, { 2, 2, 2 })
           psiout;
// not necessary to normalize, prj() takes care of it below
cmat rhoout = ptrace(prj(psiout), { 0, 1 }, { 2, 2, 2 });
cout << endl << "Teleported state:" << endl;</pre>
displn(rhoout);
cout << "Difference in norm: " << norm(prj(psi) - rhoout) << endl;</pre>
// qudit measurements
cout << endl << "Qudit measurements." << endl;</pre>
cout << "Initially in state |0><0|." << endl;</pre>
ket zd0(3);
zd0 << 1, 0, 0;
Qudit q(prj(zd0));
cout << "Measuring Z operator non-destructively. Results:" << endl;</pre>
cout << q.measure() << endl;</pre>
cout << q.measure() << endl;</pre>
cout << q.measure() << endl;
cout << q.measureing X operator non-destructively. Results:" << endl;
cout << q.measure(gt.Xd(3)) << endl;
cout << q.measure(gt.Xd(3)) << endl;</pre>
cout << q.measure(gt.Xd(3)) << endl;</pre>
// von Neumann projective measurement
cout << "Measuring X operator destructively (collapse). Results:" << endl;
cout << q.measure(gt.Xd(3), true) << endl;
cout << q.measure(gt.Xd(3)) << endl;</pre>
cout << q.measure(gt.Xd(3)) << endl;
cout << g.measure(gt.Xd(3)) << endl;
cout << "Finally measuring Z operator destructively. Results:" << endl;</pre>
cout << q.measure(true) << endl;</pre>
cout << q.measure() << endl;</pre>
cout << q.measure() << endl;
cout << "Final state of qudit:" << endl;</pre>
displn(q.getRho());
// Bell state generator
cout << endl << "Bell state generator: " << endl;</pre>
cmat circuit;
circuit = gt.CTRL(gt.X, { 0 }, { 1 }, 2) * expandout(gt.
    H, 0, { 2, 2 });
cmat input = kron(st.z0, st.z0);
cmat output = circuit * input;
cout << "Circuit matrix representation: " << endl;</pre>
displn(circuit);
cout << endl << "Output (|Bell_0> state) of the circuit on |00>: " << endl;</pre>
displn(output);
// 3-qubit repetion code
cout << endl << "3-qubit repetition code: " << endl;</pre>
cmat rep;
rep = gt.CTRL(gt.X, { 0 }, { 2 }, 3) * gt.CTRL(gt.X, { 0 }, { 1 }, 3);
input = kron(st.z1, st.z0, st.z0);
output = rep * input;
cout << "Circuit acting on |000> produces |111>. Check: " << endl;
displn(output);
// functor test
cout << endl << "Functor z^3 acting on:" << endl;</pre>
cmat a(2, 2);
a << 1, 2, 3, 4;</pre>
displn(a);
cout << "Result (with lambda):" << endl;</pre>
// functor z^3 componentwise, specify OutputScalar and Derived for lambdas  \frac{\text{displn}(\text{cwise} < \text{cplx, cmat} > (a, [](\text{const cplx\& z}) -> \text{cplx} } ) + cplx 
    return z*z*z;}));
cout << "Result (with proper function):" << endl;</pre>
// automatic type deduction for proper functions
displn(cwise(a, &pow3));
// Gram-Schmidt
cout << endl << "Gram-Schmidt on matrix:" << endl;</pre>
```

```
cmat A(3, 3);
A << 1, 1, 0, 0, 2, 0, 0, 0;
displn(A);
cmat Ags = grams(A);
cout << endl << "Result:" << endl:
displn(Aqs):
cout << endl << "Projector is:" << endl;
displn(Ags * adjoint(Ags));
// spectral decomposition test
cout << endl << "Spectral decomposition tests." << endl;</pre>
std::size_t D = 4;
cmat rH = randH(D);
dmat evalsH = hevals(rH);
cmat evectsH = hevects(rH);
cmat spec = cmat::Zero(D, D);
for (std::size_t i = 0; i < D; i++)
    spec += evalsH(i) * prj((cmat) evectsH.col(i));
cout << "Original matrix: " << endl;</pre>
displn(rH);
cout << endl << "Reconstructed from spectral decomposition: " << endl;</pre>
displn(spec);
cout << "Difference in norm: " << norm(spec - rH) << endl;</pre>
// channel tests
cout << endl << "Channel tests." << endl;</pre>
std::size\_t nk = 10, d = 2; // nk Kraus on d-dimensional system
std::vector<cmat> Ks = randkraus(nk, d);
cmat rho_in = randrho(d); // input state
cmat rho_out = channel(rho_in, Ks); // output state
cout << "Computing its Choi matrix..." << endl;</pre>
cmat choim = choi(Ks);
cout << "Choi matrix:" << endl;</pre>
displn(choim);
cout << endl << "The eigenvalues of the Choi matrix are: " << endl;</pre>
displn(transpose(hevals(choim)));
cout << endl << "Their sum is: " << sum(hevals(choim)) << endl;</pre>
std::vector<cmat> Kperps = choi2kraus(choim);
cout << endl << "The Kraus rank of the channel is: " << Kperps.size()</pre>
         << endl;
cmat rho_out1 = channel(rho_in, Kperps);
cout << end1 << "Difference in norm on output states: "</pre>
         << norm(rho_out1 - rho_out) << endl;
cout << endl << "Superoperator matrix:" << endl;</pre>
cmat smat = super(Ks);
displn(smat);
cout << endl << "The eigenvalues of the superoperator matrix are: " << endl;</pre>
cmat evalsupop = evals(smat);
displn(transpose(evalsupop));
cout << endl << "Their absolute values are: " << endl;
for (std::size_t i = 0; i < (std::size_t) evalsupop.size(); i++)
    cout << std::abs((cplx) evalsupop(i)) << " ";</pre>
cout << endl << endl << "Diference in norm for superoperator action: ";</pre>
cmat rho_out2 = transpose(
         (cmat) reshape(smat * reshape(transpose(rho_in), d * d, 1), d, d));
cout << norm(rho_out - rho_out2) << endl;</pre>
// statistics tests
cout << endl << "Statistics tests." << endl;</pre>
std::vector<cplx> ampl = { 1. + 1_i, 1. - 1_i };
cmat va(1, 4);
va << 0.1, 1, 1. + 1_i, 1. + 2_i;
DiscreteDistributionAbsSquare dc(va);
cout << "The probabilities are: ";
displn(dc.probabilities(), ", ", "{", "}");</pre>
// // TIMING tests
cout << endl << "Timing tests..." << endl;
std::size_t n = 12; // number of qubits
std::size_t N = std::pow(2, n);
vector<std::size_t> dims(n, 2); // local dimensions
cout << "n = " << n << " qubits, matrix size " << N << " x " << N << "."
         << endl;
// matrix initialization
cout << endl << "Matrix initialization timing." << endl;</pre>
// start the timer, automatic tic() in the constructor
Timer t, total;
cmat randcmat = cmat::Random(N, N);
t.toc(); // read the time
cout << "Took " << t << " seconds." << endl;
// lazv matrix product
```

```
cout << endl << "Lazy matrix product timing." << endl;</pre>
auto lazyprod = randcmat * randcmat; // lazyprod has type GenMatProduct
t.toc(); // read the time
cout << "Took " << t << " seconds." << endl;
// ptrace1 timing
cout << endl << "ptrace1 timing." << endl;</pre>
t.tic(); // reset the chronometer
// trace away half of the qubits
ptrace1(randcmat,
{ (std::size_t) std::sqrt(N), (std::size_t) std::sqrt(N) }); t.toc(); // read the time cout << "Took " << t << " seconds." << endl;
// ptrace2 timing
cout << endl << "ptrace2 timing." << endl;</pre>
t.tic(); // reset the chronometer // trace away half of the qubits
ptrace2(randcmat,
{ (std::size_t) std::sqrt(N), (std::size_t) std::sqrt(N) });
t.toc(); // read the time
cout << "Took " << t << " seconds." << endl;
// ptrace
cout << endl << "ptrace timing." << endl;</pre>
vector<std::size_t> subsys_ptrace = { 0 };
cout << "Subsytem(s): ";
displn(subsys_ptrace, ", ");</pre>
t.tic();
ptrace(randcmat, subsys ptrace, dims);
t.toc();
cout << "Took " << t << " seconds." << endl;
// ptranspose
cout << endl << "ptranspose timing." << endl;</pre>
vector<std::size_t> subsys_ptranspose; // partially transpose n-1 subsystems
for (std::size_t i = 0; i < n - 1; i++)</pre>
     subsys_ptranspose.push_back(i);
cout << "Subsytem(s): ";
displn(subsys_ptranspose, ", ");
t.tic();
ptranspose (randcmat, subsys ptranspose, dims);
t.toc();
cout << "Took " << t << " seconds." << endl;
// syspermute
cout << endl << "syspermute timing." << endl;</pre>
fout < end < syspenmete timing. < end;
vector(std::size_t) perm; // left-shift all subsystems by 1
for (std::size_t i = 0; i < n; i++)
    perm.push_back((i + 1) % n);</pre>
cout << "Subsytem(s): ";</pre>
displn(perm, ", ");
t.tic();
syspermute(randcmat, perm, dims);
t.toc();
cout << "Took " << t << " seconds." << endl;
      // matrix product
cout << endl << "Matrix product timing." << endl;</pre>
11
      t.tic(); // reset the chronometer
11
//
      cmat prodmat = randcmat * randcmat; // explicit cmat now
      t.toc(); // read the time
cout << "Took " << t << " seconds." << endl;
// END TIMING
total.toc(); // read the total running time
cout << endl << "Total time: " << total.seconds() << " seconds.";
cout << endl << "Exiting qpp..." << endl;</pre>
```

Namespace Index

Z. I Namesbace List	2.1	Nam	espa	ce L	ist
---------------------	-----	-----	------	------	-----

Here is a list of all namespaces with brief descriptions:																							
qpp																		 				. 1	3
qpp	::internal																	 				. 7	(

6 Namespace Index

Hierarchical Index

3.1 Class Hierarchy

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

qpp::DiscreteDistribution	73
qpp::DiscreteDistributionAbsSquare	74
exception	
qpp::Exception	75
qpp::NormalDistribution	84
qpp::Qudit	85
$qpp::Singleton < T > \dots \dots$	88
qpp::Gates	78
qpp::RandomDevices	87
qpp::Singleton< const Gates >	88
qpp::Singleton < const States >	88
qpp::States	89
qpp::Singleton< RandomDevices >	88
qpp::Timer	92
qpp::UniformIntDistribution	93
gpp::UniformRealDistribution	93

8 **Hierarchical Index**

Class Index

4.1 Class List

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

qpp::DiscreteDistribution	73
qpp::DiscreteDistributionAbsSquare	74
qpp::Exception	75
qpp::Gates	78
qpp::NormalDistribution	84
qpp::Qudit	85
qpp::RandomDevices	87
qpp::Singleton< T >	88
qpp::States	89
qpp::Timer	92
qpp::UniformIntDistribution	93
gpp::UniformRealDistribution	93

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File Index

5.1 File List

Here is a list of all files with brief descriptions:

include/channels.h	
include/constants.h	
include/entanglement.h	
include/entropies.h	
include/functions.h	
include/internal.h	
include/io.h	
include/matlab.h	
include/qpp.h	
include/random.h	
include/types.h	
include/classes/exception.h	
include/classes/gates.h	
include/classes/qudit.h	
include/classes/randevs.h	
include/classes/singleton.h	
include/classes/stat.h	
include/classes/states.h	
include/classes/timer.h	

12 File Index

Namespace Documentation

6.1 qpp Namespace Reference

Namespaces

· internal

Classes

- · class DiscreteDistribution
- · class DiscreteDistributionAbsSquare
- class Exception
- · class Gates
- · class NormalDistribution
- · class Qudit
- class RandomDevices
- class Singleton
- · class States
- class Timer
- class UniformIntDistribution
- · class UniformRealDistribution

Typedefs

```
    using cplx = std::complex < double >
        Complex number in double precision.
```

• using cmat = Eigen::MatrixXcd

Complex (double precision) dynamic Eigen matrix.

using dmat = Eigen::MatrixXd

Real (double precision) dynamic Eigen matrix.

using ket = Eigen::Matrix < cplx, Eigen::Dynamic, 1 >
 Complex (double precision) dynamic Eigen column matrix.

using bra = Eigen::Matrix < cplx, 1, Eigen::Dynamic >

Complex (double precision) dynamic Eigen row matrix.

```
    template < typename Scalar >
        using DynMat = Eigen::Matrix < Scalar, Eigen::Dynamic, Eigen::Dynamic >
        Dynamic Eigen matrix over the field specified by Scalar.
```

Functions

Transpose.

```
    cmat super (const std::vector < cmat > &Ks)

     Superoperator matrix representation.

    cmat choi (const std::vector < cmat > &Ks)

     Choi matrix representation.

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

     Extracts orthogonal Kraus operators from Choi matrix.

    template<typename Derived >

  cmat channel (const Eigen::MatrixBase< Derived > &rho, const std::vector< cmat > &Ks)
     Applies the channel specified by the set of Kraus operators Ks to the density matrix rho.
• template<typename Derived >
  cmat channel (const Eigen::MatrixBase< Derived > &rho, const std::vector< cmat > &Ks, const std::vector<
  std::size t > &subsys, const std::vector< std::size t > &dims)
     Applies the channel specified by the set of Kraus operators Ks to the part of the density matrix rho specified by
     subsvs.

    constexpr std::complex < double > operator""_i (unsigned long long int x)

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

    constexpr std::complex< double > operator"" i (long double x)

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

    std::complex< double > omega (std::size_t D)

     D-th root of unity.

    template<typename Derived >

  cmat schmidtcoeff (const Eigen::MatrixBase< Derived > &A, const std::vector< std::size_t > &dims)
     Schmidt coefficients of the bi-partite pure state A.
• template<typename Derived >
  cmat schmidtU (const Eigen::MatrixBase< Derived > &A, const std::vector< std::size_t > &dims)
     Schmidt basis on Alice's side.

    template<typename Derived >

  cmat schmidtV (const Eigen::MatrixBase< Derived > &A, const std::vector< std::size t > &dims)
     Schmidt basis on Bob's side.

    template<typename Derived >

  cmat schmidtprob (const Eigen::MatrixBase< Derived > &A, const std::vector< std::size t > &dims)
     Schmidt probabilities of the bi-partite pure state A.

    template<typename Derived >

  double entanglement (const Eigen::MatrixBase< Derived > &A, const std::vector< std::size_t > &dims)
     Entanglement of the bi-partite pure state A.

    template<typename Derived >

  double gconcurrence (const Eigen::MatrixBase< Derived > &A)
     G-concurrence of the bi-partite pure state A.

    template<typename Derived >

  double shannon (const Eigen::MatrixBase< Derived > &A)

    template<typename Derived >

  double renyi (const double alpha, const Eigen::MatrixBase< Derived > &A)
• template<typename Derived >
  double renyi_inf (const Eigen::MatrixBase< Derived > &A)

    template<typename Derived >

  double tsallis (const double alpha, const Eigen::MatrixBase< Derived > &A)

    template<typename Derived >

  double qmutualinfo (const Eigen::MatrixBase< Derived > &A, const std::vector< std::size_t > &subsys,
  const std::vector< std::size t > &dims)

    template<typename Derived >

  DynMat< typename Derived::Scalar > transpose (const Eigen::MatrixBase< Derived > &A)
```

```
• template<typename Derived >
  DynMat< typename Derived::Scalar > conjugate (const Eigen::MatrixBase< Derived > &A)
     Complex conjugate.

    template<typename Derived >

  DynMat< typename Derived::Scalar > adjoint (const Eigen::MatrixBase< Derived > &A)
     Adjoint.
• template<typename Derived >
  DynMat< 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.

    template<typename Derived >

  double norm (const Eigen::MatrixBase< Derived > &A)
     Trace norm.

    template<typename Derived >

  cmat evals (const Eigen::MatrixBase< Derived > &A)
     Eigenvalues.
• template<typename Derived >
  cmat evects (const Eigen::MatrixBase< Derived > &A)
     Eigenvectors.

    template<typename Derived >

  dmat hevals (const Eigen::MatrixBase< Derived > &A)
     Hermitian eigenvalues.

    template<typename Derived >

  cmat hevects (const Eigen::MatrixBase< Derived > &A)
     Hermitian eigenvectors.

    template<typename Derived >

  cmat funm (const Eigen::MatrixBase< Derived > &A, cplx(*f)(const cplx &))
     Functional calculus f(A)

    template<typename Derived >

  cmat sqrtm (const Eigen::MatrixBase< Derived > &A)
     Matrix square root.
• template<typename Derived >
  cmat absm (const Eigen::MatrixBase< Derived > &A)
     Matrix absolut value.

    template<typename Derived >

  cmat expm (const Eigen::MatrixBase< Derived > &A)
     Matrix exponential.
• template<typename Derived >
  cmat logm (const Eigen::MatrixBase< Derived > &A)
     Matrix logarithm.

    template<typename Derived >

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

Matrix sin.

• template<typename Derived >

cmat cosm (const Eigen::MatrixBase< Derived > &A)

Matrix cos.

• template<typename Derived >

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

Matrix power.

 $\bullet \ \ \text{template}{<} \text{typename Derived} >$

DynMat< typename Derived::Scalar > powm (const Eigen::MatrixBase< Derived > &A, std::size_t n)

Matrix power

• template<typename OutputScalar , typename Derived >

DynMat< OutputScalar > cwise (const Eigen::MatrixBase< Derived > &A, OutputScalar(*f)(const typename Derived::Scalar &))

Functor.

• template<typename T >

DynMat< typename T::Scalar > kron (const T &head)

Kronecker product (variadic overload)

• template<typename T , typename... Args>

DynMat< typename T::Scalar > kron (const T &head, const Args &...tail)

Kronecker product (variadic overload)

• template<typename Derived >

DynMat< typename Derived::Scalar > kron (const std::vector< Derived > &As)

Kronecker product (std::vector overload)

• template<typename Derived >

DynMat< typename Derived::Scalar > kron (const std::initializer_list< Derived > &As)

Kronecker product (std::initializer list overload)

• template<typename Derived >

DynMat< typename Derived::Scalar > kronpow (const Eigen::MatrixBase< Derived > &A, std::size t n)

Kronecker power.

 $\bullet \ \ {\sf template}{<} {\sf typename \ Derived} >$

DynMat< typename Derived::Scalar > reshape (const Eigen::MatrixBase< Derived > &A, std::size_t rows, std::size_t cols)

Reshape.

• template<typename Derived >

DynMat< typename Derived::Scalar > syspermute (const Eigen::MatrixBase< Derived > &A, const std
::vector< std::size_t > &perm, const std::vector< std::size_t > &dims)

System permutation.

• template<typename Derived >

DynMat< typename Derived::Scalar > ptrace1 (const Eigen::MatrixBase< Derived > &A, const std::vector<
std::size_t > &dims)

Partial trace.

template<typename Derived >

DynMat< typename Derived::Scalar > ptrace2 (const Eigen::MatrixBase< Derived > &A, const std::vector<
std::size_t > &dims)

Partial trace.

• template<typename Derived >

DynMat< typename Derived::Scalar > ptrace (const Eigen::MatrixBase< Derived > &A, const std::vector<
std::size_t > &subsys, const std::vector< std::size_t > &dims)

Partial trace.

• template<typename Derived >

 $\label{eq:const_def} \begin{tabular}{ll} DynMat< typename \ Derived::Scalar > ptranspose (const Eigen::MatrixBase< Derived > &A, const std::vector< std::size_t > &subsys, const std::vector< std::size_t > &dims) \\ \end{tabular}$

Partial transpose.

Commutator.

• template<typename Derived1 , typename Derived2 >

Anti-commutator.

template<typename Derived >

DynMat< typename Derived::Scalar > prj (const Eigen::MatrixBase< Derived > &V)

Projector.

template<typename Derived >

DynMat< typename Derived::Scalar > expandout (const Eigen::MatrixBase< Derived > &A, std::size_t pos,
const std::vector< std::size_t > &dims)

Expand out.

template<typename Derived >

DynMat< typename Derived::Scalar > grams (const std::vector< Derived > &Vs)

Gram-Schmidt orthogonalization (std::vector overload)

• template<typename Derived >

DynMat< typename Derived::Scalar > grams (const std::initializer_list< Derived > &Vs)

Gram-Schmidt orthogonalization (std::initializer_list overload)

template<typename Derived >

DynMat< typename Derived::Scalar > grams (const Eigen::MatrixBase< Derived > &A)

Gram-Schmidt orthogonalization (Eigen expression (matrix) overload)

std::vector< std::size_t > n2multiidx (std::size_t n, const std::vector< std::size_t > &dims)

Non-negative integer index to multi-index.

std::size_t multiidx2n (const std::vector< std::size_t > &midx, const std::vector< std::size_t > &dims)

Multi-index to non-negative integer index.

ket mket (const std::vector< std::size_t > &mask)

Multi-partite qubit ket.

ket mket (const std::vector< std::size_t > &mask, const std::vector< std::size_t > &dims)

Multi-partite qudit ket (different dimensions overload)

ket mket (const std::vector< std::size t > &mask, std::size t d)

Multi-partite qudit ket (same dimensions overload)

std::vector< std::size_t > invperm (const std::vector< std::size_t > &perm)

Inverse permutation.

std::vector< std::size_t > compperm (const std::vector< std::size_t > &perm, const std::vector< std::size_t > &sigma)

Compose permutations.

• template<typename T >

void disp (const T &x, const std::string &separator, const std::string &start="[", const std::string &end="]", std::ostream &os=std::cout)

template<typename T >

void displn (const T &x, const std::string &separator, const std::string &start="[", const std::string &end="]", std::ostream &os=std::cout)

template<typename T >

void disp (const T *x, const std::size_t n, const std::string &separator, const std::string &start="[", const std
::string &end="]", std::ostream &os=std::cout)

 $\bullet \ \ template {<} typename \ T >$

void displn (const T *x, const std::string &separator, const std::string &start="[", const std::string &end="]", std::ostream &os=std::cout)

template<typename Derived >

void disp (const Eigen::MatrixBase< Derived > &A, double chop=chop, std::ostream &os=std::cout)

- template<typename Derived > void displn (const Eigen::MatrixBase< Derived > &A, double chop=chop, std::ostream &os=std::cout) void disp (const cplx c, double chop=chop, std::ostream &os=std::cout) void displn (const cplx c, double chop=chop, std::ostream &os=std::cout) template<typename Derived > void save (const Eigen::MatrixBase< Derived > &A, const std::string &fname) template<typename Derived > DynMat< typename Derived::Scalar > load (const std::string &fname) template<typename Derived > Derived loadMATLABmatrix (const std::string &mat_file, const std::string &var_name) template<> dmat loadMATLABmatrix (const std::string &mat_file, const std::string &var_name) template<> cmat loadMATLABmatrix (const std::string &mat_file, const std::string &var_name) template<typename Derived > void saveMATLABmatrix (const Eigen::MatrixBase< Derived > &A, const std::string &mat file, const std↔ ::string &var_name, const std::string &mode) template<> void saveMATLABmatrix (const Eigen::MatrixBase < dmat > &A, const std::string &mat_file, const std::string &var name, const std::string &mode) template<> void saveMATLABmatrix (const Eigen::MatrixBase< cmat > &A, const std::string &mat_file, const std::string &var name, const std::string &mode) • template<typename Derived > Derived rand (std::size_t rows, std::size_t cols, double a=0, double b=1) template<> dmat rand (std::size_t rows, std::size_t cols, double a, double b) template<> cmat rand (std::size t rows, std::size t cols, double a, double b) double rand (double a=0, double b=1) long long randint (long long a, long long b) template<typename Derived > Derived randn (std::size_t rows, std::size_t cols, double mean=0, double sigma=1) template<> dmat randn (std::size t rows, std::size_t cols, double mean, double sigma) • template<> cmat randn (std::size t rows, std::size t cols, double mean, double sigma) • double randn (double mean=0, double sigma=1) cmat randU (std::size_t D)
- cmat randH (std::size_t D)
- ket randket (std::size_t D)
- cmat randrho (std::size_t D)
- std::vector< std::size_t > randperm (std::size_t n)

• std::vector< cmat > randkraus (std::size t n, std::size t D)

cmat randV (std::size_t Din, std::size_t Dout)

Variables

• constexpr double chop = 1e-10

Used in qpp::disp() and qpp::displn() for setting to zero numbers that have their absolute value smaller than qpp::ct← ::chop.

• constexpr double eps = 1e-12

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

• constexpr std::size_t maxn = 64

Maximum number of qubits.

constexpr double pi = 3.141592653589793238462643383279502884

 π

• constexpr double ee = 2.718281828459045235360287471352662497

Base of natural logarithm, e.

RandomDevices & rdevs = RandomDevices::get_instance()

qpp::RandomDevices Singleton

const Gates & gt = Gates::get_instance()

qpp::Gates const Singleton

const States & st = States::get_instance()

qpp::States const Singleton

6.1.1 Typedef Documentation

6.1.1.1 using qpp::bra = typedef Eigen::Matrix<cplx, 1, Eigen::Dynamic>

Complex (double precision) dynamic Eigen row matrix.

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

Complex (double precision) dynamic Eigen matrix.

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

Complex number in double precision.

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

Real (double precision) dynamic Eigen matrix.

6.1.1.5 template<typename Scalar > using qpp::DynMat = typedef Eigen::Matrix<Scalar, Eigen::Dynamic, Eigen::Dynamic>

Dynamic Eigen matrix over the field specified by Scalar.

Example:

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

6.1.1.6 using qpp::ket = typedef Eigen::Matrix<cplx, Eigen::Dynamic, 1>

Complex (double precision) dynamic Eigen column matrix.

6.1.2 Function Documentation

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

Matrix absolut value.

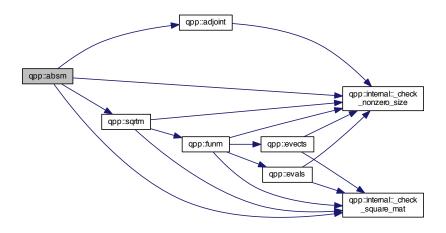
Parameters

Α	Eigen expression
---	------------------

Returns

Matrix absolut value of A, as a dynamic matrix over the complex field

Here is the call graph for this function:



6.1.2.2 template<typename Derived > DynMat<typename Derived::Scalar> qpp::adjoint (const Eigen::MatrixBase< Derived > & A)

Adjoint.

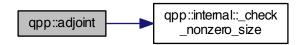
Parameters

Α	Eigen expression

Returns

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

Here is the call graph for this function:



6.1.2.3 template<typename Derived1 , typename Derived2 > DynMat<typename Derived1::Scalar> qpp::anticomm (const Eigen::MatrixBase< Derived1 > & A, const Eigen::MatrixBase< Derived2 > & B)

Anti-commutator.

Anti-commutator $\{A, B\} = AB + BA$

Both A and B must be Eigen expressions over the same scalar field

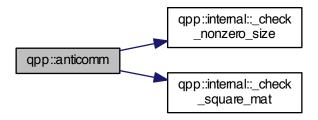
Parameters

Α	Eigen expression
В	Eigen expression

Returns

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

Here is the call graph for this function:



6.1.2.4 template<typename Derived > cmat qpp::channel (const Eigen::MatrixBase< Derived > & rho, const std::vector< cmat > & Ks)

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

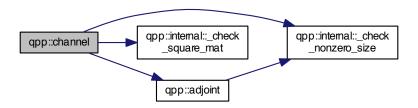
Parameters

rho	Eigen expression
Ks	std::vector of Eigen expressions representing the set of Kraus operators

Returns

Output density matrix, as a dynamic matrix over the complex field

Here is the call graph for this function:



6.1.2.5 template<typename Derived > cmat qpp::channel (const Eigen::MatrixBase< Derived > & rho, const std::vector< cmat > & Ks, const std::vector< std::size_t > & subsys, const std::vector< std::size_t > & dims)

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

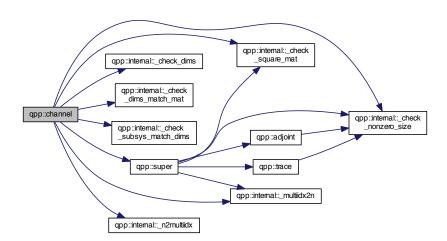
Parameters

rho	Eigen expression
Ks	std::vector of Eigen expressions representing the set of Kraus operators
subsys	Subsystems' indexes
dims	Dimensions of the multi-partite system

Returns

Output density matrix, as a dynamic matrix over the complex field

Here is the call graph for this function:



6.1.2.6 cmat qpp::choi (const std::vector< cmat > & Ks)

Choi matrix representation.

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

Note

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

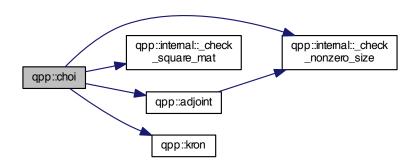
Parameters

Ks	std::vector of Eigen expressions representing the set of Kraus operators

Returns

Choi matrix representation, as a dynamic matrix over the complex field

Here is the call graph for this function:



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

Extracts orthogonal Kraus operators from Choi matrix.

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

Note

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

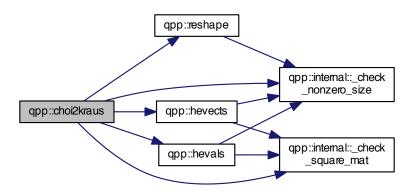
Parameters

Α	Choi matrix

Returns

std::vector of dynamic matrices over the complex field representing the set of Kraus operators

Here is the call graph for this function:



6.1.2.8 template<typename Derived1 , typename Derived2 > DynMat<typename Derived1::Scalar> qpp::comm (const Eigen::MatrixBase< Derived2 > & B)

Commutator.

Commutator [A,B] = AB - BA

Both A and B must be Eigen expressions over the same scalar field

Parameters

Α	Eigen expression
В	Eigen expression

Returns

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

Here is the call graph for this function:



Compose permutations.

perm	Permutation
sigma	Permutation

Returns

Composition of the permutations *perm* o *sigma* = perm(sigma)

Here is the call graph for this function:



6.1.2.10 template<typename Derived > DynMat<typename Derived::Scalar> qpp::conjugate (const Eigen::MatrixBase< Derived > & A)

Complex conjugate.

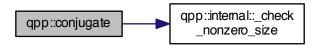
Parameters

Α	Eigen expression

Returns

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

Here is the call graph for this function:



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

Matrix cos.

Α	Eigen expression
---	------------------

Returns

Matrix cosine of A, as a dynamic matrix over the complex field

Here is the call graph for this function:



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

Functor.

Parameters

Α	Eigen expression
f	Pointer-to-function from scalars of A to OutputScalar

Returns

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

Here is the call graph for this function:



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

Determinant.

Α	Eigen expression

Returns

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

Here is the call graph for this function:



- 6.1.2.14 template<typename T > void qpp::disp (const T & x, const std::string & separator, const std::string & start = " [", const std::string & end = "] ", std::ostream & os = std::cout)
- 6.1.2.15 template < typename T > void qpp::disp (const T * x, const std::size_t n, const std::string & separator, const std::string & start = " [", const std::string & end = "] ", std::ostream & os = std::cout)
- 6.1.2.16 template < typename Derived > void qpp::disp (const Eigen::MatrixBase < Derived > & A, double chop = chop, std::ostream & os = std::cout)
- 6.1.2.17 void qpp::disp (const cplx c, double chop = chop, std::ostream & os = std::cout)



6.1.2.18 template<typename T > void qpp::displn (const T & x, const std::string & separator, const std::string & start = " [", const std::string & end = "] ", std::ostream & os = std::cout)

Here is the call graph for this function:



6.1.2.19 template<typename T > void qpp::displn (const T * x, const std::size_t n, const std::string & separator, const std::string & start = " [", const std::string & end = "] ", std::ostream & os = std::cout)

Here is the call graph for this function:



6.1.2.20 template < typename Derived > void qpp::displn (const Eigen::MatrixBase < Derived > & A, double chop = chop, std::scout)



6.1.2.21 void qpp::displn (const cplx c, double chop = chop, std::ostream & os = std::cout)

Here is the call graph for this function:



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

Entanglement of the bi-partite pure state A.

Note

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

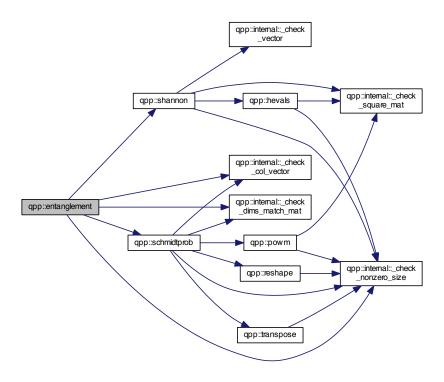
See also

qpp::shannon()

Α	Eigen expression
dims	Subsystems' dimensions

Entanglement, with the logarithm in base 2

Here is the call graph for this function:

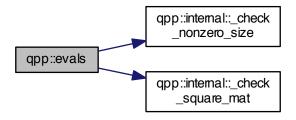


6.1.2.23 template < typename Derived > cmat qpp::evals (const Eigen::MatrixBase < Derived > & A)

Eigenvalues.

Α	Eigen expression

Eigenvalues of *A*, as a diagonal dynamic matrix over the complex field, with the eigenvalues on the diagonal Here is the call graph for this function:



6.1.2.24 template < typename Derived > cmat qpp::evects (const Eigen::MatrixBase < Derived > & A)

Eigenvectors.

Parameters

Α	Eigen expression

Returns

Eigenvectors of A, as columns of a dynamic matrix over the complex field

Here is the call graph for this function:



6.1.2.25 template < typename Derived > DynMat < typename Derived::Scalar > qpp::expandout (const Eigen::MatrixBase < Derived > & A, std::size_t pos, const std::vector < std::size_t > & dims)

Expand out.

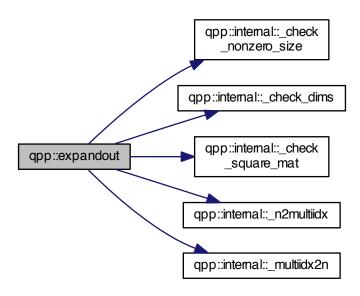
Expand out A as a matrix in a multi-partite system Faster than using *qpp::kron*(I, I, ..., I, A, I, ..., I)

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

Returns

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

Here is the call graph for this function:



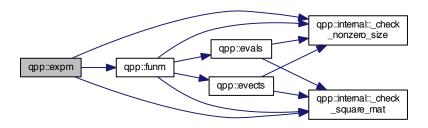
6.1.2.26 template < typename Derived > cmat qpp::expm (const Eigen::MatrixBase < Derived > & A)

Matrix exponential.

Α	Eigen expression

Matrix exponential of A, as a dynamic matrix over the complex field

Here is the call graph for this function:



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

Functional calculus f(A)

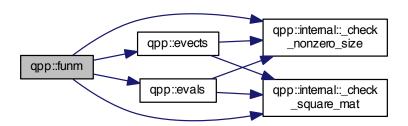
Parameters

Α	Eigen expression
f	Pointer-to-function from complex to complex

Returns

f(A), as a dynamic matrix over the complex field

Here is the call graph for this function:



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

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

Note

Uses qpp::logdet() to avoid overflows

See also

qpp::logdet()

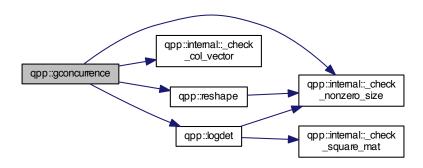
Parameters

Α	Eigen expression
dims	Subsystems' dimensions

Returns

G-concurrence

Here is the call graph for this function:



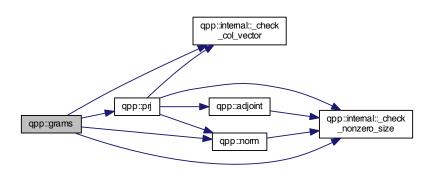
6.1.2.29 template < typename Derived > DynMat < typename Derived::Scalar > qpp::grams (const std::vector < Derived > & $\it Vs$)

Gram-Schmidt orthogonalization (std::vector overload)

Vs	std::vector of Eigen expressions as column vectors

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

Here is the call graph for this function:



6.1.2.30 template<typename Derived > DynMat<typename Derived::Scalar> qpp::grams (const std::initializer_list< Derived > & Vs)

Gram-Schmidt orthogonalization (std::initializer_list overload)

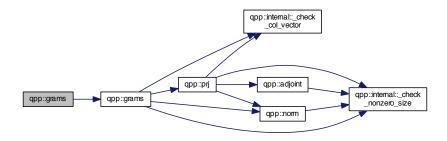
Parameters

Vs std::initializer_list of Eigen expressions as column vectors

Returns

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

Here is the call graph for this function:



6.1.2.31 template<typename Derived > DynMat<typename Derived::Scalar> qpp::grams (const Eigen::MatrixBase< Derived > & A)

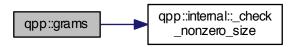
Gram-Schmidt orthogonalization (Eigen expression (matrix) overload)

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

Returns

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

Here is the call graph for this function:



6.1.2.32 template<typename Derived > dmat qpp::hevals (const Eigen::MatrixBase< Derived > & A)

Hermitian eigenvalues.

Parameters

Α	Eigen expression

Returns

Eigenvalues of Hermitian *A*, as a diagonal dynamic matrix over the real field, with eigenvalues on the diagonal Here is the call graph for this function:



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

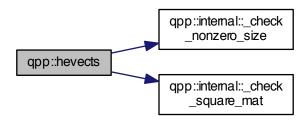
Hermitian eigenvectors.

Α	Eigen expression
---	------------------

Returns

Eigenvectors of Hermitian A, as columns of a dynamic matrix over the complex field

Here is the call graph for this function:



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

Inverse.

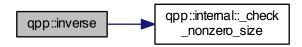
Parameters

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

Returns

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

Here is the call graph for this function:



6.1.2.35 std::vector<std::size_t> qpp::invperm (const std::vector< std::size_t > & perm)

Inverse permutation.

perm	Permutation
------	-------------

Returns

Inverse of the permutation perm

Here is the call graph for this function:



6.1.2.36 template<typename T > DynMat<typename T::Scalar> qpp::kron (const T & head)

Kronecker product (variadic overload)

Used to stop the recursion for the variadic template version of qpp::kron()

Parameters

head Eigen expression	
-----------------------	--

Returns

Its argument head

6.1.2.37 template<typename T , typename... Args> DynMat<typename T::Scalar> qpp::kron (const T & head, const Args &... tail)

Kronecker product (variadic overload)

head	Eigen expression
tail	Variadic Eigen expression (zero or more parameters)

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

Here is the call graph for this function:



6.1.2.38 template < typename Derived > DynMat < typename Derived::Scalar > qpp::kron (const std::vector < Derived > & As)

Kronecker product (std::vector overload)

Parameters

As	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

Here is the call graph for this function:



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

Kronecker product (std::initializer_list overload)

Λ -	Administration that of Figure commencions and a contract Administration Alexander
AS	std::initializer_list of Eigen expressions, such as {A1, A2, ,Ak}
, 10	otalimitalization of Eigen expressions, each as (717, 712, 111, 111)

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

Here is the call graph for this function:



6.1.2.40 template<typename Derived > DynMat<typename Derived::Scalar> qpp::kronpow (const Eigen::MatrixBase< Derived > & A, std::size_t n)

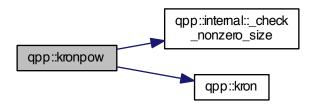
Kronecker power.

Parameters

Α	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



- $6.1.2.41 \quad template < typename \ Derived > DynMat < typename \ Derived :: Scalar > qpp:: load (\ const \ std:: string \ \& \ \textit{fname} \)$
- 6.1.2.42 template<typename Derived > Derived qpp::loadMATLABmatrix (const std::string & mat_file, const std::string & var_name)

- 6.1.2.43 template<> dmat qpp::loadMATLABmatrix (const std::string & mat_file, const std::string & var_name)
- 6.1.2.44 template <> cmat qpp::loadMATLABmatrix (const std::string & mat_file, const std::string & var_name)
- 6.1.2.45 template<typename Derived > Derived::Scalar qpp::logdet (const Eigen::MatrixBase< Derived > & A)

Logarithm of the determinant.

Especially useful when the determinant overflows/underflows

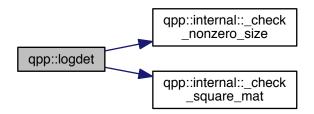
Parameters

Α	Eigen expression
---	------------------

Returns

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

Here is the call graph for this function:



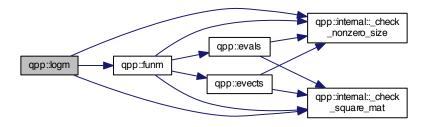
6.1.2.46 template<typename Derived > cmat qpp::logm (const Eigen::MatrixBase< Derived > & A)

Matrix logarithm.

Α	Eigen expression

Matrix logarithm of A, as a dynamic matrix over the complex field

Here is the call graph for this function:



6.1.2.47 ket qpp::mket (const std::vector < std::size_t > & mask)

Multi-partite qubit ket.

Constructs the multi-partite qubit ket $|mask\rangle$, where mask is a std::vector of 0's and 1's

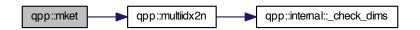
Parameters

mask	std::vector of 0's and 1's

Returns

Multi-partite qubit state vector, as a dynamic column vector over the complex field

Here is the call graph for this function:



6.1.2.48 ket qpp::mket (const std::vector < std::size_t > & mask, const std::vector < std::size_t > & dims)

Multi-partite qudit ket (different dimensions overload)

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

mask	std::vector of non-negative integers
dims	Dimensions of the multi-partite system

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

Here is the call graph for this function:



6.1.2.49 ket qpp::mket (const std::vector< std::size_t > & mask, std::size_t d)

Multi-partite qudit ket (same dimensions overload)

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

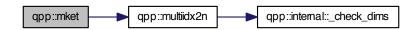
Parameters

mask	std::vector of non-negative integers
d	Subsystems' dimension

Returns

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

Here is the call graph for this function:



6.1.2.50 std::size_t qpp::multiidx2n (const std::vector < std::size_t > & midx, const std::vector < std::size_t > & dims)

Multi-index to non-negative integer index.

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

midx	Multi-index
dims	Dimensions of the multi-partite system

Returns

Non-negative integer index

Here is the call graph for this function:



 $6.1.2.51 \quad std::vector < std::size_t > qpp::n2multiidx (\ std::size_t \ \textit{n, } const \ std::vector < std::size_t > \& \ \textit{dims} \)$

Non-negative integer index to multi-index.

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

Parameters

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

Returns

Multi-index of the same size as dims

Here is the call graph for this function:



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

Trace norm.

Α	Eigen expression
---	------------------

Returns

Trace norm (Frobenius norm) of A, as a real number

Here is the call graph for this function:



6.1.2.53 std::complex<double> qpp::omega (std::size_t D)

D-th root of unity.

Parameters

```
D Non-negative integer
```

Returns

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

6.1.2.54 constexpr std::complex<double> qpp::operator""_i (unsigned long long int x)

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

Example:

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

6.1.2.55 constexpr std::complex<double> qpp::operator""_i (long double x)

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

Example:

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

6.1.2.56 template<typename Derived > DynMat<typename Derived::Scalar> qpp::powm (const Eigen::MatrixBase< Derived > & A, std::size_t n)

Matrix power.

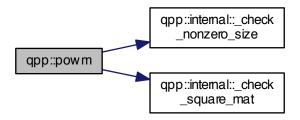
Explicitly multiplies the matrix ${\it A}$ with itself ${\it n}$ times By convention ${\it A}^0={\it I}$

Α	Eigen expression
n	Non-negative integer

Returns

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

Here is the call graph for this function:



6.1.2.57 template<typename Derived > DynMat<typename Derived::Scalar> qpp::prj (const Eigen::MatrixBase< Derived > & $\it V$)

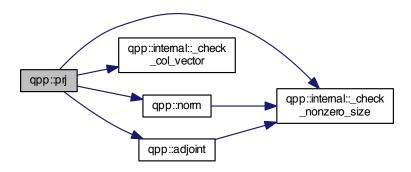
Projector.

Normalized projector onto state vector

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

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

Here is the call graph for this function:



6.1.2.58 template < typename Derived > DynMat < typename Derived::Scalar > qpp::ptrace (const Eigen::MatrixBase < Derived > & A, const std::vector < std::size_t > & subsys, const std::vector < std::size_t > & dims)

Partial trace.

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

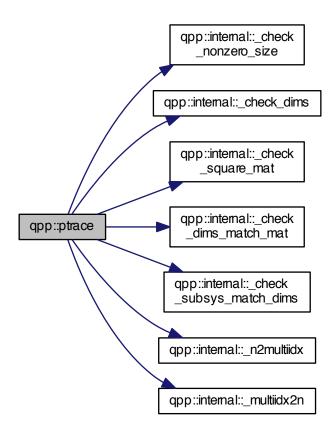
Parameters

Α	Eigen expression
subsys	Subsystems' indexes
dims	Dimensions of the multi-partite system

Returns

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

Here is the call graph for this function:



6.1.2.59 template < typename Derived > DynMat < typename Derived::Scalar > qpp::ptrace1 (const Eigen::MatrixBase < Derived > & A, const std::vector < std::size_t > & dims)

Partial trace.

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

Α	Eigen expression
dims	Dimensions of bi-partite system (must be a std::vector with 2 elements)

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

Here is the call graph for this function:



6.1.2.60 template < typename Derived > DynMat < typename Derived::Scalar > qpp::ptrace2 (const Eigen::MatrixBase < Derived > & A, const std::vector < std::size_t > & dims)

Partial trace.

Parameters

Α	Eigen expression
dims	Dimensions of bi-partite system (must be a std::vector with 2 elements)

Returns

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

Here is the call graph for this function:



Partial transpose.

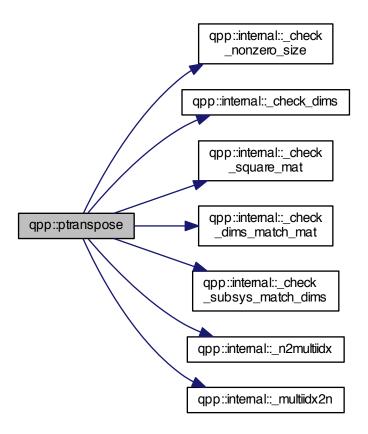
Partial transpose of the multi-partite density matrix over a list of subsystems

Parameters

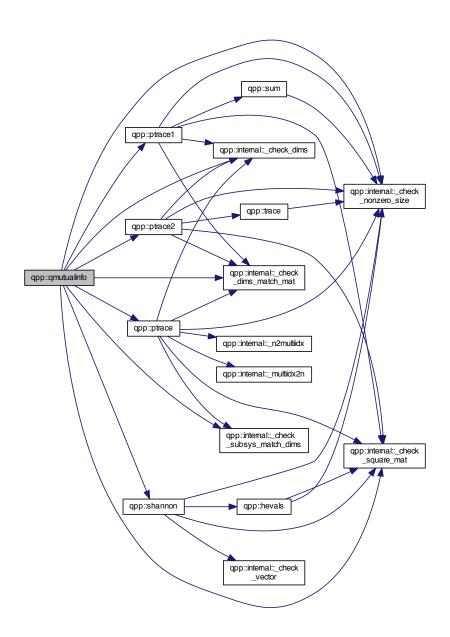
Α	Eigen expression
subsys	Subsystems' indexes
dims	Dimensions of the multi-partite system

Returns

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



6.1.2.62 template < typename Derived > double qpp::qmutualinfo (const Eigen::MatrixBase < Derived > & A, const std::vector < std::size_t > & subsys, const std::vector < std::size_t > & dims)



- 6.1.2.63 template < typename Derived > Derived qpp::rand (std::size_t rows, std::size_t cols, double a = 0, double b = 1)
- 6.1.2.64 template<> dmat qpp::rand (std::size_t rows, std::size_t cols, double a, double b)

6.1.2.65 template <> cmat qpp::rand (std::size_t rows, std::size_t cols, double a, double b)

Here is the call graph for this function:



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

Here is the call graph for this function:



6.1.2.67 cmat qpp::randH (std::size_t D)

Here is the call graph for this function:

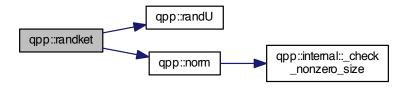


6.1.2.68 long long qpp::randint (long long a, long long b)



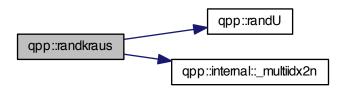
6.1.2.69 ket qpp::randket (std::size_t D)

Here is the call graph for this function:



6.1.2.70 std::vector<cmat> qpp::randkraus (std::size_t n, std::size_t D)

Here is the call graph for this function:



- 6.1.2.71 template<typename Derived > Derived qpp::randn (std::size_t rows, std::size_t cols, double mean = 0, double sigma = 1)
- 6.1.2.72 template<> dmat qpp::randn (std::size_t rows, std::size_t cols, double mean, double sigma)



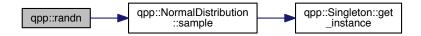
6.1.2.73 template<> cmat qpp::randn (std::size_t rows, std::size_t cols, double mean, double sigma)

Here is the call graph for this function:



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

Here is the call graph for this function:

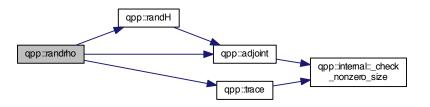


6.1.2.75 std::vector<std::size_t> qpp::randperm (std::size_t n)



6.1.2.76 cmat qpp::randrho (std::size_t D)

Here is the call graph for this function:



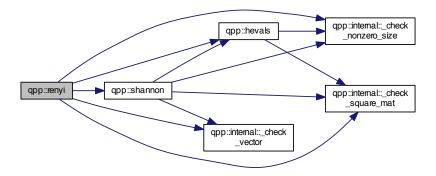
6.1.2.77 cmat qpp::randU (std::size_t D)

6.1.2.78 cmat qpp::randV (std::size_t Din, std::size_t Dout)

Here is the call graph for this function:

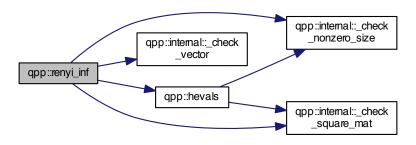


6.1.2.79 template<typename Derived > double qpp::renyi (const double alpha, const Eigen::MatrixBase< Derived > & A)



6.1.2.80 $template < typename Derived > double qpp::renyi_inf (const Eigen::MatrixBase < Derived <math>>$ & A)

Here is the call graph for this function:



Reshape.

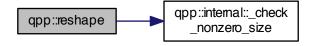
Uses column-major order when reshaping (same as MATLAB)

Parameters

Α	Eigen expression
rows	Number of rows of the reshaped matrix
cols	Number of columns of the reshaped matrix

Returns

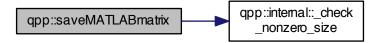
Reshaped matrix with rows rows and cols columns, as a dynamic matrix over the same scalar field



- 6.1.2.82 template < typename Derived > void qpp::save (const Eigen::MatrixBase < Derived > & A, const std::string & fname
- 6.1.2.83 template < typename Derived > void qpp::saveMATLABmatrix (const Eigen::MatrixBase < Derived > & A, const std::string & mat_file, const std::string & mode)

6.1.2.84 template<> void qpp::saveMATLABmatrix (const Eigen::MatrixBase< dmat > & A, const std::string & mat_file, const std::string & var_name, const std::string & mode)

Here is the call graph for this function:



6.1.2.85 template<> void qpp::saveMATLABmatrix (const Eigen::MatrixBase< cmat > & A, const std::string & mat_file, const std::string & var_name, const std::string & mode)

Here is the call graph for this function:



6.1.2.86 template < typename Derived > cmat qpp::schmidtcoeff (const Eigen::MatrixBase < Derived > & A, const std::vector < std::size_t > & dims)

Schmidt coefficients of the bi-partite pure state A.

Note

The sum of the squares of the Schmidt coefficients equals 1

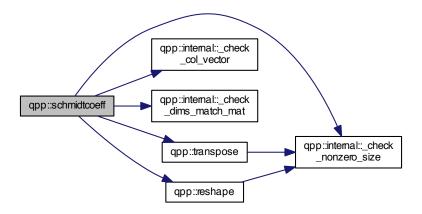
See also

app::schmidtprob()

Α	Eigen expression
dims	Subsystems' dimensions

Schmidt coefficients of A, as a dynamic matrix over the complex field, with the Schmidt coefficients on the diagonal

Here is the call graph for this function:



6.1.2.87 template<typename Derived > cmat qpp::schmidtprob (const Eigen::MatrixBase< Derived > & A, const std::vector< std::size_t > & dims)

Schmidt probabilities of the bi-partite pure state A.

Note

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

See also

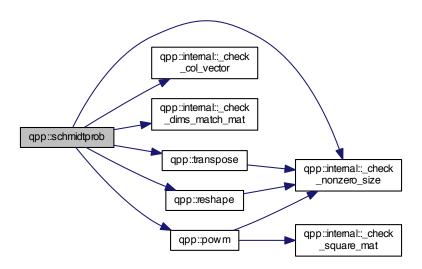
qpp::schmidtcoeff()

Α	Eigen expression
dims	Subsystems' dimensions

Returns

Schmidt probabilites of A, as a dynamic matrix over the complex field, with the Schmidt probabilities on the diagonal

Here is the call graph for this function:



6.1.2.88 template < typename Derived > cmat qpp::schmidtU (const Eigen::MatrixBase < Derived > & A, const std::vector < std::size_t > & dims)

Schmidt basis on Alice's side.

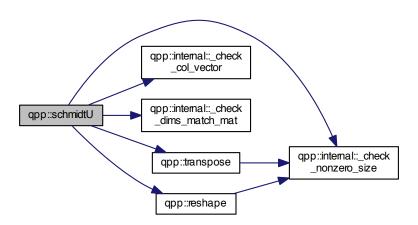
Parameters

Α	Eigen expression
dims	Subsystems' dimensions

Returns

Unitary matrix U representing the Schmidt basis on Alice's side, as a dynamic matrix over the complex field, acting on the computational basis as $U|j\rangle=|\bar{j}\rangle$ (Schmidt vector)

Here is the call graph for this function:



6.1.2.89 template < typename Derived > cmat qpp::schmidtV (const Eigen::MatrixBase < Derived > & A, const std::vector < std::size_t > & dims)

Schmidt basis on Bob's side.

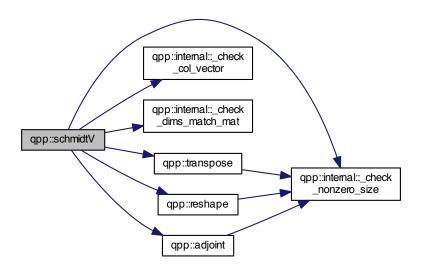
Parameters

Α	Eigen expression
dims	Subsystems' dimensions

Returns

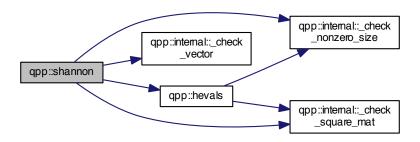
Unitary matrix V representing the Schmidt basis on Bob's side, as a dynamic matrix over the complex field, acting on the computational basis as $V|j\rangle=|\bar{j}\rangle$ (Schmidt vector)

Here is the call graph for this function:



6.1.2.90 template < typename Derived > double qpp::shannon (const Eigen::MatrixBase < Derived > & A)

Here is the call graph for this function:



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

Matrix sin.

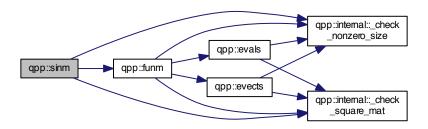
Parameters

Α	Eigen expression

Returns

Matrix sine of A, as a dynamic matrix over the complex field

Here is the call graph for this function:



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

Matrix power.

Uses the spectral decomposition of \emph{A} to compute the matrix power By convention $\emph{A}^0 = \emph{I}$

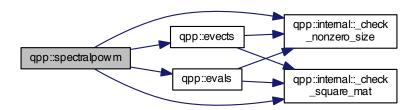
Parameters

A	Eigen expression
Z	Complex number

Returns

Matrix power A^z , as a dynamic matrix over the complex field

Here is the call graph for this function:



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

Matrix square root.

Parameters

_		
	Α	Eigen expression

Returns

Matrix square root of A, as a dynamic matrix over the complex field

Here is the call graph for this function:



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

Element-wise sum.

Parameters

A	Eigen expression

Returns

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

Here is the call graph for this function:



6.1.2.95 cmat qpp::super (const std::vector < cmat > & Ks)

Superoperator matrix representation.

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

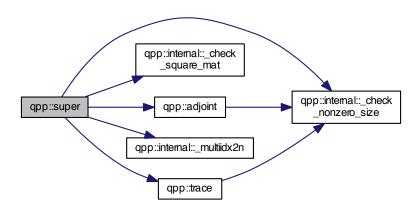
Parameters

Ks	std::vector of Eigen expressions representing the set of Kraus operators
----	--

Returns

Superoperator matrix representation, as a dynamic matrix over the complex field

Here is the call graph for this function:



System permutation.

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

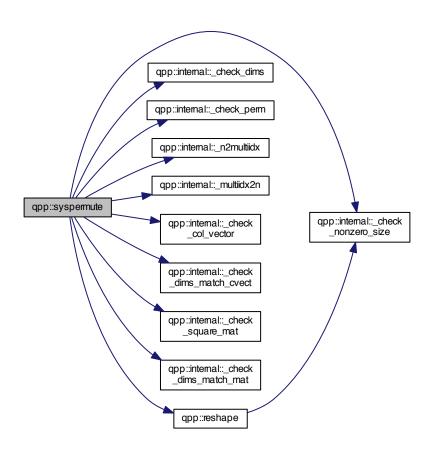
Parameters

Α	Eigen expression
perm	Permutation
dims	Subsystems' dimensions

Returns

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

Here is the call graph for this function:



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

Trace.

Parameters

Α	Eigen expression

Returns

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

Here is the call graph for this function:



6.1.2.98 template<typename Derived > DynMat<typename Derived::Scalar> qpp::transpose (const Eigen::MatrixBase < Derived > & $\bf A$)

Transpose.

Parameters

```
A Eigen expression
```

Returns

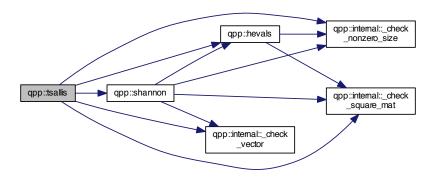
Transpose of A, as a dynamic matrix over the same scalar field

Here is the call graph for this function:



6.1.2.99 template<typename Derived > double qpp::tsallis (const double alpha, const Eigen::MatrixBase< Derived > & A)

Here is the call graph for this function:



6.1.3 Variable Documentation

6.1.3.1 constexpr double qpp::chop = 1e-10

Used in *qpp::disp()* and *qpp::displn()* for setting to zero numbers that have their absolute value smaller than *qpp ⇔ ::ct::chop*.

6.1.3.2 constexpr double qpp::ee = 2.718281828459045235360287471352662497

Base of natural logarithm, e.

6.1.3.3 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::ct::eps) // x is zero</pre>
```

6.1.3.4 const Gates& qpp::gt = Gates::get_instance()

qpp::Gates const Singleton

Initializes the gates, see the class *qpp::Gates*

6.1.3.5 constexpr std::size_t qpp::maxn = 64

Maximum number of qubits.

Used internally to statically allocate arrays (for speed reasons)

6.1.3.6 constexpr double qpp::pi = 3.141592653589793238462643383279502884

 π

6.1.3.7 RandomDevices& qpp::rdevs = RandomDevices::get_instance()

qpp::RandomDevices Singleton

Initializes the random devices, see the class *qpp::RandomDevices*

6.1.3.8 const States& qpp::st = States::get_instance()

qpp::States const Singleton

Initializes the states, see the class *qpp::States*

6.2 qpp::internal Namespace Reference

Functions

- void n2multiidx (std::size t n, std::size t numdims, const std::size t *dims, std::size t *result)
- std::size t multiidx2n (const std::size t *midx, std::size t numdims, const std::size t *dims)
- template<typename Derived >

bool <u>_check_square_mat</u> (const Eigen::MatrixBase< Derived > &A)

template<typename Derived >

bool <u>_check_vector</u> (const Eigen::MatrixBase< Derived > &A)

template<typename Derived >

bool <u>_check_row_vector</u> (const Eigen::MatrixBase< Derived > &A)

• template<typename Derived >

bool <u>_check_col_vector</u> (const Eigen::MatrixBase< Derived > &A)

 $\bullet \ \ template {<} typename \ T >$

bool <u>_check_nonzero_size</u> (const T &x)

- bool <u>_check_dims</u> (const std::vector < std::size_t > &dims)
- template<typename Derived >

 $\label{local_bool_check_dims_match_mat} \mbox{ (const std::vector} < \mbox{ std::size_t} > \mbox{\&dims, const Eigen::MatrixBase} < \mbox{ Derived} > \mbox{\&A})$

template<typename Derived >

 $\label{local_check_dims_match_cvect} \mbox{ (const std::vector} < \mbox{ std::size_t} > \& \mbox{ dims, const Eigen::MatrixBase} < \mbox{ Derived} > \& \mbox{ V)}$

 $\bullet \ \ \mathsf{template} \mathord{<} \mathsf{typename} \ \mathsf{Derived} >$

 $\label{local_check_dims_match_rvect} bool_check_dims_match_rvect \ (const \ std::vector < std::size_t > \&dims, \ const \ Eigen::MatrixBase < Derived > \&V)$

- bool check eq dims (const std::vector< std::size t > &dims, std::size t dim)
- bool _check_subsys_match_dims (const std::vector< std::size_t > &subsys, const std::vector< std::size_t > &dims)
- bool _check_perm (const std::vector< std::size_t > &perm)
- template<typename Derived1 , typename Derived2 >

DynMat< typename Derived1::Scalar > _kron2 (const Eigen::MatrixBase< Derived1 > &A, const Eigen::

MatrixBase< Derived2 > &B)

template<typename T >

void variadic_vector_emplace (std::vector< T > &)

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

6.2.1 Detailed Description

Internal functions, do not modify or use directly

- 6.2.2 Function Documentation
- 6.2.2.1 template < typename Derived > bool qpp::internal::_check_col_vector (const Eigen::MatrixBase < Derived > & A)
- 6.2.2.2 bool qpp::internal::_check_dims (const std::vector < std::size_t > & dims)
- 6.2.2.3 template<typename Derived > bool qpp::internal::_check_dims_match_cvect (const std::vector< std::size_t > & dims, const Eigen::MatrixBase< Derived > & V)
- 6.2.2.4 template<typename Derived > bool qpp::internal::_check_dims_match_mat (const std::vector< std::size_t > & dims, const Eigen::MatrixBase< Derived > & A)
- 6.2.2.5 template<typename Derived > bool qpp::internal::_check_dims_match_rvect (const std::vector< std::size_t > & dims, const Eigen::MatrixBase< Derived > & V)
- 6.2.2.6 bool qpp::internal::_check_eq_dims (const std::vector< std::size_t > & dims, std::size_t dim)
- 6.2.2.7 template<typename T > bool qpp::internal::_check_nonzero_size (const T & x)
- 6.2.2.8 bool qpp::internal::_check_perm (const std::vector < std::size_t > & perm)
- 6.2.2.9 template < typename Derived > bool qpp::internal::_check_row_vector (const Eigen::MatrixBase < Derived > & A)
- 6.2.2.10 template < typename Derived > bool qpp::internal::_check_square_mat (const Eigen::MatrixBase < Derived > & A)
- 6.2.2.11 bool qpp::internal::_check_subsys_match_dims (const std::vector < std::size_t > & subsys, const std::vector < std::size_t > & dims)
- 6.2.2.12 template < typename Derived > bool qpp::internal::_check_vector (const Eigen::MatrixBase < Derived > & A)

Here is the call graph for this function:



- 6.2.2.14 std::size_t app::internal::_multiidx2n (const std::size_t * midx, std::size_t numdims, const std::size_t * dims)
- 6.2.2.15 void qpp::internal::_n2multiidx (std::size_t n, std::size_t numdims, const std::size_t * dims, std::size_t * result)
- 6.2.2.16 template < typename T > void qpp::internal::variadic_vector_emplace (std::vector < T > &)

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

Here is the call graph for this function:



Chapter 7

Class Documentation

7.1 qpp::DiscreteDistribution Class Reference

```
#include <stat.h>
```

Public Member Functions

- template<typename InputIterator >
 DiscreteDistribution (InputIterator first, InputIterator last)
- Discrete Distribution (std::initializer_list< double > weights)
- Discrete Distribution (std::vector< double > weights)
- std::size_t sample ()
- std::vector< double > probabilities () const

Protected Attributes

```
std::discrete_distributionstd::size_t > _d
```

7.1.1 Constructor & Destructor Documentation

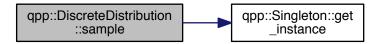
- 7.1.1.1 template < typename InputIterator > qpp::DiscreteDistribution::DiscreteDistribution (InputIterator first, InputIterator last) [inline]
- 7.1.1.2 qpp::DiscreteDistribution::DiscreteDistribution (std::initializer_list < double > weights) [inline]
- 7.1.1.3 qpp::DiscreteDistribution::DiscreteDistribution (std::vector< double > weights) [inline]

7.1.2 Member Function Documentation

7.1.2.1 std::vector<double> qpp::DiscreteDistribution::probabilities () const [inline]

7.1.2.2 std::size_t qpp::DiscreteDistribution::sample() [inline]

Here is the call graph for this function:



7.1.3 Member Data Documentation

7.1.3.1 std::discrete_distribution<std::size_t> qpp::DiscreteDistribution::_d [protected]

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

· include/classes/stat.h

7.2 qpp::DiscreteDistributionAbsSquare Class Reference

#include <stat.h>

Public Member Functions

- template<typename InputIterator >
 DiscreteDistributionAbsSquare (InputIterator first, InputIterator last)
- DiscreteDistributionAbsSquare (std::initializer_list< cplx > amplitudes)
- DiscreteDistributionAbsSquare (std::vector< cplx > amplitudes)
- template<typename Derived >
 DiscreteDistributionAbsSquare (const Eigen::MatrixBase< Derived > &V)
- std::size_t sample ()
- std::vector< double > probabilities () const

Protected Member Functions

template<typename InputIterator >
 std::vector< double > cplx2weights (InputIterator first, InputIterator last) const

Protected Attributes

std::discrete_distributionstd::size_t > _d

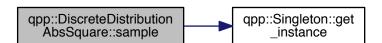
7.2.1 Constructor & Destructor Documentation

- 7.2.1.1 template < typename InputIterator > qpp::DiscreteDistributionAbsSquare::DiscreteDistributionAbsSquare (InputIterator *lirst*, InputIterator *last*) <code>[inline]</code>
- 7.2.1.2 qpp::DiscreteDistributionAbsSquare::DiscreteDistributionAbsSquare (std::initializer_list< cplx > amplitudes) [inline]
- 7.2.1.3 qpp::DiscreteDistributionAbsSquare::DiscreteDistributionAbsSquare (std::vector < cplx > amplitudes) [inline]
- 7.2.1.4 template < typename Derived > qpp::DiscreteDistributionAbsSquare::DiscreteDistributionAbsSquare (const Eigen::MatrixBase < Derived > & V) [inline]

7.2.2 Member Function Documentation

- 7.2.2.1 template<typename InputIterator > std::vector<double> qpp::DiscreteDistributionAbsSquare::cplx2weights (InputIterator first, InputIterator last) const [inline], [protected]
- **7.2.2.2** std::vector<double> qpp::DiscreteDistributionAbsSquare::probabilities () const [inline]
- **7.2.2.3** std::size_t qpp::DiscreteDistributionAbsSquare::sample() [inline]

Here is the call graph for this function:



7.2.3 Member Data Documentation

7.2.3.1 std::discrete_distribution<std::size_t> qpp::DiscreteDistributionAbsSquare::_d [protected]

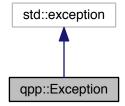
The documentation for this class was generated from the following file:

• include/classes/stat.h

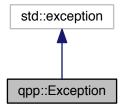
7.3 qpp::Exception Class Reference

#include <exception.h>

Inheritance diagram for qpp::Exception:



Collaboration diagram for qpp::Exception:



Public Types

• enum Type {

Type::UNKNOWN_EXCEPTION = 1, Type::ZERO_SIZE, Type::MATRIX_NOT_SQUARE, Type::MATRIX_← NOT_CVECTOR,

Type::MATRIX_NOT_RVECTOR, Type::MATRIX_NOT_VECTOR, Type::MATRIX_NOT_SQUARE_OR_C↔ VECTOR, Type::MATRIX_NOT_SQUARE_OR_RVECTOR,

Type::MATRIX_NOT_SQUARE_OR_VECTOR, Type::DIMS_INVALID, Type::DIMS_NOT_EQUAL, Type::D↔ IMS_MISMATCH_MATRIX,

 $\label{type::DIMS_MISMATCH_CVECTOR} Type::DIMS_MISMATCH_RVECTOR, Type::DIMS_MISMATCH_VE \leftarrow CTOR, Type::SUBSYS_MISMATCH_DIMS,$

Type::PERM_INVALID, Type::NOT_QUBIT_GATE, Type::NOT_QUBIT_SUBSYS, Type::NOT_BIPARTITE, Type::OUT_OF_RANGE, Type::TYPE_MISMATCH, Type::UNDEFINED_TYPE, Type::CUSTOM_EXCEPT → ION }

Public Member Functions

- Exception (const std::string &where, const Type &type)
- Exception (const std::string &where, const std::string &custom)
- virtual const char * what () const noexceptoverride

Private Member Functions

• std::string _construct_exception_msg ()

Private Attributes

- · std::string where
- std::string _msg
- Type type
- std::string custom

7.3.1 Member Enumeration Documentation

7.3.1.1 enum qpp::Exception::Type [strong]

Enumerator

UNKNOWN_EXCEPTION Unknown exception

ZERO_SIZE Zero sized object, e.g. empty Eigen::Matrix or std::vector with no elements

MATRIX_NOT_SQUARE Eigen::Matrix is not square

MATRIX_NOT_CVECTOR Eigen::Matrix is not a column vector

MATRIX_NOT_RVECTOR Eigen::Matrix is not a row vector

MATRIX_NOT_VECTOR Eigen::Matrix is not a row/column vector

MATRIX NOT SQUARE OR CVECTOR Eigen::Matrix is not square nor a column vector

MATRIX_NOT_SQUARE_OR_RVECTOR Eigen::Matrix is not square nor a row vector

MATRIX_NOT_SQUARE_OR_VECTOR Eigen::Matrix is not square nor a row/column vector

DIMS_INVALID std::vector<std::size_t> representing the dimensions has zero size or contains zeros

DIMS_NOT_EQUAL std::vector<std::size_t> representing the dimensions contains non-equal elements

DIMS_MISMATCH_MATRIX Product of the dimenisons' std::vector<std::size_t> is not equal to the number of rows of Eigen::Matrix (assumed to be square)

DIMS_MISMATCH_CVECTOR Product of the dimenisons' std::vector<std::size_t> is not equal to the number of cols of Eigen::Matrix (assumed to be a column vector)

DIMS_MISMATCH_RVECTOR Product of the dimenisons' std::vector<std::size_t> is not equal to the number of cols of Eigen::Matrix (assumed to be a row vector)

DIMS_MISMATCH_VECTOR Product of the dimenisons' std::vector<std::size_t> is not equal to the number of cols of Eigen::Matrix (assumed to be a row/column vector)

SUBSYS_MISMATCH_DIMS std::vector<std::size_t> representing the subsystems' labels has duplicatates, or has entries that are larger than the size of the std::vector<std::size_t> representing the dimensions

PERM_INVALID Invalid std::vector<std::size_t> permutation

NOT_QUBIT_GATE Eigen::Matrix is not 2 x 2

NOT_QUBIT_SUBSYS Subsystems are not 2-dimensional

NOT_BIPARTITE std::vector<std::size t> representing the dimensions has size different from 2

OUT_OF_RANGE Parameter out of range

TYPE_MISMATCH Types do not match (i.e. Matrix<double> vs Matrix<cplx>)

UNDEFINED_TYPE Templated function not defined for this type

CUSTOM_EXCEPTION Custom exception, user must provide a custom message

7.3.2 Constructor & Destructor Documentation

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

Here is the call graph for this function:



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

Here is the call graph for this function:



7.3.3 Member Function Documentation

- 7.3.3.1 std::string qpp::Exception::_construct_exception_msg() [inline], [private]
- 7.3.3.2 virtual const char* qpp::Exception::what () const [inline], [override], [virtual], [noexcept]
- 7.3.4 Member Data Documentation
- **7.3.4.1 std::string qpp::Exception::_custom** [private]
- **7.3.4.2 std::string qpp::Exception::_msg** [private]
- **7.3.4.3 Type qpp::Exception::_type** [private]
- **7.3.4.4 std::string qpp::Exception::_where** [private]

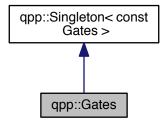
The documentation for this class was generated from the following file:

• include/classes/exception.h

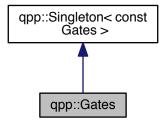
7.4 qpp::Gates Class Reference

#include <gates.h>

Inheritance diagram for qpp::Gates:



Collaboration diagram for qpp::Gates:



Public Member Functions

- cmat Rn (double theta, std::vector< double > n) const
- cmat Zd (std::size t D) const
- cmat Fd (std::size t D) const
- cmat Xd (std::size_t D) const
- template<typename Derived = Eigen::MatrixXcd>
 Derived Id (std::Size_t D) const
- template<typename Derived1 , typename Derived2 >
 DynMat< typename Derived1::Scalar > applyCTRL (const Eigen::MatrixBase< Derived1 > &state, const Eigen::MatrixBase< Derived2 > &A, const std::vector< std::size_t > &ctrl, const std::vector< std::size_t > &subsys, std::size t n, std::size t d=2) const
- template<typename Derived >
 DynMat< typename Derived::Scalar > CTRL (const Eigen::MatrixBase< Derived > &A, const std::vector< std::size_t > &ctrl, const std::vector< std::size_t > &subsys, std::size_t n, std::size_t d=2) const

Public Attributes

```
cmat Id2 { cmat::Identity(2, 2) }
cmat H { cmat::Zero(2, 2) }
cmat X { cmat::Zero(2, 2) }
cmat Y { cmat::Zero(2, 2) }
cmat Z { cmat::Zero(2, 2) }
cmat S { cmat::Zero(2, 2) }
cmat T { cmat::Zero(2, 2) }
cmat CNOTab { cmat::Identity(4, 4) }
cmat CX { cmat::Identity(4, 4) }
cmat CNOTba { cmat::Zero(4, 4) }
cmat SWAP { cmat::Identity(4, 4) }
cmat TOF { cmat::Identity(8, 8) }
cmat FRED { cmat::Identity(8, 8) }
```

Private Member Functions

• Gates ()

Friends

class Singleton < const Gates >

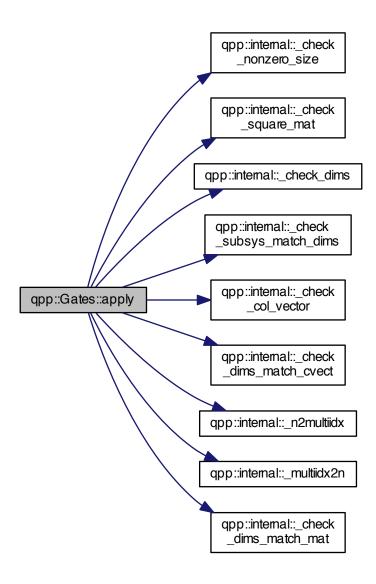
Additional Inherited Members

7.4.1 Constructor & Destructor Documentation

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

7.4.2 Member Function Documentation

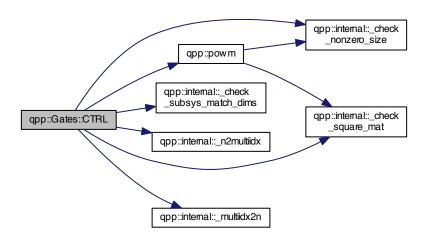
Here is the call graph for this function:



7.4.2.2 template<typename Derived1 , typename Derived2 > DynMat<typename Derived1::Scalar> qpp::Gates::applyCTRL (const Eigen::MatrixBase< Derived1 > & state, const Eigen::MatrixBase< Derived2 > & A, const std::vector< std::size_t > & ctrl, const std::vector< std::size_t n, std::size_t n, std::size_t d = 2) const [inline]

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

Here is the call graph for this function:



7.4.2.4 cmat qpp::Gates::Fd (std::size_t D) const [inline]

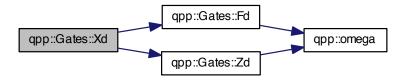
Here is the call graph for this function:



- 7.4.2.5 template<typename Derived = Eigen::MatrixXcd> Derived qpp::Gates::Id (std::size_t D) const [inline]
- 7.4.2.6 cmat qpp::Gates::Rn (double theta, std::vector < double > n) const [inline]

7.4.2.7 cmat qpp::Gates::Xd (std::size_t D) const [inline]

Here is the call graph for this function:



7.4.2.8 cmat qpp::Gates::Zd (std::size_t D) const [inline]

Here is the call graph for this function:



- 7.4.3 Friends And Related Function Documentation
- **7.4.3.1** friend class Singleton < const Gates > [friend]
- 7.4.4 Member Data Documentation
- 7.4.4.1 cmat qpp::Gates::CNOTab { cmat::Identity(4, 4) }
- 7.4.4.2 cmat qpp::Gates::CNOTba { cmat::Zero(4, 4) }
- 7.4.4.3 cmat qpp::Gates::CZ { cmat::Identity(4, 4) }
- 7.4.4.4 cmat qpp::Gates::FRED { cmat::Identity(8, 8) }
- 7.4.4.5 cmat qpp::Gates::H { cmat::Zero(2, 2) }
- 7.4.4.6 cmat qpp::Gates::ld2 { cmat::ldentity(2, 2) }
- 7.4.4.7 cmat qpp::Gates::S { cmat::Zero(2, 2) }
- 7.4.4.8 cmat qpp::Gates::SWAP { cmat::Identity(4, 4) }
- 7.4.4.9 cmat qpp::Gates::T { cmat::Zero(2, 2) }

```
    7.4.4.10 cmat qpp::Gates::TOF { cmat::Identity(8, 8) }
    7.4.4.11 cmat qpp::Gates::X { cmat::Zero(2, 2) }
    7.4.4.12 cmat qpp::Gates::Y { cmat::Zero(2, 2) }
    7.4.4.13 cmat qpp::Gates::Z { cmat::Zero(2, 2) }
```

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

• include/classes/gates.h

7.5 qpp::NormalDistribution Class Reference

```
#include <stat.h>
```

Public Member Functions

- NormalDistribution (double mean=0, double sigma=1)
- double sample ()

Protected Attributes

• std::normal_distribution_d

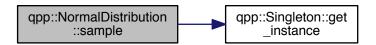
7.5.1 Constructor & Destructor Documentation

7.5.1.1 qpp::NormalDistribution::NormalDistribution (double mean = 0, double sigma = 1) [inline]

7.5.2 Member Function Documentation

7.5.2.1 double qpp::NormalDistribution::sample() [inline]

Here is the call graph for this function:



7.5.3 Member Data Documentation

7.5.3.1 std::normal_distribution qpp::NormalDistribution::_d [protected]

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

• include/classes/stat.h

7.6 qpp::Qudit Class Reference

```
#include <qudit.h>
```

Public Member Functions

- Qudit (const cmat &rho=States::get_instance().pz0)
- std::size_t measure (const cmat &U, bool destructive=false)
- std::size_t measure (bool destructive=false)
- cmat getRho () const
- std::size_t getD () const

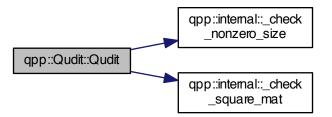
Private Attributes

- cmat _rho
- std::size_t _D

7.6.1 Constructor & Destructor Documentation

```
7.6.1.1 qpp::Qudit::Qudit ( const cmat & rho = States::get_instance () .pz0 ) [inline]
```

Here is the call graph for this function:

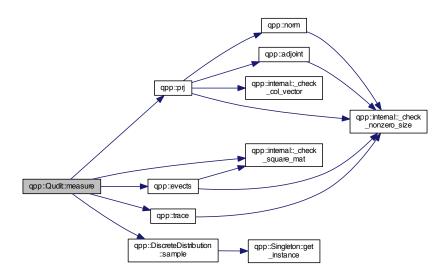


7.6.2 Member Function Documentation

- 7.6.2.1 std::size_t qpp::Qudit::getD () const [inline]
- 7.6.2.2 cmat qpp::Qudit::getRho() const [inline]

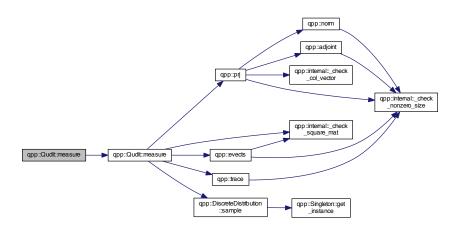
7.6.2.3 std::size_t qpp::Qudit::measure (const cmat & U, bool destructive = false) [inline]

Here is the call graph for this function:



7.6.2.4 std::size_t qpp::Qudit::measure (bool destructive = false) [inline]

Here is the call graph for this function:



7.6.3 Member Data Documentation

7.6.3.1 std::size_t qpp::Qudit::_D [private]

7.6.3.2 cmat qpp::Qudit::_rho [private]

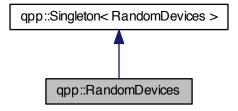
The documentation for this class was generated from the following file:

• include/classes/qudit.h

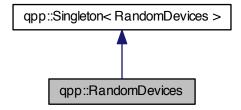
7.7 qpp::RandomDevices Class Reference

#include <randevs.h>

Inheritance diagram for qpp::RandomDevices:



Collaboration diagram for qpp::RandomDevices:



Public Attributes

• std::mt19937 _rng

Private Member Functions

• RandomDevices ()

Private Attributes

• std::random_device _rd

Friends

class Singleton < Random Devices >

Additional Inherited Members

7.7.1 Constructor & Destructor Documentation

7.7.1.1 qpp::RandomDevices::RandomDevices() [inline], [private]

7.7.2 Friends And Related Function Documentation

7.7.2.1 friend class Singleton < Random Devices > [friend]

7.7.3 Member Data Documentation

7.7.3.1 std::random_device qpp::RandomDevices::_rd [private]

7.7.3.2 std::mt19937 qpp::RandomDevices::_rng

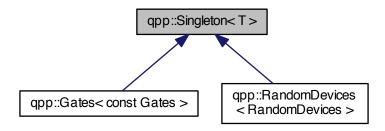
The documentation for this class was generated from the following file:

• include/classes/randevs.h

7.8 qpp::Singleton < T > Class Template Reference

#include <singleton.h>

Inheritance diagram for qpp::Singleton < T >:



Static Public Member Functions

• static T & get_instance ()

Protected Member Functions

- Singleton ()=default
- virtual ∼Singleton ()
- Singleton (const Singleton &)=delete
- Singleton & operator= (const Singleton &)=delete

7.8.1 Constructor & Destructor Documentation

- 7.8.1.1 template<typename T> qpp::Singleton< T>::Singleton() [protected], [default]
- 7.8.1.2 template<typename T> virtual qpp::Singleton < T>:: \sim Singleton () [inline], [protected], [virtual]

7.8.2 Member Function Documentation

- 7.8.2.1 template<typename T> static T& qpp::Singleton < T>::get_instance() [inline], [static]
- 7.8.2.2 template<typename T> Singleton& qpp::Singleton< T>::operator= (const Singleton< T>&) [protected], [delete]

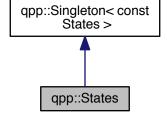
The documentation for this class was generated from the following file:

• include/classes/singleton.h

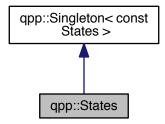
7.9 qpp::States Class Reference

#include <states.h>

Inheritance diagram for qpp::States:



Collaboration diagram for qpp::States:



Public Attributes

ket x0 { ket::Zero(2) }ket x1 { ket::Zero(2) }ket y0 { ket::Zero(2) }

```
ket y1 { ket::Zero(2) }
ket z0 { ket::Zero(2) }
ket z1 { ket::Zero(2) }
cmat px0 { cmat::Zero(2, 2) }
cmat px1 { cmat::Zero(2, 2) }
cmat py0 { cmat::Zero(2, 2) }
cmat py1 { cmat::Zero(2, 2) }
cmat pz0 { cmat::Zero(2, 2) }
cmat pz1 { cmat::Zero(2, 2) }
ket b00 { ket::Zero(4) }
ket b01 { ket::Zero(4) }
```

- ket b11 { ket::Zero(4) }cmat pb00 { cmat::Zero(4, 4) }
- cmat pb01 { cmat::Zero(4, 4) }
- cmat pb10 { cmat::Zero(4, 4) }
- cmat pb11 { cmat::Zero(4, 4) }
- ket GHZ { ket::Zero(8) }

ket b10 { ket::Zero(4) }

- ket W { ket::Zero(8) }
- cmat pGHZ { cmat::Zero(8, 8) }
- cmat pW { cmat::Zero(8, 8) }

Private Member Functions

• States ()

Friends

class Singleton < const States >

Additional Inherited Members

```
Constructor & Destructor Documentation
7.9.1.1
        qpp::States::States() [inline],[private]
7.9.2
        Friends And Related Function Documentation
7.9.2.1 friend class Singleton < const States > [friend]
        Member Data Documentation
7.9.3.1
        ket qpp::States::b00 { ket::Zero(4) }
7.9.3.2
        ket qpp::States::b01 { ket::Zero(4) }
        ket qpp::States::b10 { ket::Zero(4) }
7.9.3.3
        ket qpp::States::b11 { ket::Zero(4) }
        ket qpp::States::GHZ { ket::Zero(8) }
        cmat qpp::States::pb00 { cmat::Zero(4, 4) }
7.9.3.7
        cmat qpp::States::pb01 { cmat::Zero(4, 4) }
7.9.3.8 cmat qpp::States::pb10 { cmat::Zero(4, 4) }
7.9.3.9
        cmat qpp::States::pb11 { cmat::Zero(4, 4) }
7.9.3.10 cmat qpp::States::pGHZ { cmat::Zero(8, 8) }
7.9.3.11 cmat qpp::States::pW { cmat::Zero(8, 8) }
7.9.3.12 cmat qpp::States::px0 { cmat::Zero(2, 2) }
7.9.3.13 cmat qpp::States::px1 { cmat::Zero(2, 2) }
7.9.3.14 cmat qpp::States::py0 { cmat::Zero(2, 2) }
7.9.3.15 cmat qpp::States::py1 { cmat::Zero(2, 2) }
7.9.3.16 cmat qpp::States::pz0 { cmat::Zero(2, 2) }
7.9.3.17 cmat qpp::States::pz1 { cmat::Zero(2, 2) }
7.9.3.18 ket qpp::States::W { ket::Zero(8) }
7.9.3.19 ket qpp::States::x0 { ket::Zero(2) }
7.9.3.20 ket qpp::States::x1 { ket::Zero(2) }
7.9.3.21 ket qpp::States::y0 { ket::Zero(2) }
7.9.3.22 ket qpp::States::y1 { ket::Zero(2) }
```

```
7.9.3.23 ket qpp::States::z0 { ket::Zero(2) }7.9.3.24 ket qpp::States::z1 { ket::Zero(2) }
```

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

• include/classes/states.h

7.10 qpp::Timer Class Reference

```
#include <timer.h>
```

Public Member Functions

- Timer ()
- void tic ()
- void toc ()
- double seconds () const

Protected Attributes

- std::chrono::steady_clock::time_point _start
- · std::chrono::steady_clock::time_point_end

Friends

std::ostream & operator<< (std::ostream &os, const Timer &rhs)

7.10.1 Constructor & Destructor Documentation

```
7.10.1.1 qpp::Timer::Timer( ) [inline]
```

7.10.2 Member Function Documentation

```
7.10.2.1 double qpp::Timer::seconds ( ) const [inline]
```

```
7.10.2.2 void qpp::Timer::tic() [inline]
```

- 7.10.2.3 void qpp::Timer::toc() [inline]
- 7.10.3 Friends And Related Function Documentation
- 7.10.3.1 std::ostream& operator << (std::ostream & os, const Timer & rhs) [friend]

7.10.4 Member Data Documentation

```
7.10.4.1 std::chrono::steady_clock::time_point qpp::Timer::_end [protected]
```

7.10.4.2 std::chrono::steady_clock::time_point qpp::Timer::_start [protected]

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

• include/classes/timer.h

7.11 qpp::UniformIntDistribution Class Reference

```
#include <stat.h>
```

Public Member Functions

- UniformIntDistribution (int a=0, int b=1)
- int sample ()

Protected Attributes

· std::uniform_int_distribution_d

7.11.1 Constructor & Destructor Documentation

7.11.1.1 qpp::UniformIntDistribution::UniformIntDistribution (int a = 0, int b = 1) [inline]

7.11.2 Member Function Documentation

7.11.2.1 int qpp::UniformIntDistribution::sample() [inline]

Here is the call graph for this function:



7.11.3 Member Data Documentation

7.11.3.1 std::uniform_int_distribution qpp::UniformIntDistribution::_d [protected]

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

• include/classes/stat.h

7.12 qpp::UniformRealDistribution Class Reference

```
#include <stat.h>
```

Public Member Functions

- UniformRealDistribution (double a=0, double b=1)
- double sample ()

Protected Attributes

· std::uniform_real_distribution _d

7.12.1 Constructor & Destructor Documentation

7.12.1.1 qpp::UniformRealDistribution::UniformRealDistribution (double a = 0, double b = 1) [inline]

7.12.2 Member Function Documentation

7.12.2.1 double qpp::UniformRealDistribution::sample() [inline]

Here is the call graph for this function:



7.12.3 Member Data Documentation

7.12.3.1 std::uniform_real_distribution qpp::UniformRealDistribution::_d [protected]

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

• include/classes/stat.h

Chapter 8

File Documentation

8.1 include/channels.h File Reference

This graph shows which files directly or indirectly include this file:



Namespaces

• qpp

Functions

- cmat qpp::super (const std::vector< cmat > &Ks)
 - Superoperator matrix representation.
- cmat qpp::choi (const std::vector< cmat > &Ks)

Choi matrix representation.

- std::vector< cmat > qpp::choi2kraus (const cmat &A)
 - Extracts orthogonal Kraus operators from Choi matrix.
- $\bullet \ \ {\it template}{<} {\it typename Derived}>$
 - cmat qpp::channel (const Eigen::MatrixBase< Derived > &rho, const std::vector< cmat > &Ks)

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

 $\bullet \ \ \mathsf{template} \mathord{<} \mathsf{typename} \ \mathsf{Derived} >$

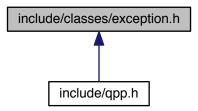
cmat qpp::channel (const Eigen::MatrixBase< Derived > &rho, const std::vector< cmat > &Ks, const std \leftrightarrow ::vector< std::size_t > &subsys, const std::vector< std::size_t > &dims)

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

96 File Documentation

8.2 include/classes/exception.h File Reference

This graph shows which files directly or indirectly include this file:



Classes

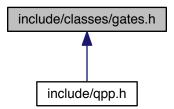
· class qpp::Exception

Namespaces

• qpp

8.3 include/classes/gates.h File Reference

This graph shows which files directly or indirectly include this file:



Classes

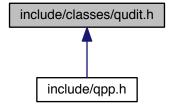
class qpp::Gates

Namespaces

qpp

8.4 include/classes/qudit.h File Reference

This graph shows which files directly or indirectly include this file:



Classes

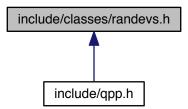
· class qpp::Qudit

Namespaces

• qpp

8.5 include/classes/randevs.h File Reference

This graph shows which files directly or indirectly include this file:



Classes

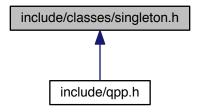
• class qpp::RandomDevices

Namespaces

qpp

8.6 include/classes/singleton.h File Reference

This graph shows which files directly or indirectly include this file:



Classes

class qpp::Singleton< T >

Namespaces

qpp

Macros

- #define CLASS_SINGLETON(Foo)
- #define CLASS_CONST_SINGLETON(Foo)

8.6.1 Macro Definition Documentation

8.6.1.1 #define CLASS_CONST_SINGLETON(Foo)

Value:

```
class Foo: public Singleton<const Foo>\
{\
          friend class Singleton<const Foo>;
```

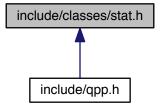
8.6.1.2 #define CLASS_SINGLETON(Foo)

Value:

```
class Foo: public Singleton<Foo>\
{\
    friend class Singleton<Foo>;
```

8.7 include/classes/stat.h File Reference

This graph shows which files directly or indirectly include this file:



Classes

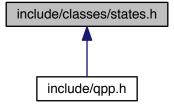
- class qpp::NormalDistribution
- class qpp::UniformRealDistribution
- class qpp::UniformIntDistribution
- class qpp::DiscreteDistribution
- class qpp::DiscreteDistributionAbsSquare

Namespaces

• qpp

8.8 include/classes/states.h File Reference

This graph shows which files directly or indirectly include this file:



Classes

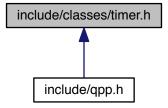
class qpp::States

Namespaces

• qpp

8.9 include/classes/timer.h File Reference

This graph shows which files directly or indirectly include this file:



Classes

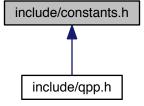
class qpp::Timer

Namespaces

qpp

8.10 include/constants.h File Reference

This graph shows which files directly or indirectly include this file:



Namespaces

qpp

Functions

```
    constexpr std::complex< double > qpp::operator""_i (unsigned long long int x)
```

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

constexpr std::complex< double > qpp::operator""_i (long double x)

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

std::complex < double > qpp::omega (std::size_t D)

D-th root of unity.

Variables

constexpr double qpp::chop = 1e-10

Used in qpp::disp() and qpp::displn() for setting to zero numbers that have their absolute value smaller than qpp::ct← ::chop.

constexpr double qpp::eps = 1e-12

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

• constexpr std::size_t qpp::maxn = 64

Maximum number of qubits.

• constexpr double qpp::pi = 3.141592653589793238462643383279502884

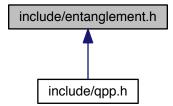
π

• constexpr double qpp::ee = 2.718281828459045235360287471352662497

Base of natural logarithm, e.

8.11 include/entanglement.h File Reference

This graph shows which files directly or indirectly include this file:



Namespaces

qpp

Functions

template<typename Derived >
 cmat qpp::schmidtcoeff (const Eigen::MatrixBase< Derived > &A, const std::vector< std::size_t > &dims)
 Schmidt coefficients of the bi-partite pure state A.

```
    template<typename Derived >
        cmat qpp::schmidtU (const Eigen::MatrixBase< Derived > &A, const std::vector< std::size_t > &dims)
    Schmidt basis on Alice's side.
```

template<typename Derived >
 cmat qpp::schmidtV (const Eigen::MatrixBase< Derived > &A, const std::vector< std::size_t > &dims)
 Schmidt basis on Bob's side.

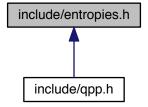
template<typename Derived >
 cmat qpp::schmidtprob (const Eigen::MatrixBase< Derived > &A, const std::vector< std::size_t > &dims)
 Schmidt probabilities of the bi-partite pure state A.

template<typename Derived >
 double qpp::entanglement (const Eigen::MatrixBase< Derived > &A, const std::vector< std::size_t > &dims)
 Entanglement of the bi-partite pure state A.

template<typename Derived >
 double qpp::gconcurrence (const Eigen::MatrixBase< Derived > &A)
 G-concurrence of the bi-partite pure state A.

8.12 include/entropies.h File Reference

This graph shows which files directly or indirectly include this file:



Namespaces

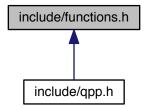
qpp

Functions

- template<typename Derived >
 double qpp::shannon (const Eigen::MatrixBase< Derived > &A)
- template<typename Derived >
 double qpp::renyi (const double alpha, const Eigen::MatrixBase< Derived > &A)
- template<typename Derived >
 double qpp::renyi_inf (const Eigen::MatrixBase< Derived > &A)
- template<typename Derived >
 double qpp::tsallis (const double alpha, const Eigen::MatrixBase< Derived > &A)
- template<typename Derived >
 double qpp::qmutualinfo (const Eigen::MatrixBase< Derived > &A, const std::vector< std::size_t > &subsys,
 const std::vector< std::size_t > &dims)

8.13 include/functions.h File Reference

This graph shows which files directly or indirectly include this file:



Namespaces

qpp

Functions

```
    template<typename Derived >

  DynMat< typename Derived::Scalar > qpp::transpose (const Eigen::MatrixBase< Derived > &A)
      Transpose.

    template<typename Derived >

  DynMat< typename Derived::Scalar > qpp::conjugate (const Eigen::MatrixBase< Derived > &A)
      Complex conjugate.

    template<typename Derived >

  DynMat< typename Derived::Scalar > qpp::adjoint (const Eigen::MatrixBase< Derived > &A)
     Adjoint.
• template<typename Derived >
  DynMat< 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 <a href="mailto:qpp::det">qpp::det</a> (const Eigen::MatrixBase</a> 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.
• template<typename Derived >
  double <a href="mailto:qpp::norm">qpp::norm</a> (const Eigen::MatrixBase</a> Derived > &A)
      Trace norm.

    template<typename Derived >
```

cmat qpp::evals (const Eigen::MatrixBase< Derived > &A)

```
Eigenvalues.
• template<typename Derived >
  cmat qpp::evects (const Eigen::MatrixBase< Derived > &A)
      Eigenvectors.
• template<typename Derived >
  dmat qpp::hevals (const Eigen::MatrixBase< Derived > &A)
     Hermitian eigenvalues.
• template<typename Derived >
  cmat <a href="mailto:qpp::hevects">qpp::hevects</a> (const Eigen::MatrixBase</a> Derived > &A)
     Hermitian eigenvectors.

    template<typename Derived >

  cmat qpp::funm (const Eigen::MatrixBase< Derived > &A, cplx(*f)(const cplx &))
      Functional calculus f(A)

    template<typename Derived >

  cmat qpp::sqrtm (const Eigen::MatrixBase< Derived > &A)
      Matrix square root.

    template<typename Derived >

  cmat qpp::absm (const Eigen::MatrixBase< Derived > &A)
      Matrix absolut value.

    template<typename Derived >

  cmat qpp::expm (const Eigen::MatrixBase< Derived > &A)
     Matrix exponential.

    template<typename Derived >

  cmat <a href="mailto:qpp::logm">qpp::logm</a> (const Eigen::MatrixBase</a> 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 >
  DynMat< typename Derived::Scalar > qpp::powm (const Eigen::MatrixBase< Derived > &A, std::size_t n)
      Matrix power.
• template<typename OutputScalar , typename Derived >
  DynMat< OutputScalar > qpp::cwise (const Eigen::MatrixBase< Derived > &A, OutputScalar(*f)(const type-
  name Derived::Scalar &))
     Functor.
template<typename T >
  DynMat< typename T::Scalar > qpp::kron (const T &head)
      Kronecker product (variadic overload)

    template<typename T, typename... Args>

  DynMat< typename T::Scalar > qpp::kron (const T &head, const Args &...tail)
      Kronecker product (variadic overload)

    template<typename Derived >

  DynMat< typename Derived::Scalar > qpp::kron (const std::vector< Derived > &As)
      Kronecker product (std::vector overload)

    template<typename Derived >

  DynMat< typename Derived::Scalar > qpp::kron (const std::initializer list< Derived > &As)
      Kronecker product (std::initializer list overload)
```

template<typename Derived >

DynMat< typename Derived::Scalar > qpp::kronpow (const Eigen::MatrixBase< Derived > &A, std::size_t n)

Kronecker power.

template<typename Derived >

DynMat< typename Derived::Scalar > qpp::reshape (const Eigen::MatrixBase< Derived > &A, std::size_t rows, std::size t cols)

Reshape.

template<typename Derived >

DynMat< typename Derived::Scalar > qpp::syspermute (const Eigen::MatrixBase< Derived > &A, const std::vector< std::size_t > &perm, const std::vector< std::size_t > &dims)

System permutation.

• template<typename Derived >

 $\label{lem:def:def:DynMat} \mbox{DynMat} < \mbox{typename Derived::Scalar} > \mbox{qpp::ptrace1} \mbox{ (const Eigen::MatrixBase} < \mbox{Derived} > \&\mbox{A, const std} \\ \mbox{::vector} < \mbox{std::size_t} > \&\mbox{dims})$

Partial trace.

template<typename Derived >

 $\label{lem:def:DynMat} \mbox{DynMat} < \mbox{typename Derived::Scalar} > \mbox{qpp::ptrace2} \mbox{ (const Eigen::MatrixBase} < \mbox{Derived} > \&\mbox{A, const std} \\ \mbox{::vector} < \mbox{std::size_t} > \&\mbox{dims})$

Partial trace.

template<typename Derived >

DynMat< typename Derived::Scalar > qpp::ptrace (const Eigen::MatrixBase< Derived > &A, const std
::vector< std::size_t > &subsys, const std::vector< std::size_t > &dims)

Partial trace.

template<typename Derived >

DynMat< typename Derived::Scalar > qpp::ptranspose (const Eigen::MatrixBase< Derived > &A, const std::vector< std::size_t > &subsys, const std::vector< std::size_t > &dims)

Partial transpose.

• template<typename Derived1 , typename Derived2 >

DynMat< typename Derived1::Scalar > qpp::comm (const Eigen::MatrixBase< Derived1 > &A, const Eigen::MatrixBase< Derived2 > &B)

Commutator.

template<typename Derived1 , typename Derived2 >

DynMat< typename Derived1::Scalar > qpp::anticomm (const Eigen::MatrixBase< Derived1 > &A, const Eigen::MatrixBase< Derived2 > &B)

Anti-commutator.

 $\bullet \ \ {\sf template}{<} {\sf typename \ Derived} >$

DynMat< typename Derived::Scalar > qpp::prj (const Eigen::MatrixBase< Derived > &V)

Projector.

template<typename Derived >

DynMat< typename Derived::Scalar > qpp::expandout (const Eigen::MatrixBase< Derived > &A, std::size ← _t pos, const std::vector< std::size_t > &dims)

Expand out.

• template<typename Derived >

DynMat< typename Derived::Scalar > qpp::grams (const std::vector< Derived > &Vs)

Gram-Schmidt orthogonalization (std::vector overload)

• template<typename Derived >

DynMat< typename Derived::Scalar > qpp::grams (const std::initializer list< Derived > &Vs)

Gram-Schmidt orthogonalization (std::initializer_list overload)

• template<typename Derived >

DynMat< typename Derived::Scalar > qpp::grams (const Eigen::MatrixBase< Derived > &A)

Gram-Schmidt orthogonalization (Eigen expression (matrix) overload)

std::vector< std::size t > qpp::n2multiidx (std::size t n, const std::vector< std::size t > &dims)

Non-negative integer index to multi-index.

std::size_t qpp::multiidx2n (const std::vector < std::size_t > &midx, const std::vector < std::size_t > &dims)
 Multi-index to non-negative integer index.

ket qpp::mket (const std::vector< std::size_t > &mask)

Multi-partite qubit ket.

ket qpp::mket (const std::vector < std::size_t > &mask, const std::vector < std::size_t > &dims)

Multi-partite qudit ket (different dimensions overload)

ket qpp::mket (const std::vector< std::size_t > &mask, std::size_t d)

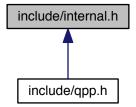
Multi-partite qudit ket (same dimensions overload)

- std::vector< std::size_t > qpp::invperm (const std::vector< std::size_t > &perm)
 Inverse permutation.
- std::vector< std::size_t > app::compperm (const std::vector< std::size_t > aperm, const std::vector< std
 ::size_t > aperm, const std::vector< std
 ::size_t

Compose permutations.

8.14 include/internal.h File Reference

This graph shows which files directly or indirectly include this file:



Namespaces

- qpp::internal
- qpp

Functions

- void qpp::internal::_n2multiidx (std::size_t n, std::size_t numdims, const std::size_t *dims, std::size_t *result)
- std::size t qpp::internal:: multiidx2n (const std::size t *midx, std::size t numdims, const std::size t *dims)
- template<typename Derived >

bool qpp::internal::_check_square_mat (const Eigen::MatrixBase< Derived > &A)

 $\bullet \ \ \text{template}{<} \text{typename Derived} >$

bool qpp::internal::_check_vector (const Eigen::MatrixBase< Derived > &A)

• template<typename Derived >

bool qpp::internal:: check row vector (const Eigen::MatrixBase< Derived > &A)

 $\bullet \ \ \mathsf{template}{<} \mathsf{typename} \ \mathsf{Derived} >$

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

• template<typename T >

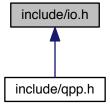
bool qpp::internal::_check_nonzero_size (const T &x)

bool qpp::internal::_check_dims (const std::vector< std::size_t > &dims)

- template<typename Derived >
 bool qpp::internal::_check_dims_match_mat (const std::vector< std::size_t > &dims, const Eigen::Matrix
 Base< Derived > &A)
- template<typename Derived >
 bool qpp::internal::_check_dims_match_cvect (const std::vector< std::size_t > &dims, const Eigen::Matrix
 Base< Derived > &V)
- template<typename Derived >
 bool qpp::internal::_check_dims_match_rvect (const std::vector< std::size_t > &dims, const Eigen::Matrix
 Base< Derived > &V)
- bool qpp::internal::_check_eq_dims (const std::vector< std::size_t > &dims, std::size_t dim)
- bool qpp::internal::_check_subsys_match_dims (const std::vector< std::size_t > &subsys, const std
 ::vector< std::size_t > &dims)
- bool qpp::internal::_check_perm (const std::vector< std::size_t > &perm)
- template<typename Derived1, typename Derived2 >
 DynMat< typename Derived1::Scalar > qpp::internal::_kron2 (const Eigen::MatrixBase< Derived1 > &A, const Eigen::MatrixBase< Derived2 > &B)
- template<typename T >
 void qpp::internal::variadic_vector_emplace (std::vector< T > &)
- template<typename T, typename First, typename... Args>
 void qpp::internal::variadic_vector_emplace (std::vector< T > &v, First &&first, Args &&...args)

8.15 include/io.h File Reference

This graph shows which files directly or indirectly include this file:



Namespaces

qpp

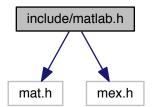
Functions

- template<typename T >
 void qpp::disp (const T &x, const std::string &separator, const std::string &start="[", const std::string &end="]",
 std::ostream &os=std::cout)
- template<typename T >
 void qpp::displn (const T &x, const std::string &separator, const std::string &start="[", const std::string &end="]", std::ostream &os=std::cout)
- template<typename T >
 void qpp::disp (const T *x, const std::size_t n, const std::string &separator, const std::string &start="[", const std::string &end="]", std::ostream &os=std::cout)

- template<typename T >
 void qpp::displn (const T *x, const std::size_t n, const std::string &separator, const std::string &start="[", const std::string &end="]", std::ostream &os=std::cout)
- template<typename Derived >
 void qpp::disp (const Eigen::MatrixBase< Derived > &A, double chop=chop, std::ostream &os=std::cout)
- template<typename Derived >
 void qpp::displn (const Eigen::MatrixBase< Derived > &A, double chop=chop, std::ostream &os=std::cout)
- void qpp::disp (const cplx c, double chop=chop, std::ostream &os=std::cout)
- void qpp::displn (const cplx c, double chop=chop, std::ostream &os=std::cout)
- template<typename Derived >
 void qpp::save (const Eigen::MatrixBase< Derived > &A, const std::string &fname)
- template<typename Derived >
 DynMat< typename Derived::Scalar > qpp::load (const std::string &fname)

8.16 include/matlab.h File Reference

```
#include "mat.h"
#include "mex.h"
Include dependency graph for matlab.h:
```



Namespaces

• qpp

Functions

- template < typename Derived >
 Derived qpp::loadMATLABmatrix (const std::string &mat_file, const std::string &var_name)
- template<>
 dmat qpp::loadMATLABmatrix (const std::string &mat_file, const std::string &var_name)
- template<>
 cmat qpp::loadMATLABmatrix (const std::string &mat_file, const std::string &var_name)
- template<typename Derived >
 void qpp::saveMATLABmatrix (const Eigen::MatrixBase< Derived > &A, const std::string &mat_file, const std::string &var_name, const std::string &mode)
- template<>
 void qpp::saveMATLABmatrix (const Eigen::MatrixBase< dmat > &A, const std::string &mat_file, const std
 ::string &var_name, const std::string &mode)

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

8.17 include/qpp.h File Reference

```
#include <algorithm>
#include <chrono>
#include <cmath>
#include <complex>
#include <cstdlib>
#include <cstring>
#include <exception>
#include <fstream>
#include <functional>
#include <iomanip>
#include <iostream>
#include <iterator>
#include <numeric>
#include <ostream>
#include <random>
#include <stdexcept>
#include <string>
#include <type_traits>
#include <utility>
#include <vector>
#include <Eigen/Dense>
#include <Eigen/SVD>
#include "constants.h"
#include "types.h"
#include "classes/exception.h"
#include "classes/singleton.h"
#include "classes/states.h"
#include "classes/randevs.h"
#include "internal.h"
#include "functions.h"
#include "classes/gates.h"
#include "classes/stat.h"
#include "entropies.h"
#include "entanglement.h"
#include "channels.h"
#include "io.h"
#include "random.h"
#include "classes/qudit.h"
#include "classes/timer.h"
Include dependency graph for qpp.h:
```



Namespaces

dbb

Variables

```
    RandomDevices & app::rdevs = RandomDevices::get_instance()
        app::RandomDevices Singleton

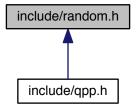
    const Gates & app::gt = Gates::get_instance()
```

qpp::Gates const Singleton
• const States & qpp::st = States::get_instance()

qpp::States const Singleton

8.18 include/random.h File Reference

This graph shows which files directly or indirectly include this file:



Namespaces

• qpp

Functions

```
Derived qpp::rand (std::size_t rows, std::size_t cols, double a=0, double b=1)

• template<>
dmat qpp::rand (std::size_t rows, std::size_t cols, double a, double b)

• template<>
cmat qpp::rand (std::size_t rows, std::size_t cols, double a, double b)

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

• long long qpp::randint (long long a, long long b)
```

- template<typename Derived >
 Derived qpp::randn (std::size_t rows, std::size_t cols, double mean=0, double sigma=1)
- template<>
 dmat qpp::randn (std::size_t rows, std::size_t cols, double mean, double sigma)
- template<>
 cmat qpp::randn (std::size_t rows, std::size_t cols, double mean, double sigma)
- double qpp::randn (double mean=0, double sigma=1)
- cmat qpp::randU (std::size_t D)

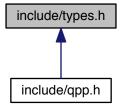
• template<typename Derived >

- cmat qpp::randV (std::size_t Din, std::size_t Dout)
- std::vector < cmat > qpp::randkraus (std::size_t n, std::size_t D)
- cmat qpp::randH (std::size_t D)

- ket qpp::randket (std::size_t D)
- cmat qpp::randrho (std::size_t D)
- std::vector< std::size_t > qpp::randperm (std::size_t n)

8.19 include/types.h File Reference

This graph shows which files directly or indirectly include this file:



Namespaces

• qpp

Typedefs

- using qpp::cplx = std::complex< double >
 - Complex number in double precision.
- using qpp::cmat = Eigen::MatrixXcd

Complex (double precision) dynamic Eigen matrix.

• using qpp::dmat = Eigen::MatrixXd

Real (double precision) dynamic Eigen matrix.

- using qpp::ket = Eigen::Matrix< cplx, Eigen::Dynamic, 1 >
 - Complex (double precision) dynamic Eigen column matrix.
- using qpp::bra = Eigen::Matrix < cplx, 1, Eigen::Dynamic >

Complex (double precision) dynamic Eigen row matrix.

 $\bullet \ \ \text{template}{<} \text{typename Scalar} >$

using qpp::DynMat = Eigen::Matrix < Scalar, Eigen::Dynamic, Eigen::Dynamic >

Dynamic Eigen matrix over the field specified by Scalar.

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