# Quantum++

v1.1

Generated by Doxygen 1.8.13

# Contents


**1 Quantum++** **1**

**2 Namespace Index** **3**

2.1 Namespace List . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 3

**3 Hierarchical Index** **5**

3.1 Class Hierarchy . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 5

**4 Class Index** **7**

4.1 Class List . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 7

**5 File Index** **11**

5.1 File List . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 11

**6 Namespace Documentation** **13**

6.1 qpp Namespace Reference . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 13

6.1.1 Detailed Description . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 26

6.1.2 Typedef Documentation . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 26

6.1.2.1 bigint . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 26

6.1.2.2 bra . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 26

6.1.2.3 cmat . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 26

6.1.2.4 cplx . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 26

6.1.2.5 dmat . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 26

6.1.2.6 dyn_col_vect . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 27

6.1.2.7 dyn_mat . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 27

6.1.2.8 dyn_row_vect . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 27

6.1.2.9 idx . . . . . . . . . . 27
6.1.2.10 ket . . . . . . . . . . 28
6.1.2.11 to_void . . . . . . . . . . 28
6.1.3 Function Documentation . . . . . . . . . . 28
6.1.3.1 absm() . . . . . . . . . . 28
6.1.3.2 abssq() [1/3] . . . . . . . . . . 28
6.1.3.3 abssq() [2/3] . . . . . . . . . . 29
6.1.3.4 abssq() [3/3] . . . . . . . . . . 29
6.1.3.5 adjoint() . . . . . . . . . . 30
6.1.3.6 anticomm() . . . . . . . . . . 30
6.1.3.7 apply() [1/5] . . . . . . . . . . 30
6.1.3.8 apply() [2/5] . . . . . . . . . . 31
6.1.3.9 apply() [3/5] . . . . . . . . . . 32
6.1.3.10 apply() [4/5] . . . . . . . . . . 32
6.1.3.11 apply() [5/5] . . . . . . . . . . 32
6.1.3.12 applyCTRL() [1/2] . . . . . . . . . . 33
6.1.3.13 applyCTRL() [2/2] . . . . . . . . . . 34
6.1.3.14 applyINVQFT() . . . . . . . . . . 34
6.1.3.15 applyQFT() . . . . . . . . . . 35
6.1.3.16 avg() . . . . . . . . . . 35
6.1.3.17 bloch2rho() . . . . . . . . . . 36
6.1.3.18 choi2kraus() . . . . . . . . . . 36
6.1.3.19 choi2super() . . . . . . . . . . 37
6.1.3.20 comm() . . . . . . . . . . 37
6.1.3.21 complement() . . . . . . . . . . 38
6.1.3.22 compperm() . . . . . . . . . . 38
6.1.3.23 concurrence() . . . . . . . . . . 38
6.1.3.24 conjugate() . . . . . . . . . . 40
6.1.3.25 contfrac2x() . . . . . . . . . . 40
6.1.3.26 cor() . . . . . . . . . . 41

6.1.3.27 cosm() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 41
6.1.3.28 cov() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 42
6.1.3.29 cwise() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 42
6.1.3.30 det() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 42
6.1.3.31 dirsum() [1/4] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 43
6.1.3.32 dirsum() [2/4] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 43
6.1.3.33 dirsum() [3/4] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 44
6.1.3.34 dirsum() [4/4] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 44
6.1.3.35 dirsumpow() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 45
6.1.3.36 disp() [1/5] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 45
6.1.3.37 disp() [2/5] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 46
6.1.3.38 disp() [3/5] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 46
6.1.3.39 disp() [4/5] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 47
6.1.3.40 disp() [5/5] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 47
6.1.3.41 egcd() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 48
6.1.3.42 eig() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 48
6.1.3.43 entanglement() [1/2] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 48
6.1.3.44 entanglement() [2/2] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 49
6.1.3.45 entropy() [1/2] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 50
6.1.3.46 entropy() [2/2] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 50
6.1.3.47 evals() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 50
6.1.3.48 evects() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 51
6.1.3.49 expm() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 51
6.1.3.50 factors() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 52
6.1.3.51 funm() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 52
6.1.3.52 gcd() [1/2] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 52
6.1.3.53 gcd() [2/2] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 53
6.1.3.54 gconcurrence() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 53
6.1.3.55 grams() [1/3] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 54
6.1.3.56 grams() [2/3] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 54

6.1.3.57 grams() [3/3] . . . . . 55
6.1.3.58 heig() . . . . . 55
6.1.3.59 hevals() . . . . . 55
6.1.3.60 hevects() . . . . . 56
6.1.3.61 inverse() . . . . . 56
6.1.3.62 invperm() . . . . . 57
6.1.3.63 INVQFT() . . . . . 57
6.1.3.64 ip() [1/2] . . . . . 57
6.1.3.65 ip() [2/2] . . . . . 58
6.1.3.66 isprime() . . . . . 58
6.1.3.67 kraus2choi() . . . . . 59
6.1.3.68 kraus2super() . . . . . 59
6.1.3.69 kron() [1/4] . . . . . 60
6.1.3.70 kron() [2/4] . . . . . 60
6.1.3.71 kron() [3/4] . . . . . 61
6.1.3.72 kron() [4/4] . . . . . 61
6.1.3.73 kronpow() . . . . . 62
6.1.3.74 lcm() [1/2] . . . . . 62
6.1.3.75 lcm() [2/2] . . . . . 63
6.1.3.76 load() . . . . . 63
6.1.3.77 loadMATLAB() [1/2] . . . . . 64
6.1.3.78 loadMATLAB() [2/2] . . . . . 64
6.1.3.79 logdet() . . . . . 65
6.1.3.80 logm() . . . . . 66
6.1.3.81 lognegativity() [1/2] . . . . . 66
6.1.3.82 lognegativity() [2/2] . . . . . 66
6.1.3.83 marginalX() . . . . . 67
6.1.3.84 marginalY() . . . . . 67
6.1.3.85 measure() [1/9] . . . . . 68
6.1.3.86 measure() [2/9] . . . . . 68

6.1.3.87 measure() [3/9] . . . . . 68
6.1.3.88 measure() [4/9] . . . . . 69
6.1.3.89 measure() [5/9] . . . . . 69
6.1.3.90 measure() [6/9] . . . . . 70
6.1.3.91 measure() [7/9] . . . . . 71
6.1.3.92 measure() [8/9] . . . . . 72
6.1.3.93 measure() [9/9] . . . . . 72
6.1.3.94 measure_seq() [1/2] . . . . . 73
6.1.3.95 measure_seq() [2/2] . . . . . 73
6.1.3.96 mket() [1/2] . . . . . 74
6.1.3.97 mket() [2/2] . . . . . 75
6.1.3.98 modinv() . . . . . 75
6.1.3.99 modmul() . . . . . 76
6.1.3.100 modpow() . . . . . 76
6.1.3.101 mprj() [1/2] . . . . . 77
6.1.3.102 mprj() [2/2] . . . . . 77
6.1.3.103 multiidx2n() . . . . . 78
6.1.3.104 n2multiidx() . . . . . 78
6.1.3.105 negativity() [1/2] . . . . . 79
6.1.3.106 negativity() [2/2] . . . . . 79
6.1.3.107 norm() . . . . . 79
6.1.3.108 omega() . . . . . 80
6.1.3.109 operator"""" _i() . . . . . 80
6.1.3.110 powm() . . . . . 80
6.1.3.111 prj() . . . . . 81
6.1.3.112 prod() [1/3] . . . . . 81
6.1.3.113 prod() [2/3] . . . . . 82
6.1.3.114 prod() [3/3] . . . . . 82
6.1.3.115 ptrace() [1/2] . . . . . 82
6.1.3.116 ptrace() [2/2] . . . . . 83

6.1.3.117 ptrace1() [1/2] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 83
6.1.3.118 ptrace1() [2/2] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 84
6.1.3.119 ptrace2() [1/2] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 84
6.1.3.120 ptrace2() [2/2] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 85
6.1.3.121 ptranspose() [1/2] . . . . . . . . . . . . . . . . . . . . . . . . . . . . 85
6.1.3.122 ptranspose() [2/2] . . . . . . . . . . . . . . . . . . . . . . . . . . . . 86
6.1.3.123 QFT() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 86
6.1.3.124 qmutualinfo() [1/2] . . . . . . . . . . . . . . . . . . . . . . . . . . . 87
6.1.3.125 qmutualinfo() [2/2] . . . . . . . . . . . . . . . . . . . . . . . . . . . 87
6.1.3.126 rand() [1/5] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 88
6.1.3.127 rand() [2/5] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 88
6.1.3.128 rand() [3/5] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 89
6.1.3.129 rand() [4/5] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 89
6.1.3.130 rand() [5/5] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 90
6.1.3.131 randH() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 90
6.1.3.132 randidx() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 91
6.1.3.133 randket() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 91
6.1.3.134 randkraus() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 91
6.1.3.135 randn() [1/4] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 92
6.1.3.136 randn() [2/4] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 92
6.1.3.137 randn() [3/4] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 93
6.1.3.138 randn() [4/4] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 93
6.1.3.139 randperm() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 94
6.1.3.140 randprime() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 94
6.1.3.141 randprob() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 95
6.1.3.142 randrho() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 95
6.1.3.143 randU() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 95
6.1.3.144 randV() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 96
6.1.3.145 renyi() [1/2] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 96
6.1.3.146 renyi() [2/2] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 97

6.1.3.147 reshape() . . . . . . 97
6.1.3.148 rho2bloch() . . . . . . 98
6.1.3.149 rho2pure() . . . . . . 98
6.1.3.150 save() . . . . . . 99
6.1.3.151 saveMATLAB() [1/2] . . . . . . 99
6.1.3.152 saveMATLAB() [2/2] . . . . . . 100
6.1.3.153 schatten() . . . . . . 100
6.1.3.154 schmidtA() [1/2] . . . . . . 101
6.1.3.155 schmidtA() [2/2] . . . . . . 101
6.1.3.156 schmidtB() [1/2] . . . . . . 101
6.1.3.157 schmidtB() [2/2] . . . . . . 102
6.1.3.158 schmidtcoeffs() [1/2] . . . . . . 102
6.1.3.159 schmidtcoeffs() [2/2] . . . . . . 103
6.1.3.160 schmidtprobs() [1/2] . . . . . . 103
6.1.3.161 schmidtprobs() [2/2] . . . . . . 104
6.1.3.162 sigma() . . . . . . 104
6.1.3.163 sinm() . . . . . . 105
6.1.3.164 spectralpowm() . . . . . . 105
6.1.3.165 sqrtm() . . . . . . 106
6.1.3.166 sum() [1/3] . . . . . . 106
6.1.3.167 sum() [2/3] . . . . . . 106
6.1.3.168 sum() [3/3] . . . . . . 107
6.1.3.169 super2choi() . . . . . . 107
6.1.3.170 svals() . . . . . . 108
6.1.3.171 svd() . . . . . . 108
6.1.3.172 svdU() . . . . . . 108
6.1.3.173 svdV() . . . . . . 109
6.1.3.174 syspermute() [1/2] . . . . . . 109
6.1.3.175 syspermute() [2/2] . . . . . . 110
6.1.3.176 trace() . . . . . . 110

6.1.3.177 transpose() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 111
6.1.3.178 tsallis() [1/2] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 111
6.1.3.179 tsallis() [2/2] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 111
6.1.3.180 uniform() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 112
6.1.3.181 var() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 112
6.1.3.182 x2contfrac() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 113
6.1.4 Variable Documentation . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 113
6.1.4.1 chop . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 113
6.1.4.2 ee . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 113
6.1.4.3 eps . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 114
6.1.4.4 infty . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 114
6.1.4.5 maxn . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 114
6.1.4.6 pi . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 114
6.2 qpp::exception Namespace Reference . . . . . . . . . . . . . . . . . . . . . . . . . . 114
6.2.1 Detailed Description . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 116
6.3 qpp::experimental Namespace Reference . . . . . . . . . . . . . . . . . . . . . . . . . 116
6.3.1 Detailed Description . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 116
6.4 qpp::internal Namespace Reference . . . . . . . . . . . . . . . . . . . . . . . . . . . 116
6.4.1 Detailed Description . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 117
6.4.2 Function Documentation . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 117
6.4.2.1 check_cvector() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 118
6.4.2.2 check_dims() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 118
6.4.2.3 check_dims_match_cvect() . . . . . . . . . . . . . . . . . . . . . . . . . . . 118
6.4.2.4 check_dims_match_mat() . . . . . . . . . . . . . . . . . . . . . . . . . . . . 118
6.4.2.5 check_dims_match_rvect() . . . . . . . . . . . . . . . . . . . . . . . . . . . 118
6.4.2.6 check_eq_dims() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 118
6.4.2.7 check_matching_sizes() . . . . . . . . . . . . . . . . . . . . . . . . . . . . 119
6.4.2.8 check_nonzero_size() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 119
6.4.2.9 check_perm() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 119
6.4.2.10 check_qubit_cvector() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 119

6.4.2.11 check_qubit_matrix() . . . . . . . . . . . . . . . . . . . . . . . . . . . . 119
6.4.2.12 check_qubit_rvector() . . . . . . . . . . . . . . . . . . . . . . . . . . . 119
6.4.2.13 check_qubit_vector() . . . . . . . . . . . . . . . . . . . . . . . . . . . . 120
6.4.2.14 check_rvector() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 120
6.4.2.15 check_square_mat() . . . . . . . . . . . . . . . . . . . . . . . . . . . . 120
6.4.2.16 check_subsys_match_dims() . . . . . . . . . . . . . . . . . . . . . . . . 120
6.4.2.17 check_vector() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 120
6.4.2.18 dirsum2() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 120
6.4.2.19 get_dim_subsys() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 121
6.4.2.20 get_num_subsys() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 121
6.4.2.21 kron2() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 121
6.4.2.22 multiidx2n() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 121
6.4.2.23 n2multiidx() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 121
6.4.2.24 variadic_vector_emplace() [1/2] . . . . . . . . . . . . . . . . . . . . . . 121
6.4.2.25 variadic_vector_emplace() [2/2] . . . . . . . . . . . . . . . . . . . . . . 122
6.5 qpp::literals Namespace Reference . . . . . . . . . . . . . . . . . . . . . . . . . 122
6.5.1 Function Documentation . . . . . . . . . . . . . . . . . . . . . . . . . . . 122
6.5.1.1 operator"""" _bra() . . . . . . . . . . . . . . . . . . . . . . . . . . . . 122
6.5.1.2 operator"""" _i() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 123
6.5.1.3 operator"""" _ket() . . . . . . . . . . . . . . . . . . . . . . . . . . . . 123
6.5.1.4 operator"""" _prj() . . . . . . . . . . . . . . . . . . . . . . . . . . . . 123

7 Class Documentation 125
7.1 qpp::Bit_circuit Class Reference . . . . . . . . . . 125
7.1.1 Detailed Description . . . . . . . . . . 127
7.1.2 Constructor & Destructor Documentation . . . . . . . . . . 127
7.1.2.1 Bit_circuit() . . . . . . . . . . 127
7.1.3 Member Function Documentation . . . . . . . . . . 127
7.1.3.1 CNOT() . . . . . . . . . . 127
7.1.3.2 FRED() . . . . . . . . . . 127
7.1.3.3 NOT() . . . . . . . . . . 128
7.1.3.4 reset() . . . . . . . . . . 128
7.1.3.5 SWAP() . . . . . . . . . . 128
7.1.3.6 TOF() . . . . . . . . . . 129
7.1.3.7 X() . . . . . . . . . . 129
7.1.4 Member Data Documentation . . . . . . . . . . 130
7.1.4.1 gate_count . . . . . . . . . . 130
7.2 qpp::Codes Class Reference . . . . . . . . . . 130
7.2.1 Detailed Description . . . . . . . . . . 131
7.2.2 Member Enumeration Documentation . . . . . . . . . . 131
7.2.2.1 Type . . . . . . . . . . 131
7.2.3 Constructor & Destructor Documentation . . . . . . . . . . 132
7.2.3.1 Codes() . . . . . . . . . . 132
7.2.3.2 ∼Codes() . . . . . . . . . . 132
7.2.4 Member Function Documentation . . . . . . . . . . 132
7.2.4.1 codeword() . . . . . . . . . . 132
7.2.5 Friends And Related Function Documentation . . . . . . . . . . 132
7.2.5.1 internal::Singleton< const Codes > . . . . . . . . . . 133
7.3 qpp::exception::CustomException Class Reference . . . . . . . . . . 133
7.3.1 Detailed Description . . . . . . . . . . 134
7.3.2 Constructor & Destructor Documentation . . . . . . . . . . 134
7.3.2.1 CustomException() . . . . . . . . . . 135

7.3.3 Member Function Documentation . . . . . . . . . . . . . . . . . . . . . . . . . 135
7.3.3.1 type_description() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 135
7.3.4 Member Data Documentation . . . . . . . . . . . . . . . . . . . . . . . . . . . 135
7.3.4.1 what_ . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 135
7.4 qpp::exception::DimsInvalid Class Reference . . . . . . . . . . . . . . . . . . . . . . 136
7.4.1 Detailed Description . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 137
7.4.2 Member Function Documentation . . . . . . . . . . . . . . . . . . . . . . . . . 137
7.4.2.1 type_description() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 137
7.5 qpp::exception::DimsMismatchCvector Class Reference . . . . . . . . . . . . . . . . . . 137
7.5.1 Detailed Description . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 139
7.5.2 Member Function Documentation . . . . . . . . . . . . . . . . . . . . . . . . . 139
7.5.2.1 type_description() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 139
7.6 qpp::exception::DimsMismatchMatrix Class Reference . . . . . . . . . . . . . . . . . . 139
7.6.1 Detailed Description . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 140
7.6.2 Member Function Documentation . . . . . . . . . . . . . . . . . . . . . . . . . 140
7.6.2.1 type_description() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 141
7.7 qpp::exception::DimsMismatchRvector Class Reference . . . . . . . . . . . . . . . . . . 141
7.7.1 Detailed Description . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 142
7.7.2 Member Function Documentation . . . . . . . . . . . . . . . . . . . . . . . . . 142
7.7.2.1 type_description() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 143
7.8 qpp::exception::DimsMismatchVector Class Reference . . . . . . . . . . . . . . . . . . 143
7.8.1 Detailed Description . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 144
7.8.2 Member Function Documentation . . . . . . . . . . . . . . . . . . . . . . . . . 144
7.8.2.1 type_description() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 145
7.9 qpp::exception::DimsNotEqual Class Reference . . . . . . . . . . . . . . . . . . . . . 145
7.9.1 Detailed Description . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 146
7.9.2 Member Function Documentation . . . . . . . . . . . . . . . . . . . . . . . . . 146
7.9.2.1 type_description() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 146
7.10 qpp::internal::Display_Impl_ Struct Reference . . . . . . . . . . . . . . . . . . . . . 147
7.10.1 Member Function Documentation . . . . . . . . . . . . . . . . . . . . . . . . . 147

7.10.1.1 display_impl_() . . . . 147
7.11 qpp::Dynamic_bitset Class Reference . . . . 148
7.11.1 Detailed Description . . . . 150
7.11.2 Member Typedef Documentation . . . . 150
7.11.2.1 storage_type . . . . 150
7.11.2.2 value_type . . . . 150
7.11.3 Constructor & Destructor Documentation . . . . 150
7.11.3.1 Dynamic_bitset() . . . . 150
7.11.4 Member Function Documentation . . . . 151
7.11.4.1 all() . . . . 151
7.11.4.2 any() . . . . 151
7.11.4.3 count() . . . . 151
7.11.4.4 data() . . . . 152
7.11.4.5 display() . . . . 152
7.11.4.6 flip() [1/2] . . . . 153
7.11.4.7 flip() [2/2] . . . . 153
7.11.4.8 get() . . . . 153
7.11.4.9 index_() . . . . 154
7.11.4.10 none() . . . . 154
7.11.4.11 offset_() . . . . 154
7.11.4.12 operator"!=() . . . . 155
7.11.4.13 operator-() . . . . 155
7.11.4.14 operator==() . . . . 155
7.11.4.15 rand() [1/2] . . . . 157
7.11.4.16 rand() [2/2] . . . . 157
7.11.4.17 reset() [1/2] . . . . 158
7.11.4.18 reset() [2/2] . . . . 158
7.11.4.19 set() [1/2] . . . . 158
7.11.4.20 set() [2/2] . . . . 159
7.11.4.21 size() . . . . 159

7.11.4.22 storage_size() . . . . . . . . . . . . . . . . . . . . . . . . . . . . 159
7.11.4.23 to_string() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 159
7.11.5 Member Data Documentation . . . . . . . . . . . . . . . . . . . . . . . . . . 160
7.11.5.1 N_ . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 160
7.11.5.2 storage_size_ . . . . . . . . . . . . . . . . . . . . . . . . . . . . 160
7.11.5.3 v_ . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 160
7.12 qpp::exception::Exception Class Reference . . . . . . . . . . . . . . . . . . . . . 161
7.12.1 Detailed Description . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 162
7.12.2 Constructor & Destructor Documentation . . . . . . . . . . . . . . . . . . . . 163
7.12.2.1 Exception() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 163
7.12.3 Member Function Documentation . . . . . . . . . . . . . . . . . . . . . . . . 163
7.12.3.1 type_description() . . . . . . . . . . . . . . . . . . . . . . . . . . 163
7.12.3.2 what() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 164
7.12.4 Member Data Documentation . . . . . . . . . . . . . . . . . . . . . . . . . . 164
7.12.4.1 msg_ . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 164
7.12.4.2 where_ . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 164
7.13 qpp::Bit_circuit::Gate_count Struct Reference . . . . . . . . . . . . . . . . . . . 164
7.13.1 Member Data Documentation . . . . . . . . . . . . . . . . . . . . . . . . . . 164
7.13.1.1 CNOT . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 165
7.13.1.2 FRED . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 165
7.13.1.3 NOT . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 165
7.13.1.4 SWAP . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 165
7.13.1.5 TOF . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 165
7.13.1.6 X . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 165
7.14 qpp::Gates Class Reference . . . . . . . . . . . . . . . . . . . . . . . . . . . . 166
7.14.1 Detailed Description . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 168
7.14.2 Constructor & Destructor Documentation . . . . . . . . . . . . . . . . . . . . 168
7.14.2.1 Gates() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 168
7.14.2.2 ∼Gates() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 168
7.14.3 Member Function Documentation . . . . . . . . . . . . . . . . . . . . . . . . 168

7.14.3.1 CTRL() . . . . . . . . . . 169
7.14.3.2 expandout() [1/3] . . . . . . . . . . 169
7.14.3.3 expandout() [2/3] . . . . . . . . . . 170
7.14.3.4 expandout() [3/3] . . . . . . . . . . 171
7.14.3.5 Fd() . . . . . . . . . . 171
7.14.3.6 Id() . . . . . . . . . . 172
7.14.3.7 MODMUL() . . . . . . . . . . 172
7.14.3.8 Rn() . . . . . . . . . . 172
7.14.3.9 RX() . . . . . . . . . . 173
7.14.3.10 RY() . . . . . . . . . . 173
7.14.3.11 RZ() . . . . . . . . . . 173
7.14.3.12 SWAPd() . . . . . . . . . . 174
7.14.3.13 Xd() . . . . . . . . . . 174
7.14.3.14 Zd() . . . . . . . . . . 175
7.14.4 Friends And Related Function Documentation . . . . . . . . . . 175
7.14.4.1 internal::Singleton< const Gates > . . . . . . . . . . 175
7.14.5 Member Data Documentation . . . . . . . . . . 175
7.14.5.1 CNOT . . . . . . . . . . 175
7.14.5.2 CNOTba . . . . . . . . . . 175
7.14.5.3 CZ . . . . . . . . . . 176
7.14.5.4 FRED . . . . . . . . . . 176
7.14.5.5 H . . . . . . . . . . 176
7.14.5.6 Id2 . . . . . . . . . . 176
7.14.5.7 S . . . . . . . . . . 176
7.14.5.8 SWAP . . . . . . . . . . 176
7.14.5.9 T . . . . . . . . . . 177
7.14.5.10 TOF . . . . . . . . . . 177
7.14.5.11 X . . . . . . . . . . 177
7.14.5.12 Y . . . . . . . . . . 177
7.14.5.13 Z . . . . . . . . . . 177

7.15 qpp::IDisplay Class Reference . . . . . 178
7.15.1 Detailed Description . . . . . 179
7.15.2 Constructor & Destructor Documentation . . . . . 179
7.15.2.1 IDisplay() [1/3] . . . . . 179
7.15.2.2 IDisplay() [2/3] . . . . . 179
7.15.2.3 IDisplay() [3/3] . . . . . 179
7.15.2.4 ∼IDisplay() . . . . . 179
7.15.3 Member Function Documentation . . . . . 179
7.15.3.1 display() . . . . . 180
7.15.3.2 operator=() [1/2] . . . . . 180
7.15.3.3 operator=() [2/2] . . . . . 180
7.15.4 Friends And Related Function Documentation . . . . . 180
7.15.4.1 operator<< . . . . . 180
7.16 qpp::Init Class Reference . . . . . 181
7.16.1 Detailed Description . . . . . 182
7.16.2 Constructor & Destructor Documentation . . . . . 182
7.16.2.1 Init() . . . . . 182
7.16.2.2 ∼Init() . . . . . 182
7.16.3 Friends And Related Function Documentation . . . . . 182
7.16.3.1 internal::Singleton< const Init > . . . . . 182
7.17 qpp::internal::IOManipEigen Class Reference . . . . . 183
7.17.1 Constructor & Destructor Documentation . . . . . 184
7.17.1.1 IOManipEigen() [1/2] . . . . . 184
7.17.1.2 IOManipEigen() [2/2] . . . . . 184
7.17.2 Member Function Documentation . . . . . 184
7.17.2.1 display() . . . . . 184
7.17.3 Member Data Documentation . . . . . 184
7.17.3.1 A_ . . . . . 185
7.17.3.2 chop_ . . . . . 185
7.18 qpp::internal::IOManipPointer< PointerType > Class Template Reference . . . . . 185

7.18.1 Constructor & Destructor Documentation . . . 186
7.18.1.1 IOManipPointer() [1/2] . . . 187
7.18.1.2 IOManipPointer() [2/2] . . . 187
7.18.2 Member Function Documentation . . . 187
7.18.2.1 display() . . . 187
7.18.2.2 operator=() . . . 187
7.18.3 Member Data Documentation . . . 187
7.18.3.1 end_ . . . 188
7.18.3.2 N_ . . . 188
7.18.3.3 p_ . . . 188
7.18.3.4 separator_ . . . 188
7.18.3.5 start_ . . . 188
7.19 qpp::internal::IOManipRange< InputIterator > Class Template Reference . . . 189
7.19.1 Constructor & Destructor Documentation . . . 190
7.19.1.1 IOManipRange() [1/2] . . . 190
7.19.1.2 IOManipRange() [2/2] . . . 190
7.19.2 Member Function Documentation . . . 190
7.19.2.1 display() . . . 190
7.19.2.2 operator=() . . . 191
7.19.3 Member Data Documentation . . . 191
7.19.3.1 end_ . . . 191
7.19.3.2 first_ . . . 191
7.19.3.3 last_ . . . 191
7.19.3.4 separator_ . . . 191
7.19.3.5 start_ . . . 191
7.20 qpp::is_complex< T > Struct Template Reference . . . 192
7.20.1 Detailed Description . . . 192
7.21 qpp::is_complex< std::complex< T > > Struct Template Reference . . . 193
7.21.1 Detailed Description . . . 193
7.22 qpp::is_iterable< T, typename > Struct Template Reference . . . 194

7.22.1 Detailed Description . . . 194
7.23 qpp::is_iterable< T, to_void< decltype(std::declval< T >().begin()), decltype(std::declval< T >().end()), typename T::value_type > > Struct Template Reference . . . 195
7.23.1 Detailed Description . . . 196
7.24 qpp::is_matrix_expression< Derived > Struct Template Reference . . . 196
7.24.1 Detailed Description . . . 197
7.25 qpp::make_void< Ts > Struct Template Reference . . . 197
7.25.1 Detailed Description . . . 197
7.25.2 Member Typedef Documentation . . . 197
7.25.2.1 type . . . 197
7.26 qpp::exception::MatrixMismatchSubsys Class Reference . . . 198
7.26.1 Detailed Description . . . 199
7.26.2 Member Function Documentation . . . 199
7.26.2.1 type_description() . . . 199
7.27 qpp::exception::MatrixNotCvector Class Reference . . . 199
7.27.1 Detailed Description . . . 201
7.27.2 Member Function Documentation . . . 201
7.27.2.1 type_description() . . . 201
7.28 qpp::exception::MatrixNotRvector Class Reference . . . 201
7.28.1 Detailed Description . . . 202
7.28.2 Member Function Documentation . . . 202
7.28.2.1 type_description() . . . 203
7.29 qpp::exception::MatrixNotSquare Class Reference . . . 203
7.29.1 Detailed Description . . . 204
7.29.2 Member Function Documentation . . . 204
7.29.2.1 type_description() . . . 205
7.30 qpp::exception::MatrixNotSquareNorCvector Class Reference . . . 205
7.30.1 Detailed Description . . . 206
7.30.2 Member Function Documentation . . . 206
7.30.2.1 type_description() . . . 207
7.31 qpp::exception::MatrixNotSquareNorRvector Class Reference . . . 207

7.31.1 Detailed Description . . . . . 208
7.31.2 Member Function Documentation . . . . . 208
7.31.2.1 type_description() . . . . . 209
7.32 qpp::exception::MatrixNotSquareNorVector Class Reference . . . . . 209
7.32.1 Detailed Description . . . . . 210
7.32.2 Member Function Documentation . . . . . 210
7.32.2.1 type_description() . . . . . 211
7.33 qpp::exception::MatrixNotVector Class Reference . . . . . 211
7.33.1 Detailed Description . . . . . 212
7.33.2 Member Function Documentation . . . . . 212
7.33.2.1 type_description() . . . . . 213
7.34 qpp::exception::NoCodeword Class Reference . . . . . 213
7.34.1 Detailed Description . . . . . 214
7.34.2 Member Function Documentation . . . . . 214
7.34.2.1 type_description() . . . . . 214
7.35 qpp::exception::NotBipartite Class Reference . . . . . 215
7.35.1 Detailed Description . . . . . 216
7.35.2 Member Function Documentation . . . . . 216
7.35.2.1 type_description() . . . . . 216
7.36 qpp::exception::NotQubitCvector Class Reference . . . . . 217
7.36.1 Detailed Description . . . . . 218
7.36.2 Member Function Documentation . . . . . 218
7.36.2.1 type_description() . . . . . 219
7.37 qpp::exception::NotQubitMatrix Class Reference . . . . . 219
7.37.1 Detailed Description . . . . . 220
7.37.2 Member Function Documentation . . . . . 220
7.37.2.1 type_description() . . . . . 221
7.38 qpp::exception::NotQubitRvector Class Reference . . . . . 221
7.38.1 Detailed Description . . . . . 222
7.38.2 Member Function Documentation . . . . . 222

7.38.2.1 type_description() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 223
7.39 qpp::exception::NotQubitSubsys Class Reference . . . . . . . . . . . . . . . . . . . . . . . . . . 223
7.39.1 Detailed Description . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 224
7.39.2 Member Function Documentation . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 224
7.39.2.1 type_description() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 225
7.40 qpp::exception::NotQubitVector Class Reference . . . . . . . . . . . . . . . . . . . . . . . . . . 225
7.40.1 Detailed Description . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 226
7.40.2 Member Function Documentation . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 226
7.40.2.1 type_description() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 227
7.41 qpp::exception::OutOfRange Class Reference . . . . . . . . . . . . . . . . . . . . . . . . . . . . 227
7.41.1 Detailed Description . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 228
7.41.2 Member Function Documentation . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 228
7.41.2.1 type_description() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 228
7.42 qpp::exception::PermInvalid Class Reference . . . . . . . . . . . . . . . . . . . . . . . . . . . . 229
7.42.1 Detailed Description . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 230
7.42.2 Member Function Documentation . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 230
7.42.2.1 type_description() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 230
7.43 qpp::exception::PermMismatchDims Class Reference . . . . . . . . . . . . . . . . . . . . . . . . 231
7.43.1 Detailed Description . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 232
7.43.2 Member Function Documentation . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 232
7.43.2.1 type_description() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 233
7.44 qpp::RandomDevices Class Reference . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 233
7.44.1 Detailed Description . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 234
7.44.2 Constructor & Destructor Documentation . . . . . . . . . . . . . . . . . . . . . . . . . . 234
7.44.2.1 RandomDevices() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 235
7.44.2.2 ∼RandomDevices() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 235
7.44.3 Member Function Documentation . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 235
7.44.3.1 get_prng() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 235
7.44.3.2 load() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 235
7.44.3.3 save() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 236

7.44.4 Friends And Related Function Documentation . . . . . . . . . . . . . . . . . . . . . . 236
7.44.4.1 internal::Singleton< RandomDevices > . . . . . . . . . . . . . . . . . . . . . 236
7.44.5 Member Data Documentation . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 236
7.44.5.1 prng_ . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 236
7.44.5.2 rd_ . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 236
7.45 qpp::internal::Singleton< T > Class Template Reference . . . . . . . . . . . . . . . . . . . . . 237
7.45.1 Detailed Description . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 237
7.45.2 Constructor & Destructor Documentation . . . . . . . . . . . . . . . . . . . . . . . . 238
7.45.2.1 Singleton() [1/2] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 238
7.45.2.2 Singleton() [2/2] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 238
7.45.2.3 ∼Singleton() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 238
7.45.3 Member Function Documentation . . . . . . . . . . . . . . . . . . . . . . . . . . . 238
7.45.3.1 get_instance() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 238
7.45.3.2 get_thread_local_instance() . . . . . . . . . . . . . . . . . . . . . . . . . . . 238
7.45.3.3 operator=() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 239
7.46 qpp::exception::SizeMismatch Class Reference . . . . . . . . . . . . . . . . . . . . . . . . . 239
7.46.1 Detailed Description . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 240
7.46.2 Member Function Documentation . . . . . . . . . . . . . . . . . . . . . . . . . . . 240
7.46.2.1 type_description() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 240
7.47 qpp::States Class Reference . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 241
7.47.1 Detailed Description . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 243
7.47.2 Constructor & Destructor Documentation . . . . . . . . . . . . . . . . . . . . . . . . 243
7.47.2.1 States() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 243
7.47.2.2 ∼States() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 243
7.47.3 Member Function Documentation . . . . . . . . . . . . . . . . . . . . . . . . . . . 244
7.47.3.1 jn() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 244
7.47.3.2 mes() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 244
7.47.3.3 minus() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 244
7.47.3.4 one() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 245
7.47.3.5 plus() . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 245

7.47.3.6 zero() . . . 246
7.47.4 Friends And Related Function Documentation . . . 246
7.47.4.1 internal::Singleton< const States > . . . 246
7.47.5 Member Data Documentation . . . 246
7.47.5.1 b00 . . . 246
7.47.5.2 b01 . . . 246
7.47.5.3 b10 . . . 247
7.47.5.4 b11 . . . 247
7.47.5.5 GHZ . . . 247
7.47.5.6 pb00 . . . 247
7.47.5.7 pb01 . . . 247
7.47.5.8 pb10 . . . 247
7.47.5.9 pb11 . . . 248
7.47.5.10 pGHZ . . . 248
7.47.5.11 pW . . . 248
7.47.5.12 px0 . . . 248
7.47.5.13 px1 . . . 248
7.47.5.14 py0 . . . 248
7.47.5.15 py1 . . . 249
7.47.5.16 pz0 . . . 249
7.47.5.17 pz1 . . . 249
7.47.5.18 W . . . 249
7.47.5.19 x0 . . . 249
7.47.5.20 x1 . . . 249
7.47.5.21 y0 . . . 250
7.47.5.22 y1 . . . 250
7.47.5.23 z0 . . . 250
7.47.5.24 z1 . . . 250
7.48 qpp::exception::SubsysMismatchDims Class Reference . . . 251
7.48.1 Detailed Description . . . 252

7.48.2 Member Function Documentation . . . . . 252
7.48.2.1 type_description() . . . . . 252
7.49 qpp::Timer< T, CLOCK_T > Class Template Reference . . . . . 252
7.49.1 Detailed Description . . . . . 254
7.49.2 Constructor & Destructor Documentation . . . . . 254
7.49.2.1 Timer() [1/3] . . . . . 254
7.49.2.2 Timer() [2/3] . . . . . 254
7.49.2.3 Timer() [3/3] . . . . . 254
7.49.2.4 ∼Timer() . . . . . 255
7.49.3 Member Function Documentation . . . . . 255
7.49.3.1 display() . . . . . 255
7.49.3.2 get_duration() . . . . . 255
7.49.3.3 operator=() [1/2] . . . . . 256
7.49.3.4 operator=() [2/2] . . . . . 256
7.49.3.5 tic() . . . . . 256
7.49.3.6 tics() . . . . . 256
7.49.3.7 toc() . . . . . 257
7.49.4 Member Data Documentation . . . . . 257
7.49.4.1 end_ . . . . . 257
7.49.4.2 start_ . . . . . 257
7.50 qpp::exception::TypeMismatch Class Reference . . . . . 258
7.50.1 Detailed Description . . . . . 259
7.50.2 Member Function Documentation . . . . . 259
7.50.2.1 type_description() . . . . . 259
7.51 qpp::exception::UndefinedType Class Reference . . . . . 259
7.51.1 Detailed Description . . . . . 261
7.51.2 Member Function Documentation . . . . . 261
7.51.2.1 type_description() . . . . . 261
7.52 qpp::exception::Unknown Class Reference . . . . . 261
7.52.1 Detailed Description . . . . . 262
7.52.2 Member Function Documentation . . . . . 262
7.52.2.1 type_description() . . . . . 262
7.53 qpp::exception::ZeroSize Class Reference . . . . . 263
7.53.1 Detailed Description . . . . . 264
7.53.2 Member Function Documentation . . . . . 264
7.53.2.1 type_description() . . . . . 264

**8 File Documentation 265**

8.1 classes/codes.h File Reference . . . 265
8.1.1 Detailed Description . . . 265
8.2 classes/exception.h File Reference . . . 266
8.2.1 Detailed Description . . . 267
8.3 classes/gates.h File Reference . . . 268
8.3.1 Detailed Description . . . 268
8.4 classes/idisplay.h File Reference . . . 268
8.4.1 Detailed Description . . . 269
8.5 classes/init.h File Reference . . . 269
8.5.1 Detailed Description . . . 269
8.6 classes/random_devices.h File Reference . . . 270
8.6.1 Detailed Description . . . 270
8.7 classes/reversible.h File Reference . . . 270
8.7.1 Detailed Description . . . 271
8.8 classes/states.h File Reference . . . 271
8.8.1 Detailed Description . . . 272
8.9 classes/timer.h File Reference . . . 272
8.9.1 Detailed Description . . . 272
8.10 constants.h File Reference . . . 273
8.10.1 Detailed Description . . . 274
8.11 entanglement.h File Reference . . . 274
8.11.1 Detailed Description . . . 275
8.12 entropies.h File Reference . . . 275
8.12.1 Detailed Description . . . 276
8.13 experimental/experimental.h File Reference . . . 277
8.13.1 Detailed Description . . . 277
8.14 functions.h File Reference . . . 277
8.14.1 Detailed Description . . . 281
8.15 input_output.h File Reference . . . 282

8.15.1 Detailed Description . . . . . . . . . . 283
8.16 instruments.h File Reference . . . . . . . . . . 283
8.16.1 Detailed Description . . . . . . . . . . 284
8.17 internal/classes/iomanip.h File Reference . . . . . . . . . . 284
8.17.1 Detailed Description . . . . . . . . . . 285
8.18 internal/classes/singleton.h File Reference . . . . . . . . . . 285
8.18.1 Detailed Description . . . . . . . . . . 286
8.19 internal/util.h File Reference . . . . . . . . . . 286
8.19.1 Detailed Description . . . . . . . . . . 287
8.20 MATLAB/matlab.h File Reference . . . . . . . . . . 288
8.20.1 Detailed Description . . . . . . . . . . 288
8.21 number_theory.h File Reference . . . . . . . . . . 288
8.21.1 Detailed Description . . . . . . . . . . 290
8.22 operations.h File Reference . . . . . . . . . . 290
8.22.1 Detailed Description . . . . . . . . . . 292
8.23 qpp.h File Reference . . . . . . . . . . 292
8.23.1 Detailed Description . . . . . . . . . . 293
8.23.2 Macro Definition Documentation . . . . . . . . . . 293
8.23.2.1 QPP_UNUSED_ . . . . . . . . . . 293
8.24 random.h File Reference . . . . . . . . . . 294
8.24.1 Detailed Description . . . . . . . . . . 295
8.25 statistics.h File Reference . . . . . . . . . . 295
8.25.1 Detailed Description . . . . . . . . . . 296
8.26 traits.h File Reference . . . . . . . . . . 296
8.26.1 Detailed Description . . . . . . . . . . 297
8.27 types.h File Reference . . . . . . . . . . 298
8.27.1 Detailed Description . . . . . . . . . . 299
8.28 /home/vlad/qpp/README.md File Reference . . . . . . . . . . 299

**Index** **301**

# Chapter 1

# Quantum++

### Version 1.1 - 26 November 2018

**Build status:**

**Chat (questions/issues)**

## About

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

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

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

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

For additional Eigen 3 documentation see http://eigen.tuxfamily.org/dox/. For a simple Eigen 3 quick ASCII reference see http://eigen.tuxfamily.org/dox/AsciiQuickReference.txt.



## License



## Installation instructions and further documentation

Please see the installation guide https://github.com/vsoftco/qpp/blob/master/INSTALL.md "‘INSTALL.md‘" and the comprehensive Wiki for further documentation and detailed examples.

The official API documentation is available in PDF and HTML formats in the doc folder.

# Chapter 2

# Namespace Index

## 2.1 Namespace List

Here is a list of all namespaces with brief descriptions:


qpp
Quantum++ main namespace . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 13
qpp::exception
Quantum++ exception hierarchy namespace . . . . . . . . . . . . . . . . . . . . . . . . . . 114
qpp::experimental
Experimental/test functions/classes, do not use or modify . . . . . . . . . . . . . . . . . . . . 116
qpp::internal
Internal utility functions, do not use them directly or modify them . . . . . . . . . . . . . . . . 116
qpp::literals . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 122

# Chapter 3

# Hierarchical Index

## 3.1 Class Hierarchy

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


qpp::internal::Display_Impl_ . . . . 147
  qpp::internal::IOManipEigen . . . . 183
std::exception
  qpp::exception::Exception . . . . 161
    qpp::exception::CustomException . . . . 133
    qpp::exception::DimsInvalid . . . . 136
    qpp::exception::DimsMismatchCvector . . . . 137
    qpp::exception::DimsMismatchMatrix . . . . 139
    qpp::exception::DimsMismatchRvector . . . . 141
    qpp::exception::DimsMismatchVector . . . . 143
    qpp::exception::DimsNotEqual . . . . 145
    qpp::exception::MatrixMismatchSubsys . . . . 198
    qpp::exception::MatrixNotCvector . . . . 199
    qpp::exception::MatrixNotRvector . . . . 201
    qpp::exception::MatrixNotSquare . . . . 203
    qpp::exception::MatrixNotSquareNorCvector . . . . 205
    qpp::exception::MatrixNotSquareNorRvector . . . . 207
    qpp::exception::MatrixNotSquareNorVector . . . . 209
    qpp::exception::MatrixNotVector . . . . 211
    qpp::exception::NoCodeword . . . . 213
    qpp::exception::NotBipartite . . . . 215
    qpp::exception::NotQubitCvector . . . . 217
    qpp::exception::NotQubitMatrix . . . . 219
    qpp::exception::NotQubitRvector . . . . 221
    qpp::exception::NotQubitSubsys . . . . 223
    qpp::exception::NotQubitVector . . . . 225
    qpp::exception::OutOfRange . . . . 227
    qpp::exception::PermInvalid . . . . 229
    qpp::exception::PermMismatchDims . . . . 231
    qpp::exception::SizeMismatch . . . . 239
    qpp::exception::SubsysMismatchDims . . . . 251
    qpp::exception::TypeMismatch . . . . 258
    qpp::exception::UndefinedType . . . . 259
    qpp::exception::Unknown . . . . 261
    qpp::exception::ZeroSize . . . . 263

false_type
qpp::is_complex< T > . . . 192
qpp::is_iterable< T, typename > . . . 194
qpp::Bit_circuit::Gate_count . . . 164
qpp::IDisplay . . . 178
qpp::Dynamic_bitset . . . 148
qpp::Bit_circuit . . . 125
qpp::internal::IOManipEigen . . . 183
qpp::internal::IOManipPointer< PointerType > . . . 185
qpp::internal::IOManipRange< InputIterator > . . . 189
qpp::Timer< T, CLOCK_T > . . . 252
is_base_of
qpp::is_matrix_expression< Derived > . . . 196
qpp::make_void< Ts > . . . 197
qpp::internal::Singleton< T > . . . 237
qpp::internal::Singleton< const Codes > . . . 237
qpp::Codes . . . 130
qpp::internal::Singleton< const Gates > . . . 237
qpp::Gates . . . 166
qpp::internal::Singleton< const Init > . . . 237
qpp::Init . . . 181
qpp::internal::Singleton< const States > . . . 237
qpp::States . . . 241
qpp::internal::Singleton< RandomDevices > . . . 237
qpp::RandomDevices . . . 233
true_type
qpp::is_complex< std::complex< T > > . . . 193
qpp::is_iterable< T, to_void< decltype(std::declval< T >().begin()), decltype(std::declval< T >().end()), typename T::value_type > > . . . 195

# Chapter 4

# Class Index

## 4.1 Class List

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


qpp::Bit_circuit
Classical reversible circuit simulator . . . . . 125
qpp::Codes
Const Singleton class that defines quantum error correcting codes . . . . . 130
qpp::exception::CustomException
Custom exception . . . . . 133
qpp::exception::DimsInvalid
Invalid dimension(s) exception . . . . . 136
qpp::exception::DimsMismatchCvector
Dimension(s) mismatch column vector size exception . . . . . 137
qpp::exception::DimsMismatchMatrix
Dimension(s) mismatch matrix size exception . . . . . 139
qpp::exception::DimsMismatchRvector
Dimension(s) mismatch row vector size exception . . . . . 141
qpp::exception::DimsMismatchVector
Dimension(s) mismatch vector size exception . . . . . 143
qpp::exception::DimsNotEqual
Dimensions not equal exception . . . . . 145
qpp::internal::Display_Impl_ . . . . . 147
qpp::Dynamic_bitset
Dynamic bitset class, allows the specification of the number of bits at runtime (unlike std::bitset<N>) . . . . . 148
qpp::exception::Exception
Base class for generating Quantum++ custom exceptions . . . . . 161
qpp::Bit_circuit::Gate_count . . . . . 164
qpp::Gates
Const Singleton class that implements most commonly used gates . . . . . 166
qpp::IDisplay
Abstract class (interface) that mandates the definition of virtual std::ostream& display(std::ostream& os) const . . . . . 178
qpp::Init
Const Singleton class that performs additional initializations/cleanups . . . . . 181
qpp::internal::IOManipEigen . . . . . 183
qpp::internal::IOManipPointer< PointerType > . . . . . 185
qpp::internal::IOManipRange< InputIterator > . . . . . 189

qpp::is_complex< T >
Checks whether the type is a complex type . . . 192
qpp::is_complex< std::complex< T > >
Checks whether the type is a complex number type, specialization for complex types . . . 193
qpp::is_iterable< T, typename >
Checks whether *T* is compatible with an STL-like iterable container . . . 194
qpp::is_iterable< T, to_void< decltype(std::declval< T >().begin()), decltype(std::declval< T >().end()), typename T::value_type > >
Checks whether *T* is compatible with an STL-like iterable container, specialization for STL-like iterable containers . . . 195
qpp::is_matrix_expression< Derived >
Checks whether the type is an Eigen matrix expression . . . 196
qpp::make_void< Ts >
Helper for qpp::to_void<> alias template . . . 197
qpp::exception::MatrixMismatchSubsys
Matrix mismatch subsystems exception . . . 198
qpp::exception::MatrixNotCvector
Matrix is not a column vector exception . . . 199
qpp::exception::MatrixNotRvector
Matrix is not a row vector exception . . . 201
qpp::exception::MatrixNotSquare
Matrix is not square exception . . . 203
qpp::exception::MatrixNotSquareNorCvector
Matrix is not square nor column vector exception . . . 205
qpp::exception::MatrixNotSquareNorRvector
Matrix is not square nor row vector exception . . . 207
qpp::exception::MatrixNotSquareNorVector
Matrix is not square nor vector exception . . . 209
qpp::exception::MatrixNotVector
Matrix is not a vector exception . . . 211
qpp::exception::NoCodeword
Codeword does not exist exception . . . 213
qpp::exception::NotBipartite
Not bi-partite exception . . . 215
qpp::exception::NotQubitCvector
Column vector is not 2 x 1 exception . . . 217
qpp::exception::NotQubitMatrix
Matrix is not 2 x 2 exception . . . 219
qpp::exception::NotQubitRvector
Row vector is not 1 x 2 exception . . . 221
qpp::exception::NotQubitSubsys
Subsystems are not qubits exception . . . 223
qpp::exception::NotQubitVector
Vector is not 2 x 1 nor 1 x 2 exception . . . 225
qpp::exception::OutOfRange
Parameter out of range exception . . . 227
qpp::exception::PermInvalid
Invalid permutation exception . . . 229
qpp::exception::PermMismatchDims
Permutation mismatch dimensions exception . . . 231
qpp::RandomDevices
Singleton class that manages the source of randomness in the library . . . 233
qpp::internal::Singleton< T >
Singleton policy class, used internally to implement the singleton pattern via CRTP (Curiously recurring template pattern) . . . 237
qpp::exception::SizeMismatch
Size mismatch exception . . . 239

qpp::States
Const Singleton class that implements most commonly used states . . . . . . . . . . . . . . . . 241
qpp::exception::SubsysMismatchDims
Subsystems mismatch dimensions exception . . . . . . . . . . . . . . . . . . . . . . . . . . 251
qpp::Timer< T, CLOCK_T >
Chronometer . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 252
qpp::exception::TypeMismatch
Type mismatch exception . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 258
qpp::exception::UndefinedType
Not defined for this type exception . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 259
qpp::exception::Unknown
Unknown exception . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 261
qpp::exception::ZeroSize
Object has zero size exception . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 263

# Chapter 5

# File Index

## 5.1 File List

Here is a list of all files with brief descriptions:


constants.h
Constants . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 273
entanglement.h
Entanglement functions . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 274
entropies.h
Entropy functions . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 275
functions.h
Generic quantum computing functions . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 277
input_output.h
Input/output functions . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 282
instruments.h
Measurement functions . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 283
number_theory.h
Number theory functions . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 288
operations.h
Quantum operation functions . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 290
qpp.h
Quantum++ main header file, includes all other necessary headers . . . . . . . . . . . . . . 292
random.h
Randomness-related functions . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 294
statistics.h
Statistics functions . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 295
traits.h
Type traits . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 296
types.h
Type aliases . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 298
classes/codes.h
Quantum error correcting codes . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 265
classes/exception.h
Exceptions . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 266
classes/gates.h
Quantum gates . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 268
classes/idisplay.h
Display interface via the non-virtual interface (NVI) . . . . . . . . . . . . . . . . . . . . . 268
classes/init.h
Initialization . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 269

classes/random_devices.h
Random devices . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 270
classes/reversible.h
Support for classical reversible circuits . . . . . . . . . . . . . . . . . . . . . . . . . . . . 270
classes/states.h
Quantum states . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 271
classes/timer.h
Timing . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 272
experimental/experimental.h
Experimental/test functions/classes . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 277
internal/util.h
Internal utility functions . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 286
internal/classes/iomanip.h
Input/output manipulators . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 284
internal/classes/singleton.h
Singleton pattern via CRTP . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 285
MATLAB/matlab.h
Input/output interfacing with MATLAB . . . . . . . . . . . . . . . . . . . . . . . . . . . . 288

# Chapter 6

# Namespace Documentation

## 6.1 qpp Namespace Reference

Quantum++ main namespace.

### Namespaces

- exception

  *Quantum++ exception hierarchy namespace.*
- experimental

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

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

### Classes

- class Bit_circuit

  *Classical reversible circuit simulator.*
- class Codes

  *const Singleton class that defines quantum error correcting codes*
- class Dynamic_bitset

  *Dynamic bitset class, allows the specification of the number of bits at runtime (unlike std::bitset<N>)*
- class Gates

  *const Singleton class that implements most commonly used gates*
- class IDisplay

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

  *const Singleton class that performs additional initializations/cleanups*
- struct is_complex

  *Checks whether the type is a complex type.*
- struct is_complex< std::complex< T > >

  *Checks whether the type is a complex number type, specialization for complex types.*
- struct is_iterable

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

- struct is_iterable< T, to_void< decltype(std::declval< T >().begin()), decltype(std::declval< T >().end()), typename T::value_type > >

  *Checks whether T is compatible with an STL-like iterable container, specialization for STL-like iterable containers.*
- struct is_matrix_expression

  *Checks whether the type is an Eigen matrix expression.*
- struct make_void

  *Helper for qpp::to_void<> alias template.*
- class RandomDevices

  *Singleton class that manages the source of randomness in the library.*
- class States

  *const Singleton class that implements most commonly used states*
- class Timer

  *Chronometer.*

## Typedefs

- template<typename... Ts>
  using to_void = typename make_void< Ts... >::type

  *Alias template that implements the proposal for void_t.*
- using idx = std::size_t

  *Non-negative integer index.*
- using bigint = long long int

  *Big integer.*
- using cplx = std::complex< double >

  *Complex number in double precision.*
- using ket = Eigen::VectorXcd

  *Complex (double precision) dynamic Eigen column vector.*
- using bra = Eigen::RowVectorXcd

  *Complex (double precision) dynamic Eigen row vector.*
- using cmat = Eigen::MatrixXcd

  *Complex (double precision) dynamic Eigen matrix.*
- using dmat = Eigen::MatrixXd

  *Real (double precision) dynamic Eigen matrix.*
- template<typename Scalar >
  using dyn_mat = Eigen::Matrix< Scalar, Eigen::Dynamic, Eigen::Dynamic >

  *Dynamic Eigen matrix over the field specified by Scalar.*
- template<typename Scalar >
  using dyn_col_vect = Eigen::Matrix< Scalar, Eigen::Dynamic, 1 >

  *Dynamic Eigen column vector over the field specified by Scalar.*
- template<typename Scalar >
  using dyn_row_vect = Eigen::Matrix< Scalar, 1, Eigen::Dynamic >

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

## Functions

- constexpr cplx operator"" _i (long double x) noexcept

  *User-defined literal for complex $i = \sqrt{-1}$ (real overload)*
- cplx omega (idx D)

  *D-th root of unity.*
- template<typename Derived >
  dyn_col_vect< double > schmidtcoeffs (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &dims)

  *Schmidt coefficients of the bi-partite pure state A.*
- template<typename Derived >
  dyn_col_vect< double > schmidtcoeffs (const Eigen::MatrixBase< Derived > &A, idx d=2)

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

  *Schmidt basis on Alice side.*
- template<typename Derived >
  cmat schmidtA (const Eigen::MatrixBase< Derived > &A, idx d=2)

  *Schmidt basis on Alice side.*
- template<typename Derived >
  cmat schmidtB (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &dims)

  *Schmidt basis on Bob side.*
- template<typename Derived >
  cmat schmidtB (const Eigen::MatrixBase< Derived > &A, idx d=2)

  *Schmidt basis on Bob side.*
- template<typename Derived >
  std::vector< double > schmidtprobs (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &dims)

  *Schmidt probabilities of the bi-partite pure state A.*
- template<typename Derived >
  std::vector< double > schmidtprobs (const Eigen::MatrixBase< Derived > &A, idx d=2)

  *Schmidt probabilities of the bi-partite pure state A.*
- template<typename Derived >
  double entanglement (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &dims)

  *Entanglement of the bi-partite pure state A.*
- template<typename Derived >
  double entanglement (const Eigen::MatrixBase< Derived > &A, idx d=2)

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

  *G-concurrence of the bi-partite pure state A.*
- template<typename Derived >
  double negativity (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &dims)

  *Negativity of the bi-partite mixed state A.*
- template<typename Derived >
  double negativity (const Eigen::MatrixBase< Derived > &A, idx d=2)

  *Negativity of the bi-partite mixed state A.*
- template<typename Derived >
  double lognegativity (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &dims)

  *Logarithmic negativity of the bi-partite mixed state A.*
- template<typename Derived >
  double lognegativity (const Eigen::MatrixBase< Derived > &A, idx d=2)

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

- template<typename Derived >
  double concurrence (const Eigen::MatrixBase< Derived > &A)

  *Wootters concurrence of the bi-partite qubit mixed state A.*
- template<typename Derived >
  double entropy (const Eigen::MatrixBase< Derived > &A)

  *von-Neumann entropy of the density matrix A*
- double entropy (const std::vector< double > &prob)

  *Shannon entropy of the probability distribution prob.*
- template<typename Derived >
  double renyi (const Eigen::MatrixBase< Derived > &A, double alpha)

  *Renyi- $\alpha$ entropy of the density matrix A, for $\alpha \geq 0$.*
- double renyi (const std::vector< double > &prob, double alpha)

  *Renyi- $\alpha$ entropy of the probability distribution prob, for $\alpha \geq 0$.*
- template<typename Derived >
  double tsallis (const Eigen::MatrixBase< Derived > &A, double q)

  *Tsallis- $q$ entropy of the density matrix A, for $q \geq 0$.*
- double tsallis (const std::vector< double > &prob, double q)

  *Tsallis- $q$ entropy of the probability distribution prob, for $q \geq 0$.*
- template<typename Derived >
  double qmutualinfo (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &subsysA, const std::vector< idx > &subsysB, const std::vector< idx > &dims)

  *Quantum mutual information between 2 subsystems of a composite system.*
- template<typename Derived >
  double qmutualinfo (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &subsysA, const std::vector< idx > &subsysB, idx d=2)

  *Quantum mutual information between 2 subsystems of a composite system.*
- template<typename Derived >
  dyn_mat< typename Derived::Scalar > transpose (const Eigen::MatrixBase< Derived > &A)

  *Transpose.*
- template<typename Derived >
  dyn_mat< typename Derived::Scalar > conjugate (const Eigen::MatrixBase< Derived > &A)

  *Complex conjugate.*
- template<typename Derived >
  dyn_mat< typename Derived::Scalar > adjoint (const Eigen::MatrixBase< Derived > &A)

  *Adjoint.*
- template<typename Derived >
  dyn_mat< typename Derived::Scalar > inverse (const Eigen::MatrixBase< Derived > &A)

  *Inverse.*
- template<typename Derived >
  Derived::Scalar trace (const Eigen::MatrixBase< Derived > &A)

  *Trace.*
- template<typename Derived >
  Derived::Scalar det (const Eigen::MatrixBase< Derived > &A)

  *Determinant.*
- template<typename Derived >
  Derived::Scalar logdet (const Eigen::MatrixBase< Derived > &A)

  *Logarithm of the determinant.*
- template<typename Derived >
  Derived::Scalar sum (const Eigen::MatrixBase< Derived > &A)

  *Element-wise sum of A.*
- template<typename Derived >
  Derived::Scalar prod (const Eigen::MatrixBase< Derived > &A)

  *Element-wise product of A.*

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

  *Frobenius norm.*
- template<typename Derived >
  std::pair< dyn_col_vect< cplx >, cmat > eig (const Eigen::MatrixBase< Derived > &A)

  *Full eigen decomposition.*
- template<typename Derived >
  dyn_col_vect< cplx > evals (const Eigen::MatrixBase< Derived > &A)

  *Eigenvalues.*
- template<typename Derived >
  cmat evects (const Eigen::MatrixBase< Derived > &A)

  *Eigenvectors.*
- template<typename Derived >
  std::pair< dyn_col_vect< double >, cmat > heig (const Eigen::MatrixBase< Derived > &A)

  *Full eigen decomposition of Hermitian expression.*
- template<typename Derived >
  dyn_col_vect< double > hevals (const Eigen::MatrixBase< Derived > &A)

  *Hermitian eigenvalues.*
- template<typename Derived >
  cmat hevects (const Eigen::MatrixBase< Derived > &A)

  *Hermitian eigenvectors.*
- template<typename Derived >
  std::tuple< cmat, dyn_col_vect< double >, cmat > svd (const Eigen::MatrixBase< Derived > &A)

  *Full singular value decomposition.*
- template<typename Derived >
  dyn_col_vect< double > svals (const Eigen::MatrixBase< Derived > &A)

  *Singular values.*
- template<typename Derived >
  cmat svdU (const Eigen::MatrixBase< Derived > &A)

  *Left singular vectors.*
- template<typename Derived >
  cmat svdV (const Eigen::MatrixBase< Derived > &A)

  *Right singular vectors.*
- template<typename Derived >
  cmat funm (const Eigen::MatrixBase< Derived > &A, cplx(*f)(const cplx &))

  *Functional calculus f(A)*
- template<typename Derived >
  cmat sqrtm (const Eigen::MatrixBase< Derived > &A)

  *Matrix square root.*
- template<typename Derived >
  cmat absm (const Eigen::MatrixBase< Derived > &A)

  *Matrix absolute value.*
- template<typename Derived >
  cmat expm (const Eigen::MatrixBase< Derived > &A)

  *Matrix exponential.*
- template<typename Derived >
  cmat logm (const Eigen::MatrixBase< Derived > &A)

  *Matrix logarithm.*
- template<typename Derived >
  cmat sinm (const Eigen::MatrixBase< Derived > &A)

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

*Matrix cos.*

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

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

  *Fast matrix power based on the SQUARE-AND-MULTIPLY algorithm.*
- template< typename Derived >
  double schatten (const Eigen::MatrixBase< Derived > &A, double p)

  *Schatten matrix norm.*
- template< typename OutputScalar , typename Derived >
  dyn_mat< OutputScalar > cwise (const Eigen::MatrixBase< Derived > &A, OutputScalar(*f)(const typename Derived::Scalar &))

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

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

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

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

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

  *Kronecker power.*
- template< typename T >
  dyn_mat< typename T::Scalar > dirsum (const T &head)

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

  *Direct sum.*
- template< typename Derived >
  dyn_mat< typename Derived::Scalar > dirsum (const std::vector< Derived > &As)

  *Direct sum.*
- template< typename Derived >
  dyn_mat< typename Derived::Scalar > dirsum (const std::initializer_list< Derived > &As)

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

  *Direct sum power.*
- template< typename Derived >
  dyn_mat< typename Derived::Scalar > reshape (const Eigen::MatrixBase< Derived > &A, idx rows, idx cols)

  *Reshape.*
- template< typename Derived1 , typename Derived2 >
  dyn_mat< typename Derived1::Scalar > comm (const Eigen::MatrixBase< Derived1 > &A, const Eigen::MatrixBase< Derived2 > &B)

  *Commutator.*

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

  *Anti-commutator.*
- template< typename Derived >
dyn_mat< typename Derived::Scalar > prj (const Eigen::MatrixBase< Derived > &A)

  *Projector.*
- template< typename Derived >
dyn_mat< typename Derived::Scalar > grams (const std::vector< Derived > &As)

  *Gram-Schmidt orthogonalization.*
- template< typename Derived >
dyn_mat< typename Derived::Scalar > grams (const std::initializer_list< Derived > &As)

  *Gram-Schmidt orthogonalization.*
- template< typename Derived >
dyn_mat< typename Derived::Scalar > grams (const Eigen::MatrixBase< Derived > &A)

  *Gram-Schmidt orthogonalization.*
- std::vector< idx > n2multiidx (idx n, const std::vector< idx > &dims)

  *Non-negative integer index to multi-index.*
- idx multiidx2n (const std::vector< idx > &midx, const std::vector< idx > &dims)

  *Multi-index to non-negative integer index.*
- ket mket (const std::vector< idx > &mask, const std::vector< idx > &dims)

  *Multi-partite qudit ket.*
- ket mket (const std::vector< idx > &mask, idx d=2)

  *Multi-partite qudit ket.*
- cmat mprj (const std::vector< idx > &mask, const std::vector< idx > &dims)

  *Projector onto multi-partite qudit ket.*
- cmat mprj (const std::vector< idx > &mask, idx d=2)

  *Projector onto multi-partite qudit ket.*
- template< typename InputIterator >
std::vector< double > abssq (InputIterator first, InputIterator last)

  *Computes the absolute values squared of an STL-like range of complex numbers.*
- template< typename Container >
std::vector< double > abssq (const Container &c, typename std::enable_if< is_iterable< Container >::value >::type *=nullptr)

  *Computes the absolute values squared of an STL-like container.*
- template< typename Derived >
std::vector< double > abssq (const Eigen::MatrixBase< Derived > &A)

  *Computes the absolute values squared of an Eigen expression.*
- template< typename InputIterator >
std::iterator_traits< InputIterator >::value_type sum (InputIterator first, InputIterator last)

  *Element-wise sum of an STL-like range.*
- template< typename Container >
Container::value_type sum (const Container &c, typename std::enable_if< is_iterable< Container >::value >::type *=nullptr)

  *Element-wise sum of the elements of an STL-like container.*
- template< typename InputIterator >
std::iterator_traits< InputIterator >::value_type prod (InputIterator first, InputIterator last)

  *Element-wise product of an STL-like range.*
- template< typename Container >
Container::value_type prod (const Container &c, typename std::enable_if< is_iterable< Container >::value >::type *=nullptr)

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

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

  *Finds the pure state representation of a matrix proportional to a projector onto a pure state.*
- template< typename T >
std::vector< T > complement (std::vector< T > subsys, idx N)

  *Constructs the complement of a subsystem vector.*
- template< typename Derived >
std::vector< double > rho2bloch (const Eigen::MatrixBase< Derived > &A)

  *Computes the 3-dimensional real Bloch vector corresponding to the qubit density matrix A.*
- cmat bloch2rho (const std::vector< double > &r)

  *Computes the density matrix corresponding to the 3-dimensional real Bloch vector r.*
- template< typename Derived >
internal::IOManipEigen disp (const Eigen::MatrixBase< Derived > &A, double chop=qpp::chop)

  *Eigen expression ostream manipulator.*
- internal::IOManipEigen disp (cplx z, double chop=qpp::chop)

  *Complex number ostream manipulator.*
- template< typename InputIterator >
internal::IOManipRange< InputIterator > disp (InputIterator first, InputIterator last, const std::string &separator, const std::string &start="[", const std::string &end="]")

  *Range ostream manipulator.*
- template< typename Container >
internal::IOManipRange< typename Container::const_iterator > disp (const Container &c, const std::string &separator, const std::string &start="[", const std::string &end="]", typename std::enable_if< is_iterable< Container >::value >::type ∗=nullptr)

  *Standard container ostream manipulator. The container must support std::begin(), std::end() and forward iteration.*
- template< typename PointerType >
internal::IOManipPointer< PointerType > disp (const PointerType ∗p, idx N, const std::string &separator, const std::string &start="[", const std::string &end="]")

  *C-style pointer ostream manipulator.*
- template< typename Derived >
void save (const Eigen::MatrixBase< Derived > &A, const std::string &fname)

  *Saves Eigen expression to a binary file (internal format) in double precision.*
- template< typename Derived >
dyn_mat< typename Derived::Scalar > load (const std::string &fname)

  *Loads Eigen matrix from a binary file (internal format) in double precision.*
- template< typename Derived >
dyn_col_vect< typename Derived::Scalar > ip (const Eigen::MatrixBase< Derived > &phi, const Eigen::↩ MatrixBase< Derived > &psi, const std::vector< idx > &subsys, const std::vector< idx > &dims)

  *Generalized inner product.*
- template< typename Derived >
dyn_col_vect< typename Derived::Scalar > ip (const Eigen::MatrixBase< Derived > &phi, const Eigen::↩ MatrixBase< Derived > &psi, const std::vector< idx > &subsys, idx d=2)

  *Generalized inner product.*
- template< typename Derived >
std::tuple< idx, std::vector< double >, std::vector< cmat > > measure (const Eigen::MatrixBase< Derived > &A, const std::vector< cmat > &Ks)

  *Measures the state A using the set of Kraus operators Ks.*
- template< typename Derived >
std::tuple< idx, std::vector< double >, std::vector< cmat > > measure (const Eigen::MatrixBase< Derived > &A, const std::initializer_list< cmat > &Ks)

  *Measures the state A using the set of Kraus operators Ks.*
- template< typename Derived >
std::tuple< idx, std::vector< double >, std::vector< cmat > > measure (const Eigen::MatrixBase< Derived > &A, const cmat &U)

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

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

  *Measures the part subsys of the multi-partite state vector or density matrix A using the set of Kraus operators Ks.*
- template< typename Derived >
  std::tuple< idx, std::vector< double >, std::vector< cmat > > measure (const Eigen::MatrixBase< Derived > &A, const std::initializer_list< cmat > &Ks, const std::vector< idx > &subsys, const std::vector< idx > &dims)

  *Measures the part subsys of the multi-partite state vector or density matrix A using the set of Kraus operators Ks.*
- template< typename Derived >
  std::tuple< idx, std::vector< double >, std::vector< cmat > > measure (const Eigen::MatrixBase< Derived > &A, const std::vector< cmat > &Ks, const std::vector< idx > &subsys, idx d=2)

  *Measures the part subsys of the multi-partite state vector or density matrix A using the set of Kraus operators Ks.*
- template< typename Derived >
  std::tuple< idx, std::vector< double >, std::vector< cmat > > measure (const Eigen::MatrixBase< Derived > &A, const std::initializer_list< cmat > &Ks, const std::vector< idx > &subsys, idx d=2)

  *Measures the part subsys of the multi-partite state vector or density matrix A using the set of Kraus operators Ks.*
- template< typename Derived >
  std::tuple< idx, std::vector< double >, std::vector< cmat > > measure (const Eigen::MatrixBase< Derived > &A, const cmat &V, const std::vector< idx > &subsys, const std::vector< idx > &dims)

  *Measures the part subsys of the multi-partite state vector or density matrix A in the orthonormal basis or rank-1 POVM specified by the matrix V.*
- template< typename Derived >
  std::tuple< idx, std::vector< double >, std::vector< cmat > > measure (const Eigen::MatrixBase< Derived > &A, const cmat &V, const std::vector< idx > &subsys, idx d=2)

  *Measures the part subsys of the multi-partite state vector or density matrix A in the orthonormal basis or rank-1 POVM specified by the matrix V.*
- template< typename Derived >
  std::tuple< std::vector< idx >, double, cmat > measure_seq (const Eigen::MatrixBase< Derived > &A, std::vector< idx > subsys, std::vector< idx > dims)

  *Sequentially measures the part subsys of the multi-partite state vector or density matrix A in the computational basis.*
- template< typename Derived >
  std::tuple< std::vector< idx >, double, cmat > measure_seq (const Eigen::MatrixBase< Derived > &A, std::vector< idx > subsys, idx d=2)

  *Sequentially measures the part subsys of the multi-partite state vector or density matrix A in the computational basis.*
- template< typename Derived >
  std::enable_if< std::is_same< typename Derived::Scalar, cplx >::value, dyn_mat< cplx > >::type loadMATLAB (const std::string &mat_file, const std::string &var_name)

  *Loads a complex Eigen dynamic matrix from a MATLAB .mat file,.*
- template< typename Derived >
  std::enable_if<!std::is_same< typename Derived::Scalar, cplx >::value, dyn_mat< typename Derived::Scalar > >::type loadMATLAB (const std::string &mat_file, const std::string &var_name)

  *Loads a non-complex Eigen dynamic matrix from a MATLAB .mat file,.*
- template< typename Derived >
  std::enable_if< std::is_same< typename Derived::Scalar, cplx >::value >::type saveMATLAB (const Eigen::MatrixBase< Derived > &A, const std::string &mat_file, const std::string &var_name, const std::string &mode)

  *Saves a complex Eigen dynamic matrix to a MATLAB .mat file,.*
- template< typename Derived >
  std::enable_if< !std::is_same< typename Derived::Scalar, cplx >::value >::type saveMATLAB (const Eigen::MatrixBase< Derived > &A, const std::string &mat_file, const std::string &var_name, const std::string &mode)

  *Saves a non-complex Eigen dynamic matrix to a MATLAB .mat file,.*
- std::vector< int > x2contfrac (double x, idx N, idx cut=1e5)

*Simple continued fraction expansion.*
- double contfrac2x (const std::vector< int > &cf, idx N=idx(-1))

    *Real representation of a simple continued fraction.*
- bigint gcd (bigint a, bigint b)

    *Greatest common divisor of two integers.*
- bigint gcd (const std::vector< bigint > &as)

    *Greatest common divisor of a list of integers.*
- bigint lcm (bigint a, bigint b)

    *Least common multiple of two integers.*
- bigint lcm (const std::vector< bigint > &as)

    *Least common multiple of a list of integers.*
- std::vector< idx > invperm (const std::vector< idx > &perm)

    *Inverse permutation.*
- std::vector< idx > compperm (const std::vector< idx > &perm, const std::vector< idx > &sigma)

    *Compose permutations.*
- std::vector< bigint > factors (bigint a)

    *Prime factor decomposition.*
- bigint modmul (bigint a, bigint b, bigint p)

    *Modular multiplication without overflow.*
- bigint modpow (bigint a, bigint n, bigint p)

    *Fast integer power modulo p based on the SQUARE-AND-MULTIPLY algorithm.*
- std::tuple< bigint, bigint, bigint > egcd (bigint a, bigint b)

    *Extended greatest common divisor of two integers.*
- bigint modinv (bigint a, bigint p)

    *Modular inverse of a mod p.*
- bool isprime (bigint p, idx k=80)

    *Primality test based on the Miller-Rabin's algorithm.*
- bigint randprime (bigint a, bigint b, idx N=1000)

    *Generates a random big prime uniformly distributed in the interval [a, b].*
- template<typename Derived1 , typename Derived2 >
  dyn_mat< typename Derived1::Scalar > applyCTRL (const Eigen::MatrixBase< Derived1 > &state, const Eigen::MatrixBase< Derived2 > &A, const std::vector< idx > &ctrl, const std::vector< idx > &subsys, const std::vector< idx > &dims)

    *Applies the controlled-gate A to the part subsys of the multi-partite state vector or density matrix state.*
- template<typename Derived1 , typename Derived2 >
  dyn_mat< typename Derived1::Scalar > applyCTRL (const Eigen::MatrixBase< Derived1 > &state, const Eigen::MatrixBase< Derived2 > &A, const std::vector< idx > &ctrl, const std::vector< idx > &subsys, idx d=2)

    *Applies the controlled-gate A to the part subsys of the multi-partite state vector or density matrix state.*
- template<typename Derived1 , typename Derived2 >
  dyn_mat< typename Derived1::Scalar > apply (const Eigen::MatrixBase< Derived1 > &state, const Eigen::MatrixBase< Derived2 > &A, const std::vector< idx > &subsys, const std::vector< idx > &dims)

    *Applies the gate A to the part subsys of the multi-partite state vector or density matrix state.*
- template<typename Derived1 , typename Derived2 >
  dyn_mat< typename Derived1::Scalar > apply (const Eigen::MatrixBase< Derived1 > &state, const Eigen::MatrixBase< Derived2 > &A, const std::vector< idx > &subsys, idx d=2)

    *Applies the gate A to the part subsys of the multi-partite state vector or density matrix state.*
- template<typename Derived >
  cmat apply (const Eigen::MatrixBase< Derived > &A, const std::vector< cmat > &Ks)

    *Applies the channel specified by the set of Kraus operators Ks to the density matrix A.*
- template<typename Derived >
  cmat apply (const Eigen::MatrixBase< Derived > &A, const std::vector< cmat > &Ks, const std::vector< idx > &subsys, const std::vector< idx > &dims)

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

- template< typename Derived >
  cmat apply (const Eigen::MatrixBase< Derived > &A, const std::vector< cmat > &Ks, const std::vector< idx > &subsys, idx d=2)

  *Applies the channel specified by the set of Kraus operators Ks to the part subsys of the multi-partite density matrix A.*
- cmat kraus2super (const std::vector< cmat > &Ks)

  *Superoperator matrix.*
- cmat kraus2choi (const std::vector< cmat > &Ks)

  *Choi matrix.*
- std::vector< cmat > choi2kraus (const cmat &A)

  *Orthogonal Kraus operators from Choi matrix.*
- cmat choi2super (const cmat &A)

  *Converts Choi matrix to superoperator matrix.*
- cmat super2choi (const cmat &A)

  *Converts superoperator matrix to Choi matrix.*
- template< typename Derived >
  dyn_mat< typename Derived::Scalar > ptrace1 (const Eigen::MatrixBase< Derived > &A, const std↩ ::vector< idx > &dims)

  *Partial trace.*
- template< typename Derived >
  dyn_mat< typename Derived::Scalar > ptrace1 (const Eigen::MatrixBase< Derived > &A, idx d=2)

  *Partial trace.*
- template< typename Derived >
  dyn_mat< typename Derived::Scalar > ptrace2 (const Eigen::MatrixBase< Derived > &A, const std↩ ::vector< idx > &dims)

  *Partial trace.*
- template< typename Derived >
  dyn_mat< typename Derived::Scalar > ptrace2 (const Eigen::MatrixBase< Derived > &A, idx d=2)

  *Partial trace.*
- template< typename Derived >
  dyn_mat< typename Derived::Scalar > ptrace (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &subsys, const std::vector< idx > &dims)

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

  *Partial trace.*
- template< typename Derived >
  dyn_mat< typename Derived::Scalar > ptranspose (const Eigen::MatrixBase< Derived > &A, const std↩ ::vector< idx > &subsys, const std::vector< idx > &dims)

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

  *Partial transpose.*
- template< typename Derived >
  dyn_mat< typename Derived::Scalar > syspermute (const Eigen::MatrixBase< Derived > &A, const std↩ ::vector< idx > &perm, const std::vector< idx > &dims)

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

  *Subsystem permutation.*

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

  *Applies the qudit quantum Fourier transform to the part subsys of the multi-partite state vector or density matrix A.*
- template< typename Derived >
  dyn_mat< typename Derived::Scalar > applyINVQFT (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &subsys, idx d=2, bool swap=true)

  *Applies the inverse (adjoint) qudit quantum Fourier transform to the part subsys of the multi-partite state vector or density matrix A.*
- template< typename Derived >
  dyn_col_vect< typename Derived::Scalar > INVQFT (const Eigen::MatrixBase< Derived > &A, idx d=2, bool swap=true)

  *Inverse (adjoint) qudit quantum Fourier transform.*
- template< typename Derived >
  dyn_col_vect< typename Derived::Scalar > QFT (const Eigen::MatrixBase< Derived > &A, idx d=2, bool swap=true)

  *Qudit quantum Fourier transform.*
- double rand (double a, double b)

  *Generates a random real number uniformly distributed in the interval [a, b)*
- bigint rand (bigint a, bigint b)

  *Generates a random big integer uniformly distributed in the interval [a, b].*
- idx randidx (idx a=std::numeric_limits< idx >::min(), idx b=std::numeric_limits< idx >::max())

  *Generates a random index (idx) uniformly distributed in the interval [a, b].*
- template< typename Derived >
  Derived rand (idx rows, idx cols, double a=0, double b=1)

  *Generates a random matrix with entries uniformly distributed in the interval [a, b)*
- template<>
  dmat rand (idx rows, idx cols, double a, double b)

  *Generates a random real matrix with entries uniformly distributed in the interval [a, b), specialization for double matrices (qpp::dmat)*
- template<>
  cmat rand (idx rows, idx cols, double a, double b)

  *Generates a random complex matrix with entries (both real and imaginary) uniformly distributed in the interval [a, b), specialization for complex matrices (qpp::cmat)*
- template< typename Derived >
  Derived randn (idx rows, idx cols, double mean=0, double sigma=1)

  *Generates a random matrix with entries normally distributed in N(mean, sigma)*
- template<>
  dmat randn (idx rows, idx cols, double mean, double sigma)

  *Generates a random real matrix with entries normally distributed in N(mean, sigma), specialization for double matrices (qpp::dmat)*
- template<>
  cmat randn (idx rows, idx cols, double mean, double sigma)

  *Generates a random complex matrix with entries (both real and imaginary) normally distributed in N(mean, sigma), specialization for complex matrices (qpp::cmat)*
- double randn (double mean=0, double sigma=1)

  *Generates a random real number (double) normally distributed in N(mean, sigma)*
- cmat randU (idx D=2)

  *Generates a random unitary matrix.*
- cmat randV (idx Din, idx Dout)

  *Generates a random isometry matrix.*
- std::vector< cmat > randkraus (idx N, idx D=2)

  *Generates a set of random Kraus operators.*

- cmat randH (idx D=2)

    *Generates a random Hermitian matrix.*
- ket randket (idx D=2)

    *Generates a random normalized ket (pure state vector)*
- cmat randrho (idx D=2)

    *Generates a random density matrix.*
- std::vector< idx > randperm (idx N)

    *Generates a random uniformly distributed permutation.*
- std::vector< double > randprob (idx N)

    *Generates a random probability vector uniformly distributed over the probability simplex.*
- std::vector< double > uniform (idx N)

    *Uniform probability distribution vector.*
- std::vector< double > marginalX (const dmat &probXY)

    *Marginal distribution.*
- std::vector< double > marginalY (const dmat &probXY)

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

    *Average.*
- template<typename Container >
  double cov (const dmat &probXY, const Container &X, const Container &Y, typename std::enable_if< is_↩ iterable< Container >::value >::type *=nullptr)

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

    *Variance.*
- template<typename Container >
  double sigma (const std::vector< double > &prob, const Container &X, typename std::enable_if< is_↩ iterable< Container >::value >::type *=nullptr)

    *Standard deviation.*
- template<typename Container >
  double cor (const dmat &probXY, const Container &X, const Container &Y, typename std::enable_if< is_↩ iterable< Container >::value >::type *=nullptr)

    *Correlation.*

## Variables

- constexpr double chop = 1e-10

    *Used in qpp::disp() for setting to zero numbers that have their absolute value smaller than qpp::chop.*
- constexpr double eps = 1e-12

    *Used to decide whether a number or expression in double precision is zero or not.*
- constexpr idx maxn = 64

    *Maximum number of allowed qubits/qudits (subsystems)*
- constexpr double pi = 3.141592653589793238462643383279502884

    $\pi$
- constexpr double ee = 2.718281828459045235360287471352662497

    *Base of natural logarithm, $e$.*
- constexpr double infty = std::numeric_limits<double>::max()

    *Used to denote infinity in double precision.*

### 6.1.1 Detailed Description

Quantum++ main namespace.

### 6.1.2 Typedef Documentation

#### 6.1.2.1 bigint

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

Big integer.

#### 6.1.2.2 bra

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

Complex (double precision) dynamic Eigen row vector.

#### 6.1.2.3 cmat

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

Complex (double precision) dynamic Eigen matrix.

#### 6.1.2.4 cplx

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

Complex number in double precision.

#### 6.1.2.5 dmat

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

Real (double precision) dynamic Eigen matrix.

#### 6.1.2.6 dyn_col_vect

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

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

Example:

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

#### 6.1.2.7 dyn_mat

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

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

Example:

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

#### 6.1.2.8 dyn_row_vect

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

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

Example:

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

#### 6.1.2.9 idx

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

Non-negative integer index.

#### 6.1.2.10 ket

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

Complex (double precision) dynamic Eigen column vector.

#### 6.1.2.11 to_void

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

Alias template that implements the proposal for void_t.

**See also**

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

### 6.1.3 Function Documentation

#### 6.1.3.1 absm()

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

Matrix absolute value.

**Parameters**

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

**Returns**

Matrix absolute value of *A*

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

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

Computes the absolute values squared of an STL-like range of complex numbers.

**Parameters**

| | |
|---|---|
| *first* | Iterator to the first element of the range |
| *last* | Iterator to the last element of the range |

**Returns**

Real vector consisting of the range absolute values squared

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

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

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

**Parameters**

| | |
|---|---|
| *c* | STL-like container |

**Returns**

Real vector consisting of the container's absolute values squared

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

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

Computes the absolute values squared of an Eigen expression.

**Parameters**

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

**Returns**

Real vector consisting of the absolute values squared

#### 6.1.3.5 adjoint()

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

Adjoint.

**Parameters**

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

**Returns**

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

#### 6.1.3.6 anticomm()

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

Anti-commutator.

**See also**

qpp::comm()

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

**Parameters**

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

**Returns**

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

#### 6.1.3.7 apply() [1/5]

```
template<typename Derived1 , typename Derived2 >
dyn_mat<typename Derived1::Scalar> qpp::apply (
```

```
            const Eigen::MatrixBase< Derived1 > & state,
            const Eigen::MatrixBase< Derived2 > & A,
            const std::vector< idx > & subsys,
            const std::vector< idx > & dims )
```

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

**Note**

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

**Parameters**

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

**Returns**

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

#### 6.1.3.8 apply() [2/5]

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

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

**Note**

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

**Parameters**

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

**Returns**

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

#### 6.1.3.9 apply() [3/5]

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

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

**Parameters**

| | |
|---|---|
| *A* | Eigen expression |
| *Ks* | Set of Kraus operators |

**Returns**

Output density matrix after the action of the channel

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

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

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

**Parameters**

| | |
|---|---|
| *A* | Eigen expression |
| *Ks* | Set of Kraus operators |
| *subsys* | Subsystem indexes where the Kraus operators *Ks* are applied |
| *dims* | Dimensions of the multi-partite system |

**Returns**

Output density matrix after the action of the channel

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

```
template<typename Derived >
cmat qpp::apply (
```

```
            const Eigen::MatrixBase< Derived > & A,
            const std::vector< cmat > & Ks,
            const std::vector< idx > & subsys,
            idx d = 2 )
```

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

**Parameters**

| | |
|---|---|
| *A* | Eigen expression |
| *Ks* | Set of Kraus operators |
| *subsys* | Subsystem indexes where the Kraus operators *Ks* are applied |
| *d* | Subsystem dimensions |

**Returns**

Output density matrix after the action of the channel

#### 6.1.3.12 applyCTRL() [1/2]

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

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

**See also**

qpp::Gates::CTRL()

**Note**

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

**Parameters**

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

**Returns**

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

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

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

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

**See also**

qpp::Gates::CTRL()

**Note**

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

**Parameters**

| | |
|---|---|
| *state* | Eigen expression |
| *A* | Eigen expression |
| *ctrl* | Control subsystem indexes |
| *subsys* | Subsystem indexes where the gate *A* is applied |
| *d* | Subsystem dimensions |

**Returns**

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

### 6.1.3.14 applyINVQFT()

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

Applies the inverse (adjoint) qudit quantum Fourier transform to the part *subsys* of the multi-partite state vector or density matrix *A*.

**Parameters**

| | |
|---|---|
| *A* | Eigen expression |
| *subsys* | Subsystem indexes where the QFT applied |
| *d* | Subsystem dimensions |
| *swap* | Swaps the qubits/qudits at the end (true by default) |

**Returns**

Inverse (adjoint) qudit Quantum Fourier transform applied to the part *subsys* of *A*

#### 6.1.3.15 applyQFT()

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

Applies the qudit quantum Fourier transform to the part *subsys* of the multi-partite state vector or density matrix *A*.

**Parameters**

| | |
|---|---|
| *A* | Eigen expression |
| *subsys* | Subsystem indexes where the QFT applied |
| *d* | Subsystem dimensions |
| *swap* | Swaps the qubits/qudits at the end (true by default) |

**Returns**

Qudit Quantum Fourier transform applied to the part *subsys* of *A*

#### 6.1.3.16 avg()

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

Average.

**Parameters**

| | |
|---|---|
| *prob* | Real probability vector representing the probability distribution of *X* |
| *X* | Real random variable values represented by an STL-like container |

**Returns**

Average of *X*

#### 6.1.3.17 bloch2rho()

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

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

**See also**

qpp::rho2bloch()

**Parameters**

| | |
|---|---|
| *r* | 3-dimensional real vector |

**Returns**

Qubit density matrix

#### 6.1.3.18 choi2kraus()

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

Orthogonal Kraus operators from Choi matrix.

**See also**

qpp::kraus2choi()

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

**Note**

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

**Parameters**

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

**Returns**

Set of orthogonal Kraus operators

#### 6.1.3.19 choi2super()

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

Converts Choi matrix to superoperator matrix.

**See also**

qpp::super2choi()

**Parameters**

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

**Returns**

Superoperator matrix

#### 6.1.3.20 comm()

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

Commutator.

**See also**

qpp::anticomm()

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

**Parameters**

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

**Returns**

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

#### 6.1.3.21 complement()

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

Constructs the complement of a subsystem vector.

**Parameters**

| | |
|---|---|
| *subsys* | Subsystem vector |
| *N* | Total number of systems |

**Returns**

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

#### 6.1.3.22 compperm()

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

Compose permutations.

**Parameters**

| | |
|---|---|
| *perm* | Permutation |
| *sigma* | Permutation |

**Returns**

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

#### 6.1.3.23 concurrence()

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

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

**Parameters**

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

**Returns**

Wootters concurrence

#### 6.1.3.24 conjugate()

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

Complex conjugate.

**Parameters**

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

**Returns**

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

#### 6.1.3.25 contfrac2x()

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

Real representation of a simple continued fraction.

**See also**

qpp::x2contfrac()

**Note**

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

**Parameters**

| | |
|---|---|
| *cf* | Integer vector containing the simple continued fraction expansion |
| *N* | Number of terms considered in the continued fraction expansion. |

**Returns**

Real representation of the simple continued fraction

#### 6.1.3.26 cor()

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

Correlation.

**Parameters**

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

**Returns**

Correlation of *X* and *Y*

#### 6.1.3.27 cosm()

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

Matrix cos.

**Parameters**

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

**Returns**

Matrix cosine of *A*

#### 6.1.3.28 cov()

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

Covariance.

**Parameters**

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

**Returns**

Covariance of *X* and *Y*

#### 6.1.3.29 cwise()

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

Functor.

**Parameters**

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

**Returns**

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

#### 6.1.3.30 det()

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

Determinant.

**Parameters**

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

**Returns**

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

#### 6.1.3.31 dirsum() [1/4]

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

Direct sum.

**See also**

qpp::dirsumpow()

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

**Parameters**

| | |
|---|---|
| *head* | Eigen expression |

**Returns**

Its argument *head*

#### 6.1.3.32 dirsum() [2/4]

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

Direct sum.

**See also**

qpp::dirsumpow()

**Parameters**

| | |
|---|---|
| *head* | Eigen expression |
| *tail* | Variadic Eigen expression (zero or more parameters) |

**Returns**

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

#### 6.1.3.33 dirsum() [3/4]

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

Direct sum.

**See also**

qpp::dirsumpow()

**Parameters**

| | |
|---|---|
| *As* | std::vector of Eigen expressions |

**Returns**

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

#### 6.1.3.34 dirsum() [4/4]

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

Direct sum.

**See also**

qpp::dirsumpow()

**Parameters**

| | |
|---|---|
| *As* | std::initializer_list of Eigen expressions, such as *{A1*, A2, ... ,Ak} |

**Returns**

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

#### 6.1.3.35 dirsumpow()

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

Direct sum power.

**See also**

qpp::dirsum()

**Parameters**

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

**Returns**

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

#### 6.1.3.36 disp() [1/5]

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

Eigen expression ostream manipulator.

**Parameters**

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

**Returns**

Instance of qpp::internal::IOManipEigen

#### 6.1.3.37 disp() [2/5]

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

Complex number ostream manipulator.

**Parameters**

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

**Returns**

Instance of qpp::internal::IOManipEigen

#### 6.1.3.38 disp() [3/5]

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

Range ostream manipulator.

**Parameters**

| | |
|---|---|
| *first* | Iterator to the first element of the range |
| *last* | Iterator to the last element of the range |
| *separator* | Separator |
| *start* | Left marking |
| *end* | Right marking |

**Returns**

Instance of qpp::internal::IOManipRange

#### 6.1.3.39 disp() [4/5]

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

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

**Parameters**

| | |
|---|---|
| *c* | Container |
| *separator* | Separator |
| *start* | Left marking |
| *end* | Right marking |

**Returns**

Instance of qpp::internal::IOManipRange

#### 6.1.3.40 disp() [5/5]

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

C-style pointer ostream manipulator.

**Parameters**

| | |
|---|---|
| *p* | Pointer to the first element |
| *N* | Number of elements to be displayed |
| *separator* | Separator |
| *start* | Left marking |
| *end* | Right marking |

**Returns**

Instance of qpp::internal::IOManipPointer

#### 6.1.3.41 egcd()

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

Extended greatest common divisor of two integers.

**See also**

qpp::gcd()

**Parameters**

| | |
|---|---|
| *a* | Integer |
| *b* | Integer |

**Returns**

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

#### 6.1.3.42 eig()

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

Full eigen decomposition.

**See also**

qpp::heig()

**Parameters**

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

**Returns**

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

#### 6.1.3.43 entanglement() [1/2]

```
template<typename Derived >
double qpp::entanglement (
```

```
const Eigen::MatrixBase< Derived > & A,
const std::vector< idx > & dims )
```

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

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

**See also**

qpp::entropy()

**Parameters**

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

**Returns**

Entanglement, with the logarithm in base 2

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

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

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

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

**See also**

qpp::entropy()

**Parameters**

| | |
|---|---|
| *A* | Eigen expression |
| *d* | Subsystem dimensions |

**Returns**

Entanglement, with the logarithm in base 2

#### 6.1.3.45 entropy() [1/2]

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

von-Neumann entropy of the density matrix *A*

**Parameters**

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

**Returns**

von-Neumann entropy, with the logarithm in base 2

#### 6.1.3.46 entropy() [2/2]

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

Shannon entropy of the probability distribution *prob*.

**Parameters**

| | |
|---|---|
| *prob* | Real probability vector |

**Returns**

Shannon entropy, with the logarithm in base 2

#### 6.1.3.47 evals()

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

Eigenvalues.

**See also**

qpp::hevals()

**Parameters**

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

**Returns**

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

#### 6.1.3.48 evects()

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

Eigenvectors.

**See also**

qpp::hevects()

**Parameters**

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

**Returns**

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

#### 6.1.3.49 expm()

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

Matrix exponential.

**Parameters**

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

**Returns**

Matrix exponential of *A*

#### 6.1.3.50 factors()

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

Prime factor decomposition.

**Note**

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

**Parameters**

| | |
|---|---|
| *a* | Integer different from 0, 1 or -1 |

**Returns**

Integer vector containing the factors

#### 6.1.3.51 funm()

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

Functional calculus f(A)

**Parameters**

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

**Returns**

$f(A)$

#### 6.1.3.52 gcd() [1/2]

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

Greatest common divisor of two integers.

**See also**

qpp::lcm()

**Parameters**

| | |
|---|---|
| *a* | Integer |
| *b* | Integer |

**Returns**

Greatest common divisor of *a* and *b*

#### 6.1.3.53 gcd() [2/2]

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

Greatest common divisor of a list of integers.

**See also**

qpp::lcm()

**Parameters**

| | |
|---|---|
| *as* | List of integers |

**Returns**

Greatest common divisor of all numbers in *as*

#### 6.1.3.54 gconcurrence()

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

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

**Note**

Both local dimensions must be equal

Uses qpp::logdet() to avoid overflows

**See also**

qpp::logdet()

**Parameters**

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

**Returns**

G-concurrence

#### 6.1.3.55 grams() [1/3]

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

Gram-Schmidt orthogonalization.

**Parameters**

| | |
|---|---|
| *As* | std::vector of Eigen expressions as column vectors |

**Returns**

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

#### 6.1.3.56 grams() [2/3]

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

Gram-Schmidt orthogonalization.

**Parameters**

| | |
|---|---|
| *As* | std::initializer_list of Eigen expressions as column vectors |

**Returns**

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

#### 6.1.3.57 grams() [3/3]

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

Gram-Schmidt orthogonalization.

**Parameters**

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

**Returns**

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

#### 6.1.3.58 heig()

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

Full eigen decomposition of Hermitian expression.

**See also**

qpp::eig()

**Parameters**

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

**Returns**

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

#### 6.1.3.59 hevals()

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

Hermitian eigenvalues.

**See also**

qpp::evals()

**Parameters**

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

**Returns**

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

#### 6.1.3.60 hevects()

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

Hermitian eigenvectors.

**See also**

qpp::evects()

**Parameters**

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

**Returns**

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

#### 6.1.3.61 inverse()

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

Inverse.

**Parameters**

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

**Returns**

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

#### 6.1.3.62 invperm()

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

Inverse permutation.

**Parameters**

| | |
|---|---|
| *perm* | Permutation |

**Returns**

Inverse of the permutation *perm*

#### 6.1.3.63 INVQFT()

```
template<typename Derived >
dyn_col_vect<typename Derived::Scalar> qpp::INVQFT (
            const Eigen::MatrixBase< Derived > & A,
            idx d = 2,
            bool swap = true )
```

Inverse (adjoint) qudit quantum Fourier transform.

**Parameters**

| | |
|---|---|
| *A* | Eigen expression |
| *d* | Subsystem dimensions |
| *swap* | Swaps the qubits/qudits at the end (true by default) |

**Returns**

Inverse (adjoint) qudit quantum Fourier transform applied on *A*

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

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

Generalized inner product.

**Parameters**

| | |
|---|---|
| *phi* | Column vector Eigen expression |
| *psi* | Column vector Eigen expression |
| *subsys* | Subsystem indexes over which *phi* is defined |
| *dims* | Dimensions of the multi-partite system |

**Returns**

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

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

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

Generalized inner product.

**Parameters**

| | |
|---|---|
| *phi* | Column vector Eigen expression |
| *psi* | Column vector Eigen expression |
| *subsys* | Subsystem indexes over which *phi* is defined |
| *d* | Subsystem dimensions |

**Returns**

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

#### 6.1.3.66 isprime()

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

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

**Parameters**

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

**Returns**

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

#### 6.1.3.67 kraus2choi()

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

Choi matrix.

**See also**

qpp::choi2kraus()

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

**Note**

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

**Parameters**

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

**Returns**

Choi matrix

#### 6.1.3.68 kraus2super()

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

Superoperator matrix.

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

**Parameters**

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

**Returns**

Superoperator matrix

#### 6.1.3.69 kron() [1/4]

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

Kronecker product.

**See also**

qpp::kronpow()

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

**Parameters**

| | |
|---|---|
| *head* | Eigen expression |

**Returns**

Its argument *head*

#### 6.1.3.70 kron() [2/4]

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

Kronecker product.

**See also**

qpp::kronpow()

**Parameters**

| | |
|---|---|
| *head* | Eigen expression |
| *tail* | Variadic Eigen expression (zero or more parameters) |

**Returns**

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

#### 6.1.3.71 kron() [3/4]

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

Kronecker product.

**See also**

qpp::kronpow()

**Parameters**

| | |
|---|---|
| *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 as its arguments

#### 6.1.3.72 kron() [4/4]

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

Kronecker product.

**See also**

qpp::kronpow()

**Parameters**

| | |
|---|---|
| *As* | std::initializer_list of Eigen expressions, such as *{A1*, A2, ... ,Ak} |

**Returns**

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

#### 6.1.3.73 kronpow()

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

Kronecker power.

**See also**

qpp::kron()

**Parameters**

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

**Returns**

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

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

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

Least common multiple of two integers.

**See also**

qpp::gcd()

**Parameters**

| | |
|---|---|
| *a* | Integer |
| *b* | Integer |

**Returns**

Least common multiple of *a* and *b*

#### 6.1.3.75 lcm() [2/2]

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

Least common multiple of a list of integers.

**See also**

qpp::gcd()

**Parameters**

| | |
|---|---|
| *as* | List of integers |

**Returns**

Least common multiple of all numbers in *as*

#### 6.1.3.76 load()

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

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

**See also**

qpp::save()

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

Example:

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

**Parameters**

| | |
|---|---|
| *fname* | Output file name |

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

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

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

**See also**

qpp::saveMATLAB()

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

Example:

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

**Template Parameters**

| | |
|---|---|
| *Derived* | Complex Eigen type |

**Parameters**

| | |
|---|---|
| *mat_file* | MATALB .mat file |
| *var_name* | Variable name in the .mat file representing the matrix to be loaded |

**Returns**

Eigen dynamic matrix

#### 6.1.3.78 loadMATLAB() [2/2]

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

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

**See also**

qpp::saveMATLAB()

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

Example:

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

**Template Parameters**

| | |
|---|---|
| *Derived* | Non-complex Eigen type |

**Parameters**

| | |
|---|---|
| *mat_file* | MATALB .mat file |
| *var_name* | Variable name in the .mat file representing the matrix to be loaded |

**Returns**

Eigen dynamic matrix

#### 6.1.3.79 logdet()

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

Logarithm of the determinant.

Useful when the determinant overflows/underflows

**Parameters**

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

**Returns**

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

#### 6.1.3.80 logm()

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

Matrix logarithm.

**Parameters**

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

**Returns**

Matrix logarithm of *A*

#### 6.1.3.81 lognegativity() [1/2]

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

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

**Parameters**

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

**Returns**

Logarithmic negativity, with the logarithm in base 2

#### 6.1.3.82 lognegativity() [2/2]

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

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

**Parameters**

| | |
|---|---|
| *A* | Eigen expression |
| *d* | Subsystem dimensions |

**Returns**

Logarithmic negativity, with the logarithm in base 2

#### 6.1.3.83 marginalX()

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

Marginal distribution.

**Parameters**

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

**Returns**

Real vector consisting of the marginal distribution of *X*

#### 6.1.3.84 marginalY()

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

Marginal distribution.

**Parameters**

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

**Returns**

Real vector consisting of the marginal distribution of *Y*

#### 6.1.3.85 measure() [1/9]

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

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

**Parameters**

| | |
|---|---|
| *A* | Eigen expression |
| *Ks* | Set of Kraus operators |

**Returns**

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

#### 6.1.3.86 measure() [2/9]

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

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

**Parameters**

| | |
|---|---|
| *A* | Eigen expression |
| *Ks* | Set of Kraus operators |

**Returns**

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

#### 6.1.3.87 measure() [3/9]

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

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

**Parameters**

| | |
|---|---|
| *A* | Eigen expression |
| *U* | Unitary matrix whose columns represent the measurement basis vectors |

**Returns**

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

#### 6.1.3.88 measure() [4/9]

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

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

**See also**

qpp::measure_seq()

**Note**

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

**Parameters**

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

**Returns**

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

#### 6.1.3.89 measure() [5/9]

```
template<typename Derived >
std::tuple<idx, std::vector<double>, std::vector<cmat> > qpp::measure (
```

```
const Eigen::MatrixBase< Derived > & A,
const std::initializer_list< cmat > & Ks,
const std::vector< idx > & subsys,
const std::vector< idx > & dims )
```

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

**See also**

qpp::measure_seq()

**Note**

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

**Parameters**

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

**Returns**

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

### 6.1.3.90 measure() [6/9]

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

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

**See also**

qpp::measure_seq()

**Note**

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

**Parameters**

| | |
|---|---|
| *A* | Eigen expression |
| *Ks* | Set of Kraus operators |
| *subsys* | Subsystem indexes that are measured |
| *d* | Subsystem dimensions |

**Returns**

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

#### 6.1.3.91 measure() [7/9]

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

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

**See also**

qpp::measure_seq()

**Note**

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

**Parameters**

| | |
|---|---|
| *A* | Eigen expression |
| *Ks* | Set of Kraus operators |
| *subsys* | Subsystem indexes that are measured |
| *d* | Subsystem dimensions |

**Returns**

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

#### 6.1.3.92 measure() [8/9]

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

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

**See also**

qpp::measure_seq()

**Note**

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

**Parameters**

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

**Returns**

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

#### 6.1.3.93 measure() [9/9]

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

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

**See also**

qpp::measure_seq()

**Note**

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

**Parameters**

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

**Returns**

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

#### 6.1.3.94 measure_seq() [1/2]

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

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

**See also**

qpp::measure()

**Parameters**

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

**Returns**

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

#### 6.1.3.95 measure_seq() [2/2]

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

```
std::vector< idx > subsys,
idx d = 2 )
```

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

**See also**

qpp::measure()

**Parameters**

| | |
|---|---|
| *A* | Eigen expression |
| *subsys* | Subsystem indexes that are measured |
| *d* | Subsystem dimensions |

**Returns**

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

#### 6.1.3.96 mket() [1/2]

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

Multi-partite qudit ket.

**See also**

ket template<char... Bits> qpp::operator "" _ket()

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

**Parameters**

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

**Returns**

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

#### 6.1.3.97 mket() [2/2]

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

Multi-partite qudit ket.

**See also**

ket template<char... Bits> qpp::operator "" _ket()

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

**Parameters**

| | |
|---|---|
| *mask* | std::vector of non-negative integers |
| *d* | Subsystem dimensions |

**Returns**

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

#### 6.1.3.98 modinv()

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

Modular inverse of *a* mod *p*.

**See also**

qpp::egcd()

**Note**

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

**Parameters**

| | |
|---|---|
| *a* | Non-negative integer |
| *p* | Non-negative integer |

**Returns**

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

#### 6.1.3.99 modmul()

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

Modular multiplication without overflow.

Computes $ab \bmod p$ without overflow

**Parameters**

| | |
|---|---|
| *a* | Integer |
| *b* | Integer |
| *p* | Positive integer |

**Returns**

$ab \bmod p$ avoiding overflow

#### 6.1.3.100 modpow()

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

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

**Note**

Uses qpp::modmul() that avoids overflows

Computes $a^n \bmod p$

**Parameters**

| | |
|---|---|
| *a* | Non-negative integer |
| *n* | Non-negative integer |
| *p* | Strictly positive integer |

**Returns**

$a^n \bmod p$

#### 6.1.3.101 mprj() [1/2]

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

Projector onto multi-partite qudit ket.

**See also**

cmat template<char... Bits> qpp::operator "" _prj()

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

**Parameters**

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

**Returns**

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

#### 6.1.3.102 mprj() [2/2]

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

Projector onto multi-partite qudit ket.

**See also**

cmat template<char... Bits> qpp::operator "" _prj()

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

**Parameters**

| | |
|---|---|
| *mask* | std::vector of non-negative integers |
| *d* | Subsystem dimensions |

**Returns**

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

#### 6.1.3.103 multiidx2n()

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

Multi-index to non-negative integer index.

**See also**

qpp::n2multiidx()

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

**Parameters**

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

**Returns**

Non-negative integer index

#### 6.1.3.104 n2multiidx()

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

Non-negative integer index to multi-index.

**See also**

qpp::multiidx2n()

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

**Parameters**

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

**Returns**

Multi-index of the same size as *dims*

#### 6.1.3.105 negativity() [1/2]

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

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

**Parameters**

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

**Returns**

Negativity

#### 6.1.3.106 negativity() [2/2]

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

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

**Parameters**

| | |
|---|---|
| *A* | Eigen expression |
| *d* | Subsystem dimensions |

**Returns**

Negativity

#### 6.1.3.107 norm()

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

Frobenius norm.

**Parameters**

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

**Returns**

Frobenius norm of *A*

#### 6.1.3.108 omega()

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

D-th root of unity.

**Parameters**

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

**Returns**

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

#### 6.1.3.109 operator"""" _i()

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

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

Example:

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

#### 6.1.3.110 powm()

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

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

**See also**

qpp::spectralpowm()

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

**Parameters**

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

**Returns**

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

#### 6.1.3.111 prj()

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

Projector.

Normalized projector onto state vector

**Parameters**

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

**Returns**

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

#### 6.1.3.112 prod() [1/3]

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

Element-wise product of *A*.

**Parameters**

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

**Returns**

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

#### 6.1.3.113 prod() [2/3]

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

Element-wise product of an STL-like range.

**Parameters**

| | |
|---|---|
| *first* | Iterator to the first element of the range |
| *last* | Iterator to the last element of the range |

**Returns**

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

#### 6.1.3.114 prod() [3/3]

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

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

**Parameters**

| | |
|---|---|
| *c* | STL-like container |

**Returns**

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

#### 6.1.3.115 ptrace() [1/2]

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

Partial trace.

**See also**

qpp::ptrace1(), qpp::ptrace2()

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

**Parameters**

| | |
|---|---|
| *A* | Eigen expression |
| *subsys* | Subsystem 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 as *A*

#### 6.1.3.116 ptrace() [2/2]

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

Partial trace.

**See also**

qpp::ptrace1(), qpp::ptrace2()

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

**Parameters**

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

**Returns**

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

#### 6.1.3.117 ptrace1() [1/2]

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

Partial trace.

**See also**

qpp::ptrace2()

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

**Parameters**

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

**Returns**

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

#### 6.1.3.118 ptrace1() [2/2]

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

Partial trace.

**See also**

qpp::ptrace2()

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

**Parameters**

| | |
|---|---|
| *A* | Eigen expression |
| *d* | Subsystem dimensions |

**Returns**

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

#### 6.1.3.119 ptrace2() [1/2]

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

Partial trace.

**See also**

qpp::ptrace1()

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

**Parameters**

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

**Returns**

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

#### 6.1.3.120 ptrace2() [2/2]

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

Partial trace.

**See also**

qpp::ptrace1()

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

**Parameters**

| | |
|---|---|
| *A* | Eigen expression |
| *d* | Subsystem dimensions |

**Returns**

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

#### 6.1.3.121 ptranspose() [1/2]

```
template<typename Derived >
dyn_mat<typename Derived::Scalar> qpp::ptranspose (
```

```
            const Eigen::MatrixBase< Derived > & A,
            const std::vector< idx > & subsys,
            const std::vector< idx > & dims )
```

Partial transpose.

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

**Parameters**

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

**Returns**

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

#### 6.1.3.122 ptranspose() [2/2]

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

Partial transpose.

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

**Parameters**

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

**Returns**

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

#### 6.1.3.123 QFT()

```
template<typename Derived >
dyn_col_vect<typename Derived::Scalar> qpp::QFT (
```

```
            const Eigen::MatrixBase< Derived > & A,
            idx d = 2,
            bool swap = true )
```

Qudit quantum Fourier transform.

**Parameters**

| | |
|---|---|
| *A* | Eigen expression |
| *d* | Subsystem dimensions |
| *swap* | Swaps the qubits/qudits at the end (true by default) |

**Returns**

Qudit quantum Fourier transform applied on *A*

#### 6.1.3.124 qmutualinfo() [1/2]

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

Quantum mutual information between 2 subsystems of a composite system.

**Parameters**

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

**Returns**

Mutual information between the 2 subsystems

#### 6.1.3.125 qmutualinfo() [2/2]

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

Quantum mutual information between 2 subsystems of a composite system.

**Parameters**

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

**Returns**

Mutual information between the 2 subsystems

#### 6.1.3.126 rand() [1/5]

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

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

**Parameters**

| | |
|---|---|
| *a* | Beginning of the interval, belongs to it |
| *b* | End of the interval, does not belong to it |

**Returns**

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

#### 6.1.3.127 rand() [2/5]

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

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

**Note**

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

**Parameters**

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

**Returns**

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

#### 6.1.3.128 rand() [3/5]

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

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

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

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

#### 6.1.3.129 rand() [4/5]

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

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

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

Example:

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

**Parameters**

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

**Returns**

Random real matrix

#### 6.1.3.130 rand() [5/5]

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

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

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

Example:

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

**Parameters**

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

**Returns**

Random complex matrix

#### 6.1.3.131 randH()

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

Generates a random Hermitian matrix.

**Parameters**

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

**Returns**

Random Hermitian matrix

#### 6.1.3.132 randidx()

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

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

**Parameters**

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

**Returns**

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

#### 6.1.3.133 randket()

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

Generates a random normalized ket (pure state vector)

**Parameters**

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

**Returns**

Random normalized ket

#### 6.1.3.134 randkraus()

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

Generates a set of random Kraus operators.

**Note**

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

**Parameters**

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

**Returns**

Set of *N* Kraus operators satisfying the closure condition

#### 6.1.3.135 randn() [1/4]

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

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

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

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

#### 6.1.3.136 randn() [2/4]

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

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

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

Example:

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

**Parameters**

| | |
|---|---|
| *rows* | Number of rows of the random generated matrix |
| *cols* | Number of columns of the random generated matrix |
| *mean* | Mean |
| *sigma* | Standard deviation |

**Returns**

Random real matrix

#### 6.1.3.137 randn() [3/4]

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

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

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

Example:

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

**Parameters**

| | |
|---|---|
| *rows* | Number of rows of the random generated matrix |
| *cols* | Number of columns of the random generated matrix |
| *mean* | Mean |
| *sigma* | Standard deviation |

**Returns**

Random complex matrix

#### 6.1.3.138 randn() [4/4]

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

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

**Parameters**

| | |
|---|---|
| *mean* | Mean |
| *sigma* | Standard deviation |

**Returns**

Random real number normally distributed in N(mean, sigma)

#### 6.1.3.139 randperm()

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

Generates a random uniformly distributed permutation.

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

**Parameters**

| | |
|---|---|
| *N* | Size of the permutation |

**Returns**

Random permutation of size *N*

#### 6.1.3.140 randprime()

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

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

**Parameters**

| | |
|---|---|
| *a* | Beginning of the interval, belongs to it |
| *b* | End of the interval, belongs to it |
| *N* | Maximum number of candidates |

**Returns**

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

#### 6.1.3.141 randprob()

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

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

**Parameters**

| | |
|---|---|
| *N* | Size of the probability vector |

**Returns**

Random probability vector

#### 6.1.3.142 randrho()

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

Generates a random density matrix.

**Parameters**

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

**Returns**

Random density matrix

#### 6.1.3.143 randU()

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

Generates a random unitary matrix.

**Parameters**

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

**Returns**

Random unitary

#### 6.1.3.144 randV()

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

Generates a random isometry matrix.

**Parameters**

| | |
|---|---|
| *Din* | Size of the input Hilbert space |
| *Dout* | Size of the output Hilbert space |

**Returns**

Random isometry matrix

#### 6.1.3.145 renyi() [1/2]

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

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

**Note**

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

**Parameters**

| | |
|---|---|
| *A* | Eigen expression |
| *alpha* | Non-negative real number, use qpp::infty for $\alpha = \infty$ |

**Returns**

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

#### 6.1.3.146 renyi() [2/2]

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

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

**Note**

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

**Parameters**

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

**Returns**

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

#### 6.1.3.147 reshape()

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

Reshape.

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

**Parameters**

| | |
|---|---|
| *A* | 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 as *A*

#### 6.1.3.148 rho2bloch()

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

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

**See also**

qpp::bloch2rho()

**Note**

It is implicitly assumed that the density matrix is Hermitian

**Parameters**

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

**Returns**

3-dimensional Bloch vector

#### 6.1.3.149 rho2pure()

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

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

**Note**

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

**Parameters**

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

**Returns**

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

#### 6.1.3.150 save()

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

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

**See also**

qpp::load()

**Parameters**

| | |
|---|---|
| *A* | Eigen expression |
| *fname* | Output file name |

#### 6.1.3.151 saveMATLAB() [1/2]

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

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

**See also**

qpp::loadMATLAB()

**Template Parameters**

| | |
|---|---|
| *Complex* | Eigen type |

**Parameters**

| | |
|---|---|
| *A* | Eigen expression over the complex field |

**Parameters**

| | |
|---|---|
| *mat_file* | MATALB .mat file |
| *var_name* | Variable name in the .mat file representing the matrix to be saved |
| *mode* | Saving mode (append, overwrite etc.), see MATLAB *matOpen()* documentation for details |

#### 6.1.3.152 saveMATLAB() [2/2]

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

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

**See also**

qpp::loadMATLAB()

**Template Parameters**

| | |
|---|---|
| *Npn-complex* | Eigen type |

**Parameters**

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

#### 6.1.3.153 schatten()

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

Schatten matrix norm.

**Parameters**

| | |
|---|---|
| *A* | Eigen expression |
| *p* | Real number, greater or equal to 1, use qpp::infty for $p = \infty$ |

**Returns**

Schatten-*p* matrix norm of *A*

#### 6.1.3.154 schmidtA() [1/2]

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

Schmidt basis on Alice side.

**Parameters**

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

**Returns**

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

#### 6.1.3.155 schmidtA() [2/2]

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

Schmidt basis on Alice side.

**Parameters**

| | |
|---|---|
| *A* | Eigen expression |
| *d* | Subsystem dimensions |

**Returns**

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

#### 6.1.3.156 schmidtB() [1/2]

```
template<typename Derived >
cmat qpp::schmidtB (
```

```
            const Eigen::MatrixBase< Derived > & A,
            const std::vector< idx > & dims )
```

Schmidt basis on Bob side.

**Parameters**

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

**Returns**

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

#### 6.1.3.157 schmidtB() [2/2]

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

Schmidt basis on Bob side.

**Parameters**

| | |
|---|---|
| *A* | Eigen expression |
| *d* | Subsystem dimensions |

**Returns**

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

#### 6.1.3.158 schmidtcoeffs() [1/2]

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

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

**Note**

The sum of the squares of the Schmidt coefficients equals 1

**See also**

qpp::schmidtprobs()

**Parameters**

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

**Returns**

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

#### 6.1.3.159 schmidtcoeffs() [2/2]

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

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

**Note**

The sum of the squares of the Schmidt coefficients equals 1

**See also**

qpp::schmidtprobs()

**Parameters**

| | |
|---|---|
| *A* | Eigen expression |
| *d* | Subsystem dimensions |

**Returns**

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

#### 6.1.3.160 schmidtprobs() [1/2]

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

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

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

**See also**

qpp::schmidtcoeffs()

**Parameters**

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

**Returns**

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

#### 6.1.3.161 schmidtprobs() [2/2]

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

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

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

**See also**

qpp::schmidtcoeffs()

**Parameters**

| | |
|---|---|
| *A* | Eigen expression |
| *d* | Subsystem dimensions |

**Returns**

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

#### 6.1.3.162 sigma()

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

Standard deviation.

**Parameters**

| | |
|---|---|
| *prob* | Real probability vector representing the probability distribution of *X* |
| *X* | Real random variable values represented by an STL-like container |

**Returns**

Standard deviation of *X*

#### 6.1.3.163 sinm()

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

Matrix sin.

**Parameters**

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

**Returns**

Matrix sine of *A*

#### 6.1.3.164 spectralpowm()

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

Matrix power.

**See also**

qpp::powm()

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

**Parameters**

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

**Returns**

Matrix power $A^z$

#### 6.1.3.165 sqrtm()

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

Matrix square root.

**Parameters**

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

**Returns**

Matrix square root of *A*

#### 6.1.3.166 sum() [1/3]

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

Element-wise sum of *A*.

**Parameters**

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

**Returns**

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

#### 6.1.3.167 sum() [2/3]

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

Element-wise sum of an STL-like range.

**Parameters**

| | |
|---|---|
| *first* | Iterator to the first element of the range |
| *last* | Iterator to the last element of the range |

**Returns**

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

#### 6.1.3.168 sum() [3/3]

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

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

**Parameters**

| | |
|---|---|
| *c* | STL-like container |

**Returns**

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

#### 6.1.3.169 super2choi()

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

Converts superoperator matrix to Choi matrix.

**See also**

qpp::choi2super()

**Parameters**

| | |
|---|---|
| *A* | Superoperator matrix |

**Returns**

Choi matrix

#### 6.1.3.170 svals()

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

Singular values.

**Parameters**

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

**Returns**

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

#### 6.1.3.171 svd()

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

Full singular value decomposition.

**Parameters**

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

**Returns**

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

#### 6.1.3.172 svdU()

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

Left singular vectors.

**Parameters**

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

**Returns**

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

#### 6.1.3.173 svdV()

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

Right singular vectors.

**Parameters**

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

**Returns**

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

#### 6.1.3.174 syspermute() [1/2]

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

Subsystem permutation.

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

**Parameters**

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

**Returns**

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

#### 6.1.3.175 syspermute() [2/2]

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

Subsystem permutation.

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

**Parameters**

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

**Returns**

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

#### 6.1.3.176 trace()

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

Trace.

**Parameters**

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

**Returns**

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

#### 6.1.3.177 transpose()

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

Transpose.

**Parameters**

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

**Returns**

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

#### 6.1.3.178 tsallis() [1/2]

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

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

**Note**

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

**Parameters**

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

**Returns**

Tsallis- $q$ entropy

#### 6.1.3.179 tsallis() [2/2]

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

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

**Note**

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

**Parameters**

| | |
|---|---|
| *prob* | Real probability vector |
| *q* | Non-negative real number |

**Returns**

Tsallis- $q$ entropy

#### 6.1.3.180 uniform()

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

Uniform probability distribution vector.

**Parameters**

| | |
|---|---|
| *N* | Size of the alphabet |

**Returns**

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

#### 6.1.3.181 var()

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

Variance.

**Parameters**

| | |
|---|---|
| *prob* | Real probability vector representing the probability distribution of *X* |
| *X* | Real random variable values represented by an STL-like container |

**Returns**

Variance of *X*

#### 6.1.3.182 x2contfrac()

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

Simple continued fraction expansion.

**See also**

qpp::contfrac2x()

**Parameters**

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

**Returns**

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

### 6.1.4 Variable Documentation

#### 6.1.4.1 chop

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

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

#### 6.1.4.2 ee

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

Base of natural logarithm, $e$.

#### 6.1.4.3 eps

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

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

Example:

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

#### 6.1.4.4 infty

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

Used to denote infinity in double precision.

#### 6.1.4.5 maxn

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

Maximum number of allowed qubits/qudits (subsystems)

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

#### 6.1.4.6 pi

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

$\pi$

## 6.2 qpp::exception Namespace Reference

Quantum++ exception hierarchy namespace.

## Classes

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

*Invalid permutation exception.*
- class PermMismatchDims

  *Permutation mismatch dimensions exception.*
- class SizeMismatch

  *Size mismatch exception.*
- class SubsysMismatchDims

  *Subsystems mismatch dimensions exception.*
- class TypeMismatch

  *Type mismatch exception.*
- class UndefinedType

  *Not defined for this type exception.*
- class Unknown

  *Unknown exception.*
- class ZeroSize

  *Object has zero size exception.*

### 6.2.1 Detailed Description

Quantum++ exception hierarchy namespace.

## 6.3 qpp::experimental Namespace Reference

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

### 6.3.1 Detailed Description

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

## 6.4 qpp::internal Namespace Reference

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

### Classes

- struct Display_Impl_
- class IOManipEigen
- class IOManipPointer
- class IOManipRange
- class Singleton

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

### Functions

- void n2multiidx (idx n, idx numdims, const idx ∗const dims, idx ∗result) noexcept
- idx multiidx2n (const idx ∗const midx, idx numdims, const idx ∗const dims) noexcept
- template< typename Derived >
  bool check_square_mat (const Eigen::MatrixBase< Derived > &A)
- template< typename Derived >
  bool check_vector (const Eigen::MatrixBase< Derived > &A)
- template< typename Derived >
  bool check_rvector (const Eigen::MatrixBase< Derived > &A)
- template< typename Derived >
  bool check_cvector (const Eigen::MatrixBase< Derived > &A)
- template< typename T >
  bool check_nonzero_size (const T &x) noexcept
- template< typename T1 , typename T2 >
  bool check_matching_sizes (const T1 &lhs, const T2 &rhs) noexcept
- bool check_dims (const std::vector< idx > &dims)
- template< typename Derived >
  bool check_dims_match_mat (const std::vector< idx > &dims, const Eigen::MatrixBase< Derived > &A)
- template< typename Derived >
  bool check_dims_match_cvect (const std::vector< idx > &dims, const Eigen::MatrixBase< Derived > &A)
- template< typename Derived >
  bool check_dims_match_rvect (const std::vector< idx > &dims, const Eigen::MatrixBase< Derived > &A)
- bool check_eq_dims (const std::vector< idx > &dims, idx dim) noexcept
- bool check_subsys_match_dims (const std::vector< idx > &subsys, const std::vector< idx > &dims)
- template< typename Derived >
  bool check_qubit_matrix (const Eigen::MatrixBase< Derived > &A) noexcept
- template< typename Derived >
  bool check_qubit_cvector (const Eigen::MatrixBase< Derived > &A) noexcept
- template< typename Derived >
  bool check_qubit_rvector (const Eigen::MatrixBase< Derived > &A) noexcept
- template< typename Derived >
  bool check_qubit_vector (const Eigen::MatrixBase< Derived > &A) noexcept
- bool check_perm (const std::vector< idx > &perm)
- template< typename Derived1 , typename Derived2 >
  dyn_mat< typename Derived1::Scalar > kron2 (const Eigen::MatrixBase< Derived1 > &A, const Eigen::↩
  MatrixBase< Derived2 > &B)
- template< typename Derived1 , typename Derived2 >
  dyn_mat< typename Derived1::Scalar > dirsum2 (const Eigen::MatrixBase< Derived1 > &A, const Eigen↩
  ::MatrixBase< Derived2 > &B)
- template< typename T >
  void variadic_vector_emplace (std::vector< T > &)
- template< typename T , typename First , typename... Args>
  void variadic_vector_emplace (std::vector< T > &v, First &&first, Args &&... args)
- idx get_num_subsys (idx sz, idx d)
- idx get_dim_subsys (idx sz, idx N)

### 6.4.1 Detailed Description

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

### 6.4.2 Function Documentation

#### 6.4.2.1 check_cvector()

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

#### 6.4.2.2 check_dims()

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

#### 6.4.2.3 check_dims_match_cvect()

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

#### 6.4.2.4 check_dims_match_mat()

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

#### 6.4.2.5 check_dims_match_rvect()

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

#### 6.4.2.6 check_eq_dims()

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

#### 6.4.2.7 check_matching_sizes()

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

#### 6.4.2.8 check_nonzero_size()

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

#### 6.4.2.9 check_perm()

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

#### 6.4.2.10 check_qubit_cvector()

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

#### 6.4.2.11 check_qubit_matrix()

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

#### 6.4.2.12 check_qubit_rvector()

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

#### 6.4.2.13 check_qubit_vector()

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

#### 6.4.2.14 check_rvector()

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

#### 6.4.2.15 check_square_mat()

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

#### 6.4.2.16 check_subsys_match_dims()

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

#### 6.4.2.17 check_vector()

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

#### 6.4.2.18 dirsum2()

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

#### 6.4.2.19 get_dim_subsys()

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

#### 6.4.2.20 get_num_subsys()

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

#### 6.4.2.21 kron2()

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

#### 6.4.2.22 multiidx2n()

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

#### 6.4.2.23 n2multiidx()

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

#### 6.4.2.24 variadic_vector_emplace() [1/2]

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

#### 6.4.2.25 variadic_vector_emplace() [2/2]

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

## 6.5 qpp::literals Namespace Reference

### Functions

- constexpr cplx operator"" _i (unsigned long long int x) noexcept
  *User-defined literal for complex $i = \sqrt{-1}$ (integer overload)*
- template<char... Bits>
  ket operator"" _ket ()
  *Multi-partite qubit ket user-defined literal.*
- template<char... Bits>
  bra operator"" _bra ()
  *Multi-partite qubit bra user-defined literal.*
- template<char... Bits>
  cmat operator"" _prj ()
  *Multi-partite qubit projector user-defined literal.*

### 6.5.1 Function Documentation

#### 6.5.1.1 operator"""" _bra()

```
template<char... Bits>
bra qpp::literals::operator"" _bra ( )
```

Multi-partite qubit bra user-defined literal.

**See also**

qpp::mket() and qpp::adjoint()

Constructs the multi-partite qubit bra $\langle \mathrm{Bits}|$

**Template Parameters**

| | |
|---|---|
| *Bits* | String of binary numbers representing the qubit bra |

**Returns**

Multi-partite qubit bra, as a complex dynamic row vector

#### 6.5.1.2 operator"""" _i()

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

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

Example:

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

#### 6.5.1.3 operator"""" _ket()

```
template<char... Bits>
ket qpp::literals::operator"" _ket ( )
```

Multi-partite qubit ket user-defined literal.

**See also**

qpp::mket()

Constructs the multi-partite qubit ket $|\mathrm{Bits}\rangle$

**Template Parameters**

| | |
|---|---|
| *Bits* | String of binary numbers representing the qubit ket |

**Returns**

Multi-partite qubit ket, as a complex dynamic column vector

#### 6.5.1.4 operator"""" _prj()

```
template<char... Bits>
cmat qpp::literals::operator"" _prj ( )
```

Multi-partite qubit projector user-defined literal.

**See also**

qpp::mprj()

Constructs the multi-partite qubit projector $|\mathrm{Bits}\rangle\langle\mathrm{Bits}|$ (in the computational basis)

**Template Parameters**

| | |
|---|---|
| *Bits* | String of binary numbers representing the qubit state to project on |

**Returns**

Multi-partite qubit projector, as a complex dynamic matrix

# Chapter 7

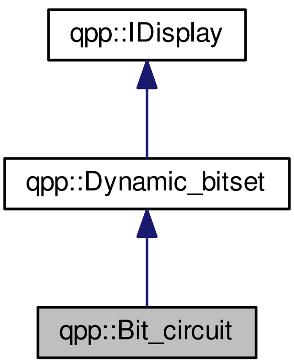
# Class Documentation

## 7.1 qpp::Bit_circuit Class Reference

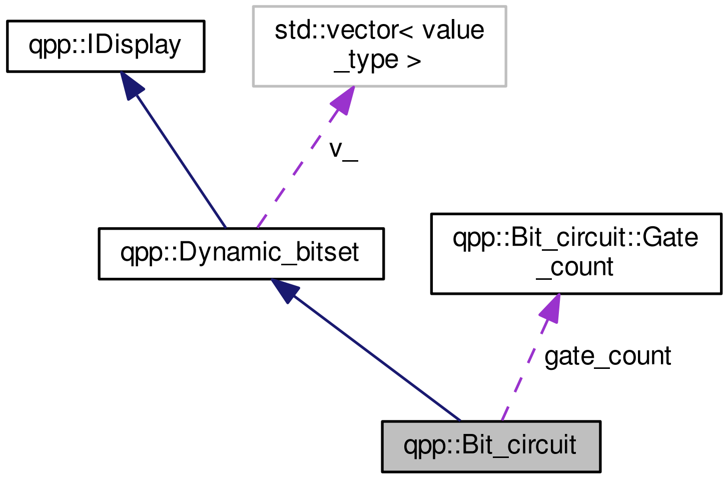
Classical reversible circuit simulator.

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

Inheritance diagram for qpp::Bit_circuit:



Collaboration diagram for qpp::Bit_circuit:




## Classes

- struct Gate_count

## Public Member Functions

- Bit_circuit (const Dynamic_bitset &dynamic_bitset)

  *Conversion constructor, used to initialize a qpp::Bit_circuit with a qpp::Dynamic_bitset.*
- Bit_circuit & X (idx pos)

  *Bit flip.*
- Bit_circuit & NOT (idx pos)

  *Bit flip.*
- Bit_circuit & CNOT (const std::vector< idx > &pos)

  *Controlled-NOT.*
- Bit_circuit & TOF (const std::vector< idx > &pos)

  *Toffoli gate.*
- Bit_circuit & SWAP (const std::vector< idx > &pos)

  *Swap bits.*
- Bit_circuit & FRED (const std::vector< idx > &pos)

  *Fredkin gate (Controlled-SWAP)*
- Bit_circuit & reset () noexcept

  *Reset the circuit all zero, clear all gates.*

## Public Attributes

- struct qpp::Bit_circuit::Gate_count gate_count

  *Gate counters.*

## Additional Inherited Members

### 7.1.1 Detailed Description

Classical reversible circuit simulator.

### 7.1.2 Constructor & Destructor Documentation

#### 7.1.2.1 Bit_circuit()

```
qpp::Bit_circuit::Bit_circuit (
            const Dynamic_bitset & dynamic_bitset )  [inline]
```

Conversion constructor, used to initialize a qpp::Bit_circuit with a qpp::Dynamic_bitset.

**Parameters**

| | |
|---|---|
| *dynamic_bitset* | Dynamic bitset |

### 7.1.3 Member Function Documentation

#### 7.1.3.1 CNOT()

```
Bit_circuit& qpp::Bit_circuit::CNOT (
            const std::vector< idx > & pos )  [inline]
```

Controlled-NOT.

**Parameters**

| | |
|---|---|
| *pos* | Bit position in the circuit |

**Returns**

Reference to the current instance

#### 7.1.3.2 FRED()

```
Bit_circuit& qpp::Bit_circuit::FRED (
            const std::vector< idx > & pos )  [inline]
```

Fredkin gate (Controlled-SWAP)

**Parameters**

| | |
|---|---|
| *pos* | Bit positions in the circuit, in the order control-target-target |

**Returns**

Reference to the current instance

#### 7.1.3.3 NOT()

```
Bit_circuit& qpp::Bit_circuit::NOT (
             idx pos )  [inline]
```

Bit flip.

**See also**

qpp::Bit_circuit::X()

**Parameters**

| | |
|---|---|
| *pos* | Bit position in the circuit |

**Returns**

Reference to the current instance

#### 7.1.3.4 reset()

```
Bit_circuit& qpp::Bit_circuit::reset ( )  [inline], [noexcept]
```

Reset the circuit all zero, clear all gates.

**Returns**

Reference to the current instance

#### 7.1.3.5 SWAP()

```
Bit_circuit& qpp::Bit_circuit::SWAP (
             const std::vector< idx > & pos )  [inline]
```

Swap bits.

**Parameters**

| | |
|---|---|
| *pos* | Bit positions in the circuit |

**Returns**

Reference to the current instance

### 7.1.3.6 TOF()

```
Bit_circuit& qpp::Bit_circuit::TOF (
            const std::vector< idx > & pos ) [inline]
```

Toffoli gate.

**Parameters**

| | |
|---|---|
| *pos* | Bit positions in the circuit, in the order control-control-target |

**Returns**

Reference to the current instance

### 7.1.3.7 X()

```
Bit_circuit& qpp::Bit_circuit::X (
            idx pos ) [inline]
```

Bit flip.

**See also**

qpp::Bit_circuit::NOT()

**Parameters**

| | |
|---|---|
| *pos* | Bit position in the circuit |

**Returns**

Reference to the current instance

### 7.1.4 Member Data Documentation

#### 7.1.4.1 gate_count

`struct qpp::Bit_circuit::Gate_count qpp::Bit_circuit::gate_count`

Gate counters.

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

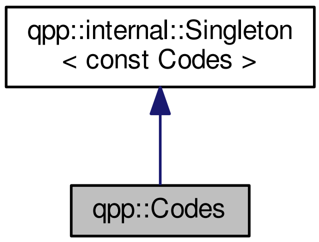
- classes/reversible.h

## 7.2 qpp::Codes Class Reference

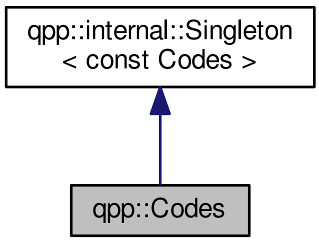
const Singleton class that defines quantum error correcting codes

`#include <classes/codes.h>`

Inheritance diagram for qpp::Codes:




Collaboration diagram for qpp::Codes:



## Public Types

- enum Type { Type::FIVE_QUBIT = 1, Type::SEVEN_QUBIT_STEANE, Type::NINE_QUBIT_SHOR }

  *Code types, add more codes here if needed.*

## Public Member Functions

- ket codeword (Type type, idx i) const

  *Returns the codeword of the specified code type.*

## Private Member Functions

- Codes ()

  *Default constructor.*
- ∼Codes ()=default

  *Default destructor.*

## Friends

- class internal::Singleton< const Codes >

## Additional Inherited Members

### 7.2.1 Detailed Description

const Singleton class that defines quantum error correcting codes

### 7.2.2 Member Enumeration Documentation

#### 7.2.2.1 Type

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

Code types, add more codes here if needed.

**See also**

qpp::Codes::codeword()

**Enumerator**

| | |
|---|---|
| FIVE_QUBIT | [[5,1,3]] qubit code |
| SEVEN_QUBIT_STEANE | [[7,1,3]] Steane qubit code |
| NINE_QUBIT_SHOR | [[9,1,3]] Shor qubit code |

## 7.2.3 Constructor & Destructor Documentation

#### 7.2.3.1 Codes()

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

Default constructor.

#### 7.2.3.2 ∼Codes()

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

Default destructor.

## 7.2.4 Member Function Documentation

#### 7.2.4.1 codeword()

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

Returns the codeword of the specified code type.

**See also**

qpp::Codes::Type

**Parameters**

| | |
|---|---|
| *type* | Code type |
| *i* | Codeword index |

**Returns**

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

## 7.2.5 Friends And Related Function Documentation

#### 7.2.5.1 internal::Singleton< const Codes >

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

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

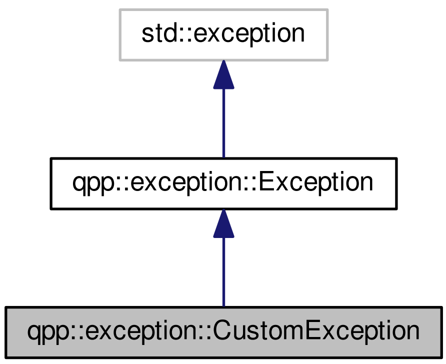
- classes/codes.h

## 7.3 qpp::exception::CustomException Class Reference

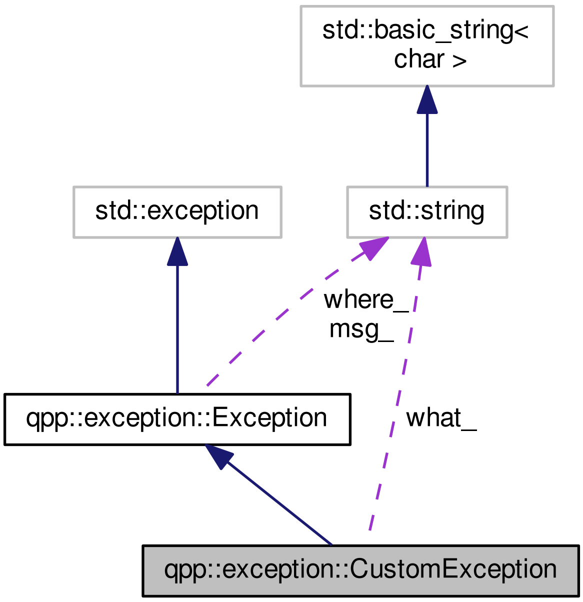
Custom exception.

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

Inheritance diagram for qpp::exception::CustomException:



Collaboration diagram for qpp::exception::CustomException:




## Public Member Functions

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

## Private Member Functions

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

## Private Attributes

- std::string what_ {}

### 7.3.1 Detailed Description

Custom exception.

Custom exception, the user must provide a custom message

### 7.3.2 Constructor & Destructor Documentation

#### 7.3.2.1 CustomException()

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

### 7.3.3 Member Function Documentation

#### 7.3.3.1 type_description()

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

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

### 7.3.4 Member Data Documentation

#### 7.3.4.1 what_

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

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

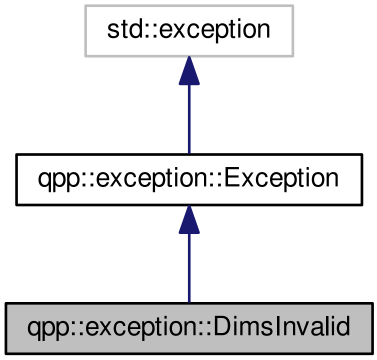
- classes/exception.h

## 7.4 qpp::exception::DimsInvalid Class Reference

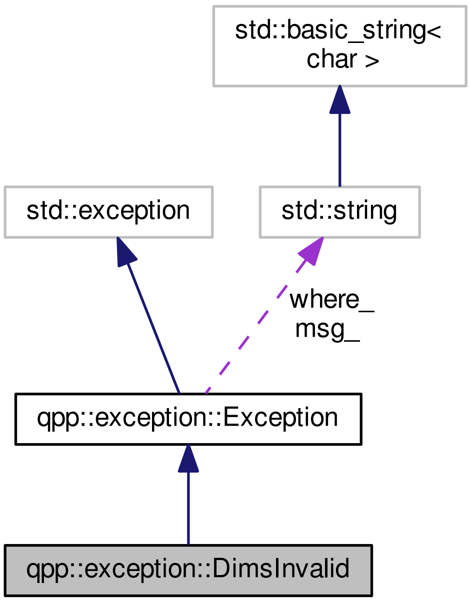
Invalid dimension(s) exception.

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

Inheritance diagram for qpp::exception::DimsInvalid:




Collaboration diagram for qpp::exception::DimsInvalid:



### Public Member Functions

- std::string type_description () const override

    *Exception type description.*

### 7.4.1 Detailed Description

Invalid dimension(s) exception.

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

### 7.4.2 Member Function Documentation

#### 7.4.2.1 type_description()

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

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

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

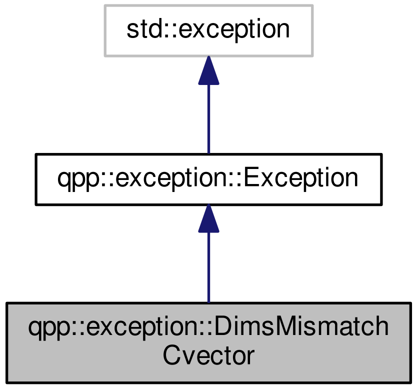
- classes/exception.h

## 7.5 qpp::exception::DimsMismatchCvector Class Reference

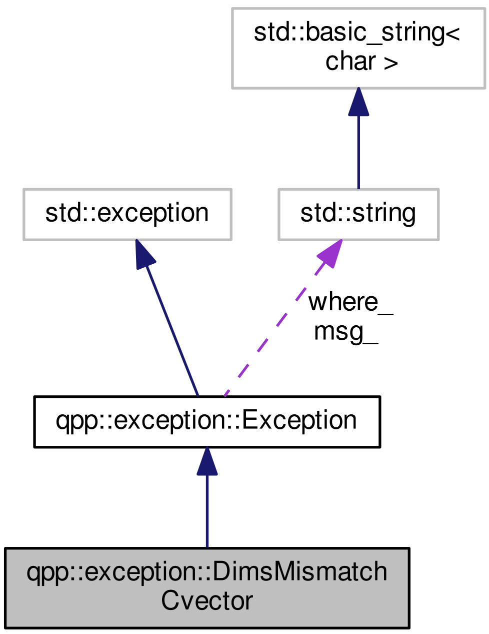
Dimension(s) mismatch column vector size exception.

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

Inheritance diagram for qpp::exception::DimsMismatchCvector:




Collaboration diagram for qpp::exception::DimsMismatchCvector:




## Public Member Functions

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

### 7.5.1 Detailed Description

Dimension(s) mismatch column vector size exception.

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

### 7.5.2 Member Function Documentation

#### 7.5.2.1 type_description()

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

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

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

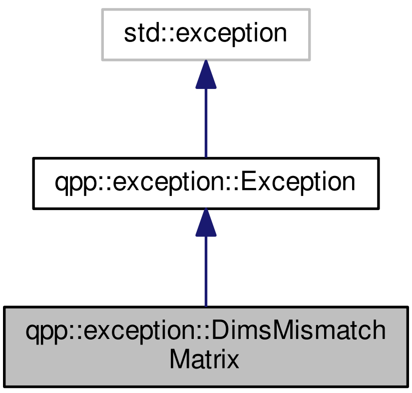
- classes/exception.h

## 7.6 qpp::exception::DimsMismatchMatrix Class Reference

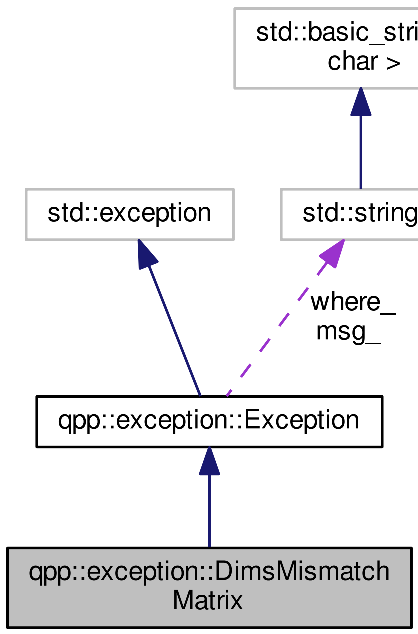
Dimension(s) mismatch matrix size exception.

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

Inheritance diagram for qpp::exception::DimsMismatchMatrix:



Collaboration diagram for qpp::exception::DimsMismatchMatrix:




## Public Member Functions

- std::string type_description () const override

  *Exception type description.*

### 7.6.1 Detailed Description

Dimension(s) mismatch matrix size exception.

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

### 7.6.2 Member Function Documentation

#### 7.6.2.1 type_description()

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

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

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

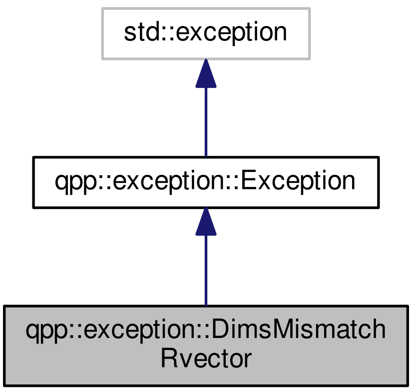
- classes/exception.h

## 7.7 qpp::exception::DimsMismatchRvector Class Reference

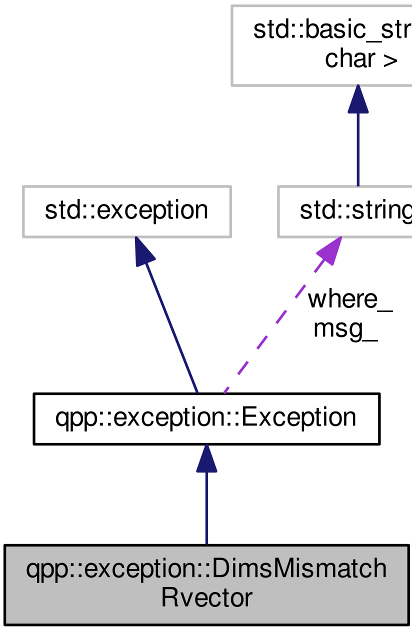
Dimension(s) mismatch row vector size exception.

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

Inheritance diagram for qpp::exception::DimsMismatchRvector:



Collaboration diagram for qpp::exception::DimsMismatchRvector:




## Public Member Functions

- std::string type_description () const override

  *Exception type description.*

### 7.7.1 Detailed Description

Dimension(s) mismatch row vector size exception.

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

### 7.7.2 Member Function Documentation

#### 7.7.2.1 type_description()

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

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

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

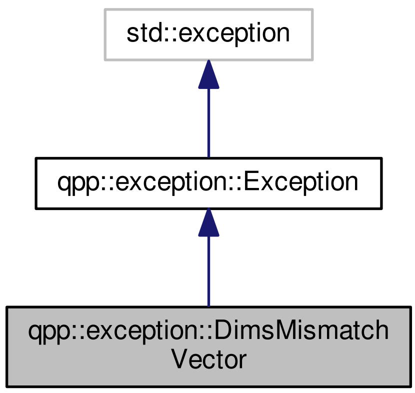
- classes/exception.h

## 7.8 qpp::exception::DimsMismatchVector Class Reference

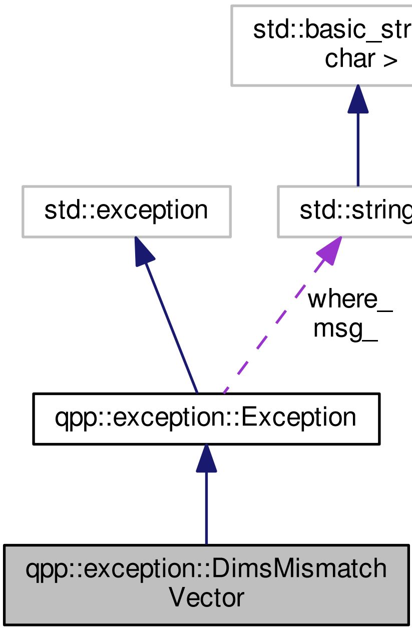
Dimension(s) mismatch vector size exception.

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

Inheritance diagram for qpp::exception::DimsMismatchVector:



Collaboration diagram for qpp::exception::DimsMismatchVector:




## Public Member Functions

- std::string type_description () const override

    *Exception type description.*

### 7.8.1 Detailed Description

Dimension(s) mismatch vector size exception.

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

### 7.8.2 Member Function Documentation

#### 7.8.2.1 type_description()

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

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

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

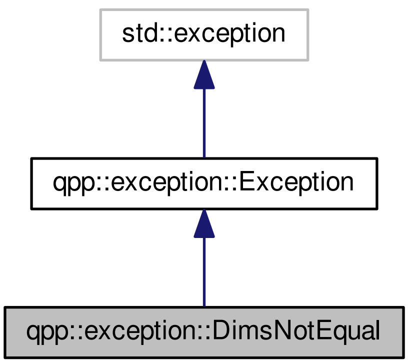
- classes/exception.h

## 7.9 qpp::exception::DimsNotEqual Class Reference

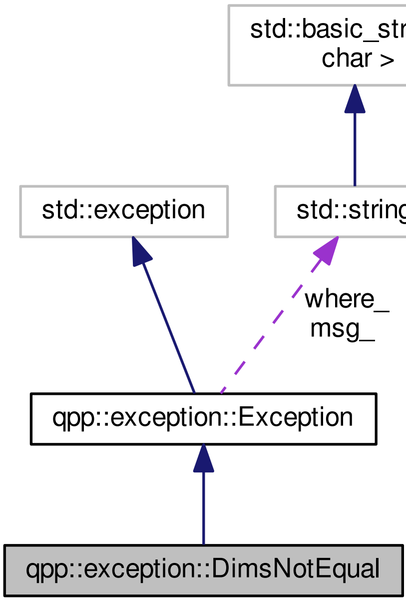
Dimensions not equal exception.

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

Inheritance diagram for qpp::exception::DimsNotEqual:



Collaboration diagram for qpp::exception::DimsNotEqual:




### Public Member Functions

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

## 7.9.1 Detailed Description

Dimensions not equal exception.

Local/global dimensions are not equal

## 7.9.2 Member Function Documentation

### 7.9.2.1 type_description()

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

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

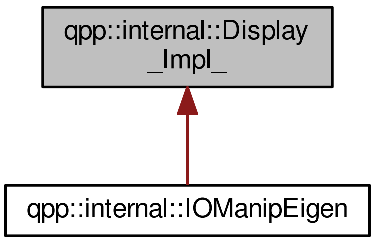
The documentation for this class was generated from the following file:

- classes/exception.h

## 7.10 qpp::internal::Display_Impl_ Struct Reference

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

Inheritance diagram for qpp::internal::Display_Impl_:




### Public Member Functions

- template<typename T >
  std::ostream & display_impl_ (const T &A, std::ostream &os, double chop=qpp::chop) const

### 7.10.1 Member Function Documentation

#### 7.10.1.1 display_impl_()

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

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

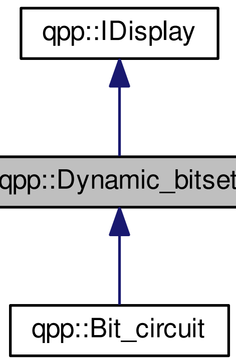
- internal/util.h

## 7.11 qpp::Dynamic_bitset Class Reference

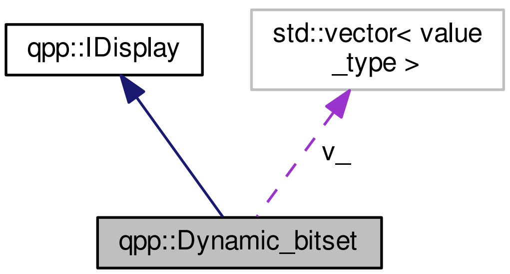
Dynamic bitset class, allows the specification of the number of bits at runtime (unlike std::bitset<N>)

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

Inheritance diagram for qpp::Dynamic_bitset:




Collaboration diagram for qpp::Dynamic_bitset:




### Public Types

- using value_type = unsigned int

    *Type of the storage elements.*
- using storage_type = std::vector< value_type >

    *Type of the storage.*

### Public Member Functions

- Dynamic_bitset (idx N)
  *Constructor, initializes all bits to false (zero)*
- const storage_type & data () const
  *Raw storage space of the bitset.*
- idx size () const noexcept
  *Number of bits stored in the bitset.*
- idx storage_size () const noexcept
  *Size of the underlying storage space (in units of value_type, unsigned int by default)*
- idx count () const noexcept
  *Number of bits set to one in the bitset (Hamming weight)*
- bool get (idx pos) const noexcept
  *The value of the bit at position pos.*
- bool none () const noexcept
  *Checks whether none of the bits are set.*
- bool all () const noexcept
  *Checks whether all bits are set.*
- bool any () const noexcept
  *Checks whether any bit is set.*
- Dynamic_bitset & set (idx pos, bool value=true)
  *Sets the bit at position pos.*
- Dynamic_bitset & set () noexcept
  *Set all bits to true.*
- Dynamic_bitset & rand (idx pos, double p=0.5)
  *Sets the bit at position pos according to a Bernoulli(p) distribution.*
- Dynamic_bitset & rand (double p=0.5)
  *Sets all bits according to a Bernoulli(p) distribution.*
- Dynamic_bitset & reset (idx pos)
  *Sets the bit at position pos to false.*
- Dynamic_bitset & reset () noexcept
  *Sets all bits to false.*
- Dynamic_bitset & flip (idx pos)
  *Flips the bit at position pos.*
- Dynamic_bitset & flip () noexcept
  *Flips all bits.*
- bool operator== (const Dynamic_bitset &rhs) const noexcept
  *Equality operator.*
- bool operator!= (const Dynamic_bitset &rhs) const noexcept
  *Inequality operator.*
- idx operator- (const Dynamic_bitset &rhs) const noexcept
  *Number of places the two bitsets differ (Hamming distance)*
- template<class CharT = char, class Traits = std::char_traits<CharT>, class Allocator = std::allocator<CharT>>
  std::basic_string< CharT, Traits, Allocator > to_string (CharT zero=CharT('0'), CharT one=CharT('1')) const
  *String representation.*

### Protected Member Functions

- idx index_ (idx pos) const
  *Index of the pos bit in the storage space.*
- idx offset_ (idx pos) const
  *Offset of the pos bit in the storage space relative to its index.*

## Protected Attributes

- idx storage_size_

  *Storage size.*
- idx N_

  *Number of bits.*
- std::vector< value_type > v_

  *Storage space.*

## Private Member Functions

- std::ostream & display (std::ostream &os) const override

  *qpp::IDisplay::display() override, displays the bitset bit by bit*

### 7.11.1 Detailed Description

Dynamic bitset class, allows the specification of the number of bits at runtime (unlike std::bitset<N>)

### 7.11.2 Member Typedef Documentation

#### 7.11.2.1 storage_type

```
using qpp::Dynamic_bitset::storage_type = std::vector<value_type>
```

Type of the storage.

#### 7.11.2.2 value_type

```
using qpp::Dynamic_bitset::value_type = unsigned int
```

Type of the storage elements.

### 7.11.3 Constructor & Destructor Documentation

#### 7.11.3.1 Dynamic_bitset()

```
qpp::Dynamic_bitset::Dynamic_bitset (
            idx N ) [inline]
```

Constructor, initializes all bits to false (zero)

**Parameters**

| | |
|---|---|
| *N* | Number of bits in the bitset |

## 7.11.4 Member Function Documentation

### 7.11.4.1 all()

```
bool qpp::Dynamic_bitset::all ( ) const [inline], [noexcept]
```

Checks whether all bits are set.

**Returns**

True if all of the bits are set

### 7.11.4.2 any()

```
bool qpp::Dynamic_bitset::any ( ) const [inline], [noexcept]
```

Checks whether any bit is set.

**Returns**

True if any of the bits is set

### 7.11.4.3 count()

```
idx qpp::Dynamic_bitset::count ( ) const [inline], [noexcept]
```

Number of bits set to one in the bitset (Hamming weight)

**Returns**

Hamming weight

#### 7.11.4.4 data()

```
const storage_type& qpp::Dynamic_bitset::data ( ) const [inline]
```

Raw storage space of the bitset.

**Returns**

Const reference to the underlying storage space

#### 7.11.4.5 display()

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

qpp::IDisplay::display() override, displays the bitset bit by bit

**Parameters**

| | |
|---|---|
| *os* | Output stream |

**Returns**

Reference to the output stream

Implements qpp::IDisplay.

#### 7.11.4.6 flip() [1/2]

```
Dynamic_bitset& qpp::Dynamic_bitset::flip (
            idx pos )  [inline]
```

Flips the bit at position *pos*.

**Parameters**

| | |
|---|---|
| *pos* | Position in the bitset |

**Returns**

Reference to the current instance

#### 7.11.4.7 flip() [2/2]

```
Dynamic_bitset& qpp::Dynamic_bitset::flip ( )  [inline], [noexcept]
```

Flips all bits.

**Returns**

Reference to the current instance

#### 7.11.4.8 get()

```
bool qpp::Dynamic_bitset::get (
            idx pos ) const  [inline], [noexcept]
```

The value of the bit at position *pos*.

**Parameters**

| | |
|---|---|
| *pos* | Position in the bitset |

**Returns**

The value of the bit at position *pos*

#### 7.11.4.9 index_()

```
idx qpp::Dynamic_bitset::index_ (
            idx pos ) const  [inline], [protected]
```

Index of the *pos* bit in the storage space.

**Parameters**

| | |
|---|---|
| *pos* | Bit location |

**Returns**

Index of the *pos* bit in the storage space

#### 7.11.4.10 none()

```
bool qpp::Dynamic_bitset::none ( ) const  [inline], [noexcept]
```

Checks whether none of the bits are set.

**Returns**

True if none of the bits are set

#### 7.11.4.11 offset_()

```
idx qpp::Dynamic_bitset::offset_ (
            idx pos ) const  [inline], [protected]
```

Offset of the *pos* bit in the storage space relative to its index.

**Parameters**

| | |
|---|---|
| *pos* | Bit location |

**Returns**

Offset of the *pos* bit in the storage space relative to its index

#### 7.11.4.12 operator"!=()

```
bool qpp::Dynamic_bitset::operator!= (
            const Dynamic_bitset & rhs ) const  [inline], [noexcept]
```

Inequality operator.

**Parameters**

| | |
|---|---|
| *rhs* | Dynamic_bitset against which the inequality is being tested |

**Returns**

True if the bitsets are not equal (bit by bit), false otherwise

#### 7.11.4.13 operator-()

```
idx qpp::Dynamic_bitset::operator- (
            const Dynamic_bitset & rhs ) const  [inline], [noexcept]
```

Number of places the two bitsets differ (Hamming distance)

**Parameters**

| | |
|---|---|
| *rhs* | Dynamic_bitset against which the the Hamming distance is computed |

**Returns**

Hamming distance

#### 7.11.4.14 operator==()

```
bool qpp::Dynamic_bitset::operator== (
            const Dynamic_bitset & rhs ) const  [inline], [noexcept]
```

Equality operator.

**Parameters**

| | |
|---|---|
| *rhs* | Dynamic_bitset against which the equality is being tested |

**Returns**

True if the bitsets are equal (bit by bit), false otherwise

#### 7.11.4.15 rand() [1/2]

```
Dynamic_bitset& qpp::Dynamic_bitset::rand (
            idx pos,
            double p = 0.5 )  [inline]
```

Sets the bit at position *pos* according to a Bernoulli(p) distribution.

**Parameters**

| | |
|---|---|
| *pos* | Position in the bitset |
| *p* | Probability |

**Returns**

Reference to the current instance

#### 7.11.4.16 rand() [2/2]

```
Dynamic_bitset& qpp::Dynamic_bitset::rand (
            double p = 0.5 )  [inline]
```

Sets all bits according to a Bernoulli(p) distribution.

**Parameters**

| | |
|---|---|
| *p* | Probability |

**Returns**

Reference to the current instance

#### 7.11.4.17 reset() [1/2]

```
Dynamic_bitset& qpp::Dynamic_bitset::reset (
            idx pos ) [inline]
```

Sets the bit at position *pos* to false.

**Parameters**

| | |
|---|---|
| *pos* | Position in the bitset |

**Returns**

Reference to the current instance

#### 7.11.4.18 reset() [2/2]

```
Dynamic_bitset& qpp::Dynamic_bitset::reset ( ) [inline], [noexcept]
```

Sets all bits to false.

**Returns**

Reference to the current instance

#### 7.11.4.19 set() [1/2]

```
Dynamic_bitset& qpp::Dynamic_bitset::set (
            idx pos,
            bool value = true ) [inline]
```

Sets the bit at position *pos*.

**Parameters**

| | |
|---|---|
| *pos* | Position in the bitset |
| *value* | Bit value |

**Returns**

Reference to the current instance

#### 7.11.4.20 set() [2/2]

```
Dynamic_bitset& qpp::Dynamic_bitset::set ( )  [inline], [noexcept]
```

Set all bits to true.

**Returns**

Reference to the current instance

#### 7.11.4.21 size()

```
idx qpp::Dynamic_bitset::size ( ) const  [inline], [noexcept]
```

Number of bits stored in the bitset.

**Returns**

Number of bits stored in the bitset

#### 7.11.4.22 storage_size()

```
idx qpp::Dynamic_bitset::storage_size ( ) const  [inline], [noexcept]
```

Size of the underlying storage space (in units of value_type, unsigned int by default)

**Returns**

Size of the underlying storage space

#### 7.11.4.23 to_string()

```
template<class CharT = char, class Traits = std::char_traits<CharT>, class Allocator = std↩
::allocator<CharT>>
std::basic_string<CharT, Traits, Allocator> qpp::Dynamic_bitset::to_string (
            CharT zero = CharT('0'),
            CharT one = CharT('1') ) const  [inline]
```

String representation.

**Template Parameters**

| | |
|---|---|
| *CharT* | String character type |
| *Traits* | String traits |
| *Allocator* | String Allocator |

**Parameters**

| | |
|---|---|
| *zero* | Character representing the zero |
| *one* | Character representing the one |

**Returns**

The bitset as a string

### 7.11.5 Member Data Documentation

#### 7.11.5.1 N_

```
idx qpp::Dynamic_bitset::N_ [protected]
```

Number of bits.

#### 7.11.5.2 storage_size_

```
idx qpp::Dynamic_bitset::storage_size_ [protected]
```

Storage size.

#### 7.11.5.3 v_

```
std::vector<value_type> qpp::Dynamic_bitset::v_ [protected]
```

Storage space.

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

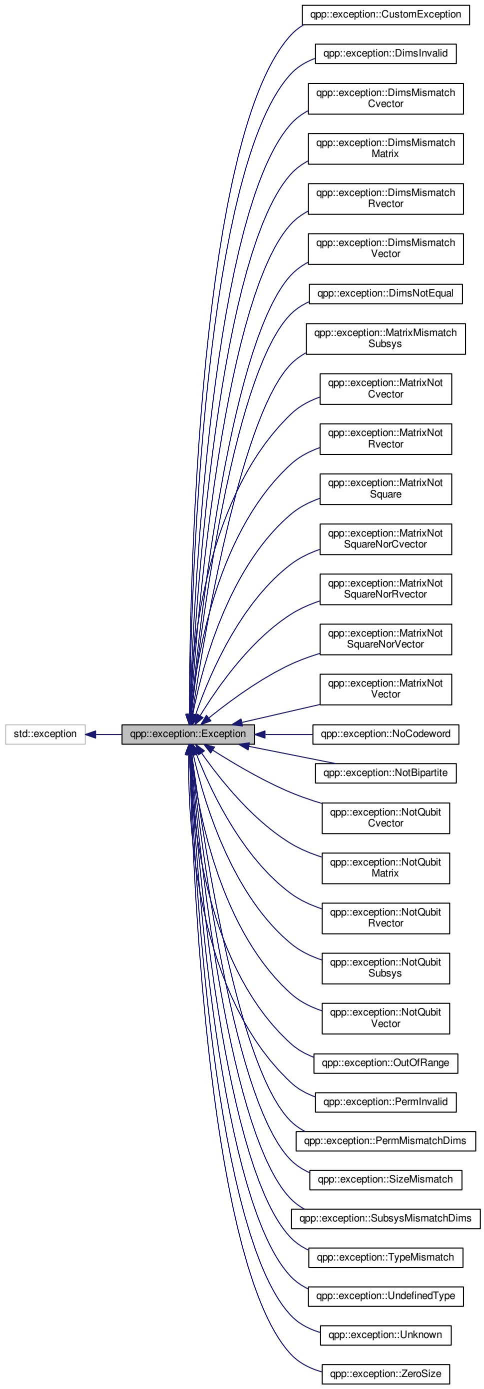
- classes/reversible.h

## 7.12 qpp::exception::Exception Class Reference

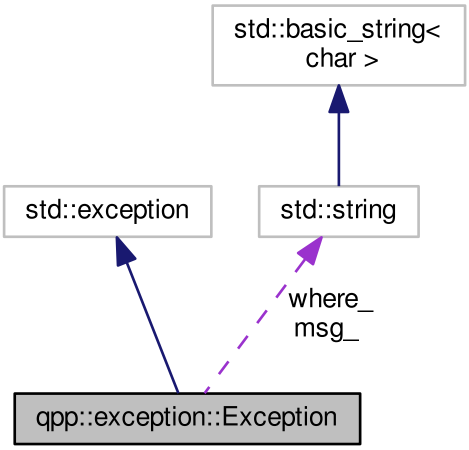
Base class for generating Quantum++ custom exceptions.

`#include <classes/exception.h>`

Inheritance diagram for qpp::exception::Exception:



Collaboration diagram for qpp::exception::Exception:




## Public Member Functions

- Exception (const std::string &where)

  *Constructs an exception.*
- virtual const char ∗ what () const noexcept override

  *Overrides std::exception::what()*
- virtual std::string type_description () const =0

  *Exception type description.*

## Private Attributes

- std::string where_
- std::string msg_

### 7.12.1 Detailed Description

Base class for generating Quantum++ custom exceptions.

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

Example:

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

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

## 7.12.2 Constructor & Destructor Documentation

### 7.12.2.1 Exception()

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

Constructs an exception.

**Parameters**

| | |
|---|---|
| *where* | Text representing where the exception occurred |

## 7.12.3 Member Function Documentation

### 7.12.3.1 type_description()

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

Exception type description.

**Returns**

Exception type description

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

#### 7.12.3.2 what()

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

Overrides std::exception::what()

**Returns**

Exception description

### 7.12.4 Member Data Documentation

#### 7.12.4.1 msg_

std::string qpp::exception::Exception::msg_ [mutable], [private]

#### 7.12.4.2 where_

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

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

- classes/exception.h

## 7.13 qpp::Bit_circuit::Gate_count Struct Reference

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

### Public Attributes

- idx NOT = 0
- idx & X = NOT
- idx CNOT = 0
- idx SWAP = 0
- idx FRED = 0
- idx TOF = 0

### 7.13.1 Member Data Documentation

#### 7.13.1.1 CNOT

```
idx qpp::Bit_circuit::Gate_count::CNOT = 0
```

#### 7.13.1.2 FRED

```
idx qpp::Bit_circuit::Gate_count::FRED = 0
```

#### 7.13.1.3 NOT

```
idx qpp::Bit_circuit::Gate_count::NOT = 0
```

#### 7.13.1.4 SWAP

```
idx qpp::Bit_circuit::Gate_count::SWAP = 0
```

#### 7.13.1.5 TOF

```
idx qpp::Bit_circuit::Gate_count::TOF = 0
```

#### 7.13.1.6 X

```
idx& qpp::Bit_circuit::Gate_count::X = NOT
```

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

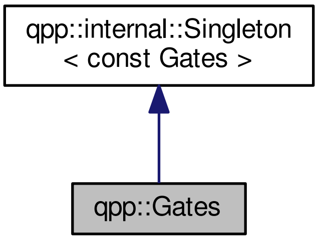
- classes/reversible.h

## 7.14 qpp::Gates Class Reference

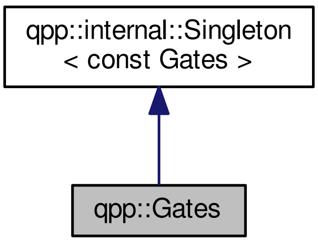
const Singleton class that implements most commonly used gates

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

Inheritance diagram for qpp::Gates:




Collaboration diagram for qpp::Gates:




### Public Member Functions

- cmat Rn (double theta, const std::vector< double > &n) const

  *Qubit rotation of theta about the 3-dimensional real (unit) vector n.*
- cmat RX (double theta) const

  *Qubit rotation of theta about the X axis.*
- cmat RY (double theta) const

  *Qubit rotation of theta about the Y axis.*
- cmat RZ (double theta) const

  *Qubit rotation of theta about the Z axis.*
- cmat Zd (idx D=2) const

  *Generalized Z gate for qudits.*

- cmat SWAPd (idx D=2) const

  *SWAP gate for qudits.*
- cmat Fd (idx D=2) const

  *Quantum Fourier transform gate for qudits.*
- cmat MODMUL (idx a, idx N) const

  *Modular multiplication gate for qubits Implements* $|x\rangle \longrightarrow |x \bmod N\rangle$.
- cmat Xd (idx D=2) const

  *Generalized X gate for qudits.*
- template<typename Derived = Eigen::MatrixXcd>
  Derived Id (idx D=2) const

  *Identity gate.*
- template<typename Derived >
  dyn_mat< typename Derived::Scalar > CTRL (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &ctrl, const std::vector< idx > &subsys, idx n, idx d=2) const

  *Generates the multi-partite multiple-controlled-A gate in matrix form.*
- template<typename Derived >
  dyn_mat< typename Derived::Scalar > expandout (const Eigen::MatrixBase< Derived > &A, idx pos, const std::vector< idx > &dims) const

  *Expands out.*
- template<typename Derived >
  dyn_mat< typename Derived::Scalar > expandout (const Eigen::MatrixBase< Derived > &A, idx pos, const std::initializer_list< idx > &dims) const

  *Expands out.*
- template<typename Derived >
  dyn_mat< typename Derived::Scalar > expandout (const Eigen::MatrixBase< Derived > &A, idx pos, idx n, idx d=2) const

  *Expands out.*

## Public Attributes

- cmat Id2 {cmat::Identity(2, 2)}

  *Identity gate.*
- cmat H {cmat::Zero(2, 2)}

  *Hadamard gate.*
- cmat X {cmat::Zero(2, 2)}

  *Pauli Sigma-X gate.*
- cmat Y {cmat::Zero(2, 2)}

  *Pauli Sigma-Y gate.*
- cmat Z {cmat::Zero(2, 2)}

  *Pauli Sigma-Z gate.*
- cmat S {cmat::Zero(2, 2)}

  *S gate.*
- cmat T {cmat::Zero(2, 2)}

  *T gate.*
- cmat CNOT {cmat::Identity(4, 4)}

  *Controlled-NOT control target gate.*
- cmat CZ {cmat::Identity(4, 4)}

  *Controlled-Phase gate.*
- cmat CNOTba {cmat::Zero(4, 4)}

  *Controlled-NOT target control gate.*
- cmat SWAP {cmat::Identity(4, 4)}

*SWAP gate.*
- cmat TOF {cmat::Identity(8, 8)}

  *Toffoli gate.*
- cmat FRED {cmat::Identity(8, 8)}

  *Fredkin gate.*

### Private Member Functions

- Gates ()

  *Initializes the gates.*
- ∼Gates ()=default

  *Default destructor.*

### Friends

- class internal::Singleton< const Gates >

### Additional Inherited Members

## 7.14.1 Detailed Description

const Singleton class that implements most commonly used gates

## 7.14.2 Constructor & Destructor Documentation

### 7.14.2.1 Gates()

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

Initializes the gates.

### 7.14.2.2 ∼Gates()

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

Default destructor.

## 7.14.3 Member Function Documentation

#### 7.14.3.1 CTRL()

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

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

**See also**

qpp::applyCTRL()

**Note**

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

**Parameters**

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

**Returns**

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

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

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

Expands out.

**See also**

qpp::kron()

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

**Parameters**

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

**Returns**

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

#### 7.14.3.3 expandout() [2/3]

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

Expands out.

**See also**

qpp::kron()

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

**Note**

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

**Parameters**

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

**Returns**

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

#### 7.14.3.4 expandout() [3/3]

```
template<typename Derived >
dyn_mat<typename Derived::Scalar> qpp::Gates::expandout (
            const Eigen::MatrixBase< Derived > & A,
            idx pos,
            idx n,
            idx d = 2 ) const  [inline]
```

Expands out.

**See also**

qpp::kron()

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

**Parameters**

| | |
|---|---|
| *A* | Eigen expression |
| *pos* | Position |
| *n* | Number of subsystems |
| *d* | Subsystem dimension |

**Returns**

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

#### 7.14.3.5 Fd()

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

Quantum Fourier transform gate for qudits.

**Note**

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

**Parameters**

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

**Returns**

Fourier transform gate for qudits

#### 7.14.3.6 Id()

```
template<typename Derived = Eigen::MatrixXcd>
Derived qpp::Gates::Id (
            idx D = 2 ) const [inline]
```

Identity gate.

**Note**

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

**Parameters**

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

**Returns**

Identity gate on a Hilbert space of dimension *D*

#### 7.14.3.7 MODMUL()

```
cmat qpp::Gates::MODMUL (
            idx a,
            idx N ) const [inline]
```

Modular multiplication gate for qubits Implements $|x\rangle \longrightarrow |x \mathrm{mod} N\rangle$.

**Parameters**

| | |
|---|---|
| *a* | |
| *N* | |

**Returns**

Modular multiplication gate

#### 7.14.3.8 Rn()

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

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

**Parameters**

| | |
|---|---|
| *theta* | Rotation angle |
| *n* | 3-dimensional real (unit) vector |

**Returns**

Rotation gate

#### 7.14.3.9 RX()

```
cmat qpp::Gates::RX (
            double theta ) const  [inline]
```

Qubit rotation of *theta* about the X axis.

**Parameters**

| | |
|---|---|
| *theta* | Rotation angle |

**Returns**

Rotation gate

#### 7.14.3.10 RY()

```
cmat qpp::Gates::RY (
            double theta ) const  [inline]
```

Qubit rotation of *theta* about the Y axis.

**Parameters**

| | |
|---|---|
| *theta* | Rotation angle |

**Returns**

Rotation gate

#### 7.14.3.11 RZ()

```
cmat qpp::Gates::RZ (
            double theta ) const  [inline]
```

Qubit rotation of *theta* about the Z axis.

**Parameters**

| | |
|---|---|
| *theta* | Rotation angle |

**Returns**

Rotation gate

#### 7.14.3.12 SWAPd()

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

SWAP gate for qudits.

**Parameters**

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

**Returns**

SWAP gate for qudits

#### 7.14.3.13 Xd()

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

Generalized X gate for qudits.

**Note**

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

**Parameters**

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

**Returns**

Generalized X gate for qudits

#### 7.14.3.14 Zd()

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

Generalized Z gate for qudits.

**Note**

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

**Parameters**

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

**Returns**

Generalized Z gate for qudits

### 7.14.4 Friends And Related Function Documentation

#### 7.14.4.1 internal::Singleton< const Gates >

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

### 7.14.5 Member Data Documentation

#### 7.14.5.1 CNOT

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

Controlled-NOT control target gate.

#### 7.14.5.2 CNOTba

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

Controlled-NOT target control gate.

#### 7.14.5.3 CZ

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

Controlled-Phase gate.

#### 7.14.5.4 FRED

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

Fredkin gate.

#### 7.14.5.5 H

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

Hadamard gate.

#### 7.14.5.6 Id2

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

Identity gate.

#### 7.14.5.7 S

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

S gate.

#### 7.14.5.8 SWAP

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

SWAP gate.

#### 7.14.5.9 T

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

T gate.

#### 7.14.5.10 TOF

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

Toffoli gate.

#### 7.14.5.11 X

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

Pauli Sigma-X gate.

#### 7.14.5.12 Y

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

Pauli Sigma-Y gate.

#### 7.14.5.13 Z

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

Pauli Sigma-Z gate.

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

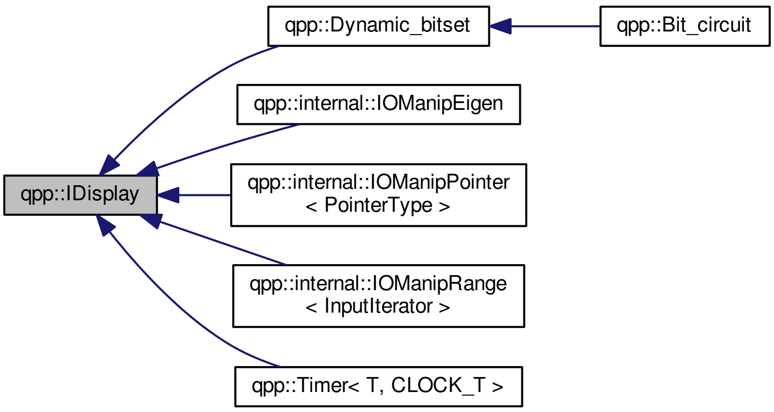
- classes/gates.h

## 7.15 qpp::IDisplay Class Reference

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

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

Inheritance diagram for qpp::IDisplay:




### Public Member Functions

- IDisplay ()=default

    *Default constructor.*
- IDisplay (const IDisplay &)=default

    *Default copy constructor.*
- IDisplay (IDisplay &&)=default

    *Default move constructor.*
- IDisplay & operator= (const IDisplay &)=default

    *Default copy assignment operator.*
- IDisplay & operator= (IDisplay &&)=default

    *Default move assignment operator.*
- virtual ∼IDisplay ()=default

    *Default virtual destructor.*

### Private Member Functions

- virtual std::ostream & display (std::ostream &os) const =0

    *Must be overridden by all derived classes.*

### Friends

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

    *Overloads the extraction operator.*

### 7.15.1 Detailed Description

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

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

### 7.15.2 Constructor & Destructor Documentation

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

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

Default constructor.

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

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

Default copy constructor.

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

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

Default move constructor.

#### 7.15.2.4 ∼IDisplay()

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

Default virtual destructor.

### 7.15.3 Member Function Documentation

#### 7.15.3.1 display()

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

Must be overridden by all derived classes.

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

Implemented in qpp::Dynamic_bitset, qpp::internal::IOManipEigen, qpp::Timer< T, CLOCK_T >, qpp::internal::IOManipPointer< PointerType >, and qpp::internal::IOManipRange< InputIterator >.

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

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

Default copy assignment operator.

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

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

Default move assignment operator.

### 7.15.4 Friends And Related Function Documentation

#### 7.15.4.1 operator<<

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

Overloads the extraction operator.

Delegates the work to the virtual function qpp::IDisplay::display()

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

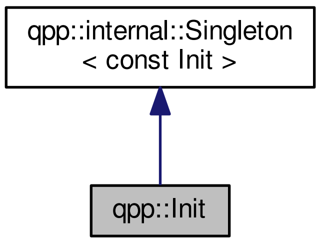
- classes/idisplay.h

## 7.16 qpp::Init Class Reference

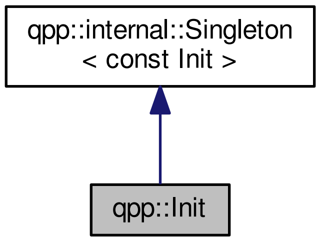
const Singleton class that performs additional initializations/cleanups

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

Inheritance diagram for qpp::Init:




Collaboration diagram for qpp::Init:




### Private Member Functions

- Init ()

    *Additional initializations.*
- ∼Init ()

    *Cleanups.*

### Friends

- class internal::Singleton< const Init >

## Additional Inherited Members

### 7.16.1 Detailed Description

const Singleton class that performs additional initializations/cleanups

### 7.16.2 Constructor & Destructor Documentation

#### 7.16.2.1 Init()

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

Additional initializations.

#### 7.16.2.2 ∼Init()

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

Cleanups.

### 7.16.3 Friends And Related Function Documentation

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

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

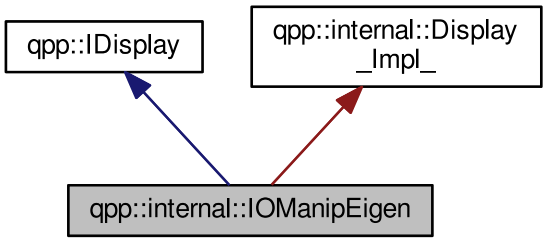
The documentation for this class was generated from the following file:

- classes/init.h

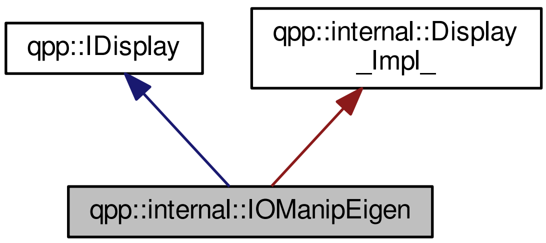
## 7.17 qpp::internal::IOManipEigen Class Reference

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

Inheritance diagram for qpp::internal::IOManipEigen:




Collaboration diagram for qpp::internal::IOManipEigen:




### Public Member Functions

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

### Private Member Functions

- std::ostream & display (std::ostream &os) const override

  *Must be overridden by all derived classes.*

### Private Attributes

- cmat A_
- double chop_

## 7.17.1 Constructor & Destructor Documentation

### 7.17.1.1 IOManipEigen() [1/2]

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

### 7.17.1.2 IOManipEigen() [2/2]

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

## 7.17.2 Member Function Documentation

### 7.17.2.1 display()

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

Must be overridden by all derived classes.

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

Implements qpp::IDisplay.

## 7.17.3 Member Data Documentation

#### 7.17.3.1 A_

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

#### 7.17.3.2 chop_

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

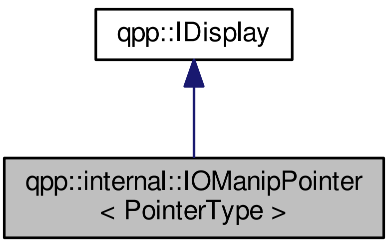
The documentation for this class was generated from the following file:

- internal/classes/iomanip.h

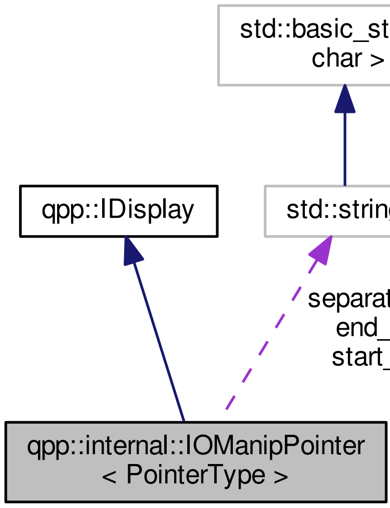
## 7.18 qpp::internal::IOManipPointer< PointerType > Class Template Reference

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

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



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




### Public Member Functions

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

### Private Member Functions

- std::ostream & display (std::ostream &os) const override

  *Must be overridden by all derived classes.*

### Private Attributes

- const PointerType ∗ p_
- idx N_
- std::string separator_
- std::string start_
- std::string end_

## 7.18.1 Constructor & Destructor Documentation

#### 7.18.1.1 IOManipPointer() [1/2]

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

#### 7.18.1.2 IOManipPointer() [2/2]

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

### 7.18.2 Member Function Documentation

#### 7.18.2.1 display()

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

Must be overridden by all derived classes.

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

Implements qpp::IDisplay.

#### 7.18.2.2 operator=()

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

### 7.18.3 Member Data Documentation

#### 7.18.3.1 end_

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

#### 7.18.3.2 N_

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

#### 7.18.3.3 p_

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

#### 7.18.3.4 separator_

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

#### 7.18.3.5 start_

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

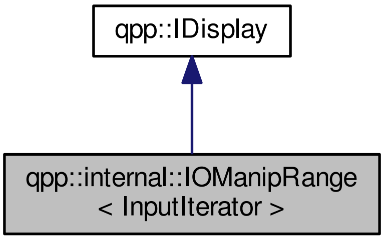
The documentation for this class was generated from the following file:

- internal/classes/iomanip.h

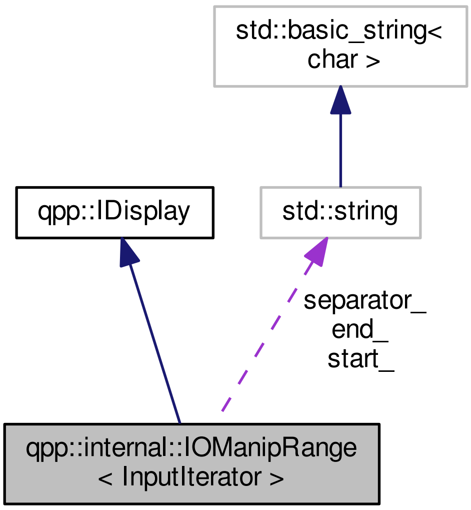
## 7.19 qpp::internal::IOManipRange< InputIterator > Class Template Reference

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

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




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




### Public Member Functions

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

### Private Member Functions

- std::ostream & display (std::ostream &os) const override

  *Must be overridden by all derived classes.*

### Private Attributes

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

## 7.19.1 Constructor & Destructor Documentation

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

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

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

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

## 7.19.2 Member Function Documentation

### 7.19.2.1 display()

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

Must be overridden by all derived classes.

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

Implements qpp::IDisplay.

#### 7.19.2.2 operator=()

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

### 7.19.3 Member Data Documentation

#### 7.19.3.1 end_

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

#### 7.19.3.2 first_

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

#### 7.19.3.3 last_

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

#### 7.19.3.4 separator_

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

#### 7.19.3.5 start_

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

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

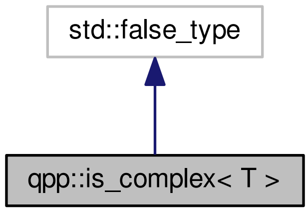
- internal/classes/iomanip.h

## 7.20 qpp::is_complex< T > Struct Template Reference

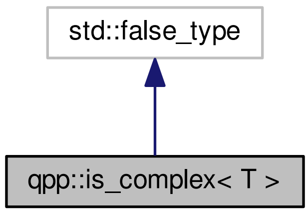
Checks whether the type is a complex type.

`#include <traits.h>`

Inheritance diagram for qpp::is_complex< T >:




Collaboration diagram for qpp::is_complex< T >:




### 7.20.1 Detailed Description

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

Checks whether the type is a complex type.

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

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

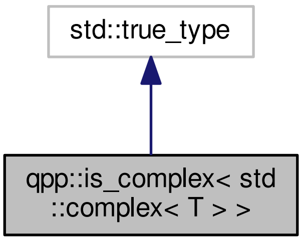
- traits.h

## 7.21 qpp::is_complex< std::complex< T > > Struct Template Reference

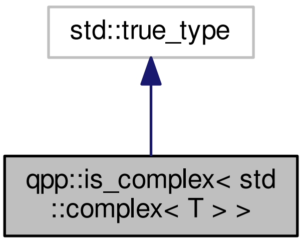
Checks whether the type is a complex number type, specialization for complex types.

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

Inheritance diagram for qpp::is_complex< std::complex< T > >:




Collaboration diagram for qpp::is_complex< std::complex< T > >:




### 7.21.1 Detailed Description

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

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

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

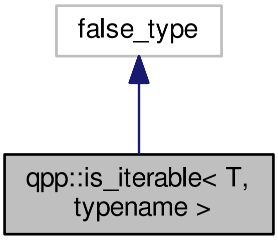
- traits.h

## 7.22 qpp::is_iterable< T, typename > Struct Template Reference

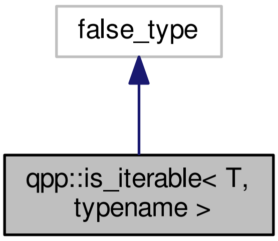
Checks whether *T* is compatible with an STL-like iterable container.

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

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




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




### 7.22.1 Detailed Description

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

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

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

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

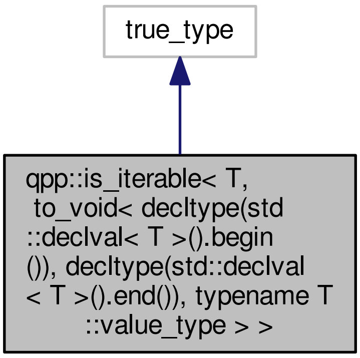
- traits.h

## 7.23 qpp::is_iterable< T, to_void< decltype(std::declval< T >().begin()), decltype(std::declval< T >().end()), typename T::value_type > > Struct Template Reference

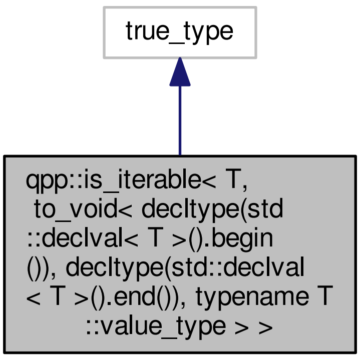
Checks whether *T* is compatible with an STL-like iterable container, specialization for STL-like iterable containers.

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

Inheritance diagram for qpp::is_iterable< T, to_void< decltype(std::declval< T >().begin()), decltype(std::declval< T >().end()), typename T::value_type > >:




Collaboration diagram for qpp::is_iterable< T, to_void< decltype(std::declval< T >().begin()), decltype(std::declval< T >().end()), typename T::value_type > >:



### 7.23.1 Detailed Description

**template< typename T >**
**struct qpp::is_iterable< T, to_void< decltype(std::declval< T >().begin()), decltype(std::declval< T >().end()), typename T::value_type > >**

Checks whether *T* is compatible with an STL-like iterable container, specialization for STL-like iterable containers.

The documentation for this struct was generated from the following file:

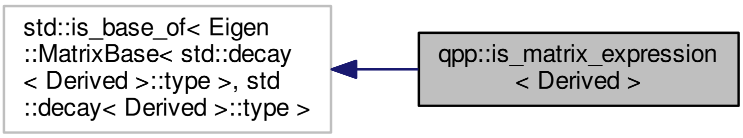
- traits.h

## 7.24 qpp::is_matrix_expression< Derived > Struct Template Reference

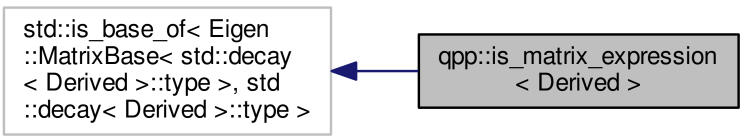
Checks whether the type is an Eigen matrix expression.

```
#include <traits.h>
```

Inheritance diagram for qpp::is_matrix_expression< Derived >:




Collaboration diagram for qpp::is_matrix_expression< Derived >:



### 7.24.1 Detailed Description

**template<typename Derived>**
**struct qpp::is_matrix_expression< Derived >**

Checks whether the type is an Eigen matrix expression.

Provides the constant member *value* which is equal to *true*, if the type is an Eigen matrix expression of type *Eigen::MatrixBase<Derived>*. Otherwise, *value* is equal to *false*.

The documentation for this struct was generated from the following file:

- traits.h

## 7.25 qpp::make_void< Ts > Struct Template Reference

Helper for qpp::to_void<> alias template.

```
#include <traits.h>
```

### Public Types

- typedef void type

### 7.25.1 Detailed Description

**template<typename... Ts>**
**struct qpp::make_void< Ts >**

Helper for qpp::to_void<> alias template.

**See also**

qpp::to_void<>

### 7.25.2 Member Typedef Documentation

#### 7.25.2.1 type

```
template<typename... Ts>
typedef void qpp::make_void< Ts >::type
```

The documentation for this struct was generated from the following file:

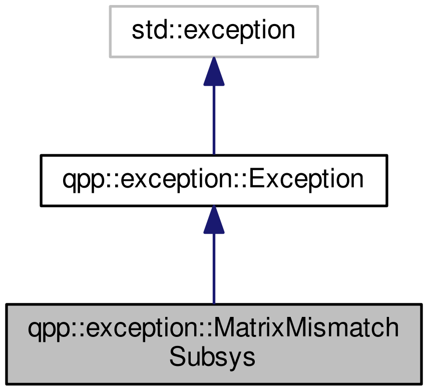
- traits.h

## 7.26 qpp::exception::MatrixMismatchSubsys Class Reference

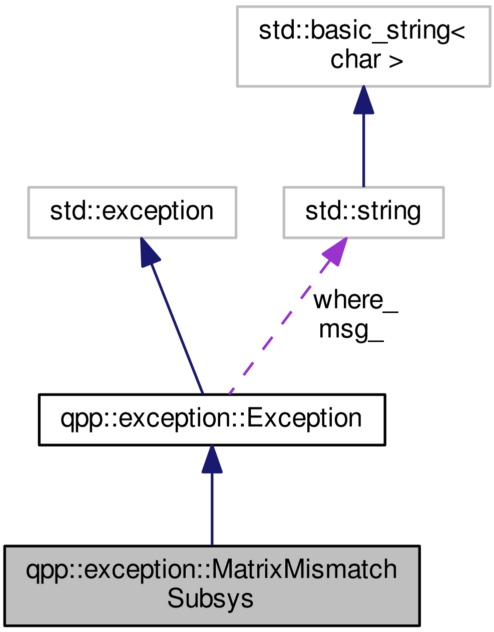
Matrix mismatch subsystems exception.

`#include <classes/exception.h>`

Inheritance diagram for qpp::exception::MatrixMismatchSubsys:




Collaboration diagram for qpp::exception::MatrixMismatchSubsys:



### Public Member Functions

- std::string type_description () const override

    *Exception type description.*

### 7.26.1 Detailed Description

Matrix mismatch subsystems exception.

Matrix size mismatch subsystem sizes (e.g. in qpp::apply())

### 7.26.2 Member Function Documentation

#### 7.26.2.1 type_description()

```
std::string qpp::exception::MatrixMismatchSubsys::type_description ( ) const  [inline], [override],
[virtual]
```

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

The documentation for this class was generated from the following file:

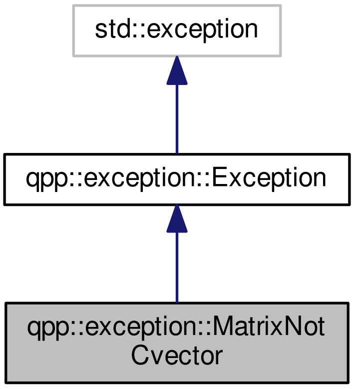
- classes/exception.h

## 7.27 qpp::exception::MatrixNotCvector Class Reference

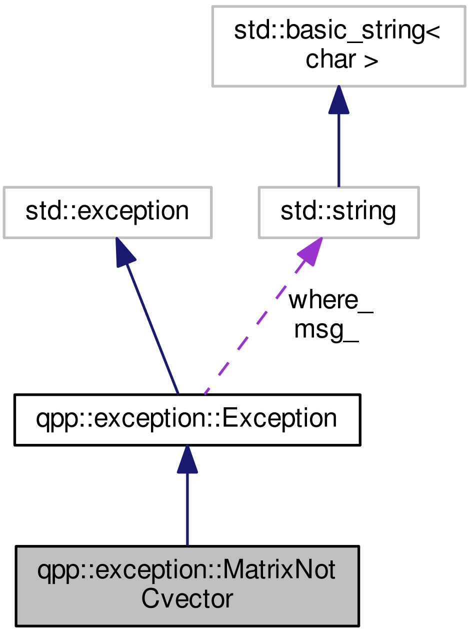
Matrix is not a column vector exception.

```
#include <classes/exception.h>
```

Inheritance diagram for qpp::exception::MatrixNotCvector:




Collaboration diagram for qpp::exception::MatrixNotCvector:




### Public Member Functions

- std::string type_description () const override

  *Exception type description.*

### 7.27.1 Detailed Description

Matrix is not a column vector exception.

Eigen::Matrix is not a column vector

### 7.27.2 Member Function Documentation

#### 7.27.2.1 type_description()

```
std::string qpp::exception::MatrixNotCvector::type_description ( ) const [inline], [override],
[virtual]
```

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

The documentation for this class was generated from the following file:

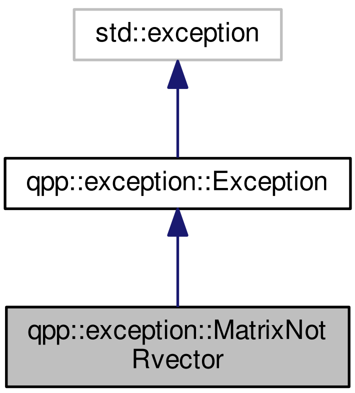
- classes/exception.h

## 7.28 qpp::exception::MatrixNotRvector Class Reference

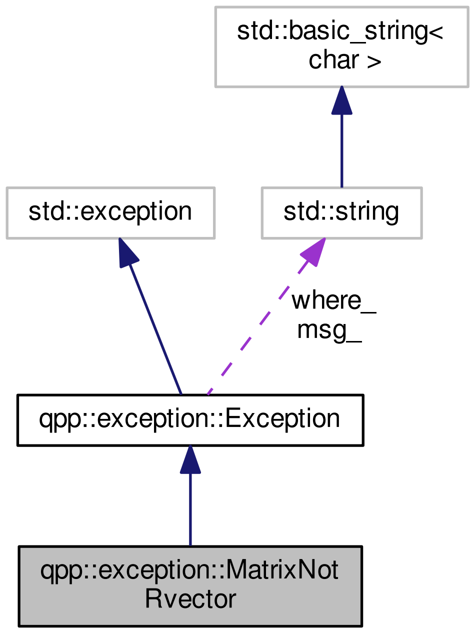
Matrix is not a row vector exception.

```
#include <classes/exception.h>
```

Inheritance diagram for qpp::exception::MatrixNotRvector:



Collaboration diagram for qpp::exception::MatrixNotRvector:




### Public Member Functions

- std::string type_description () const override

    *Exception type description.*

## 7.28.1 Detailed Description

Matrix is not a row vector exception.

Eigen::Matrix is not a row vector

## 7.28.2 Member Function Documentation

#### 7.28.2.1 type_description()

```
std::string qpp::exception::MatrixNotRvector::type_description ( ) const  [inline], [override],
[virtual]
```

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

The documentation for this class was generated from the following file:

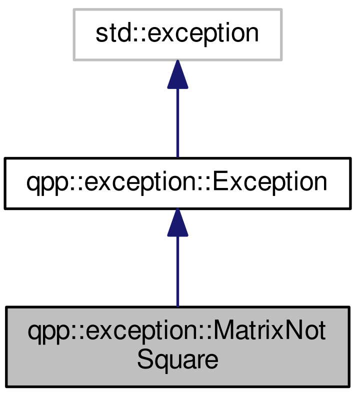
- classes/exception.h

## 7.29 qpp::exception::MatrixNotSquare Class Reference

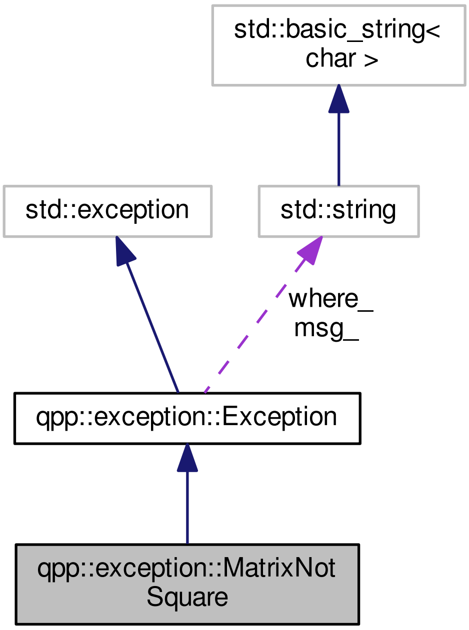
Matrix is not square exception.

```
#include <classes/exception.h>
```

Inheritance diagram for qpp::exception::MatrixNotSquare:



Collaboration diagram for qpp::exception::MatrixNotSquare:




## Public Member Functions

- std::string type_description () const override

  *Exception type description.*

### 7.29.1 Detailed Description

Matrix is not square exception.

Eigen::Matrix is not a square matrix

### 7.29.2 Member Function Documentation

#### 7.29.2.1 type_description()

std::string qpp::exception::MatrixNotSquare::type_description ( ) const [inline], [override], [virtual]

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

The documentation for this class was generated from the following file:

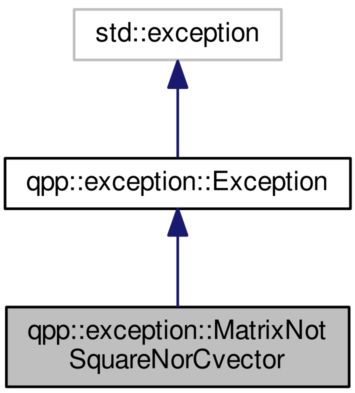
- classes/exception.h

## 7.30 qpp::exception::MatrixNotSquareNorCvector Class Reference

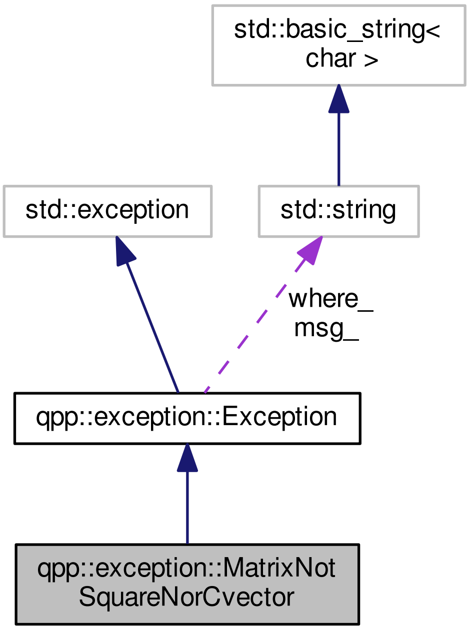
Matrix is not square nor column vector exception.

```
#include <classes/exception.h>
```

Inheritance diagram for qpp::exception::MatrixNotSquareNorCvector:



Collaboration diagram for qpp::exception::MatrixNotSquareNorCvector:




## Public Member Functions

- std::string type_description () const override

    *Exception type description.*

### 7.30.1 Detailed Description

Matrix is not square nor column vector exception.

Eigen::Matrix is not a square matrix nor a column vector

### 7.30.2 Member Function Documentation

#### 7.30.2.1 type_description()

```
std::string qpp::exception::MatrixNotSquareNorCvector::type_description ( ) const [inline],
[override], [virtual]
```

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

The documentation for this class was generated from the following file:

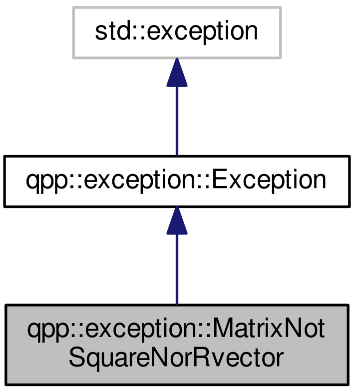
- classes/exception.h

## 7.31 qpp::exception::MatrixNotSquareNorRvector Class Reference

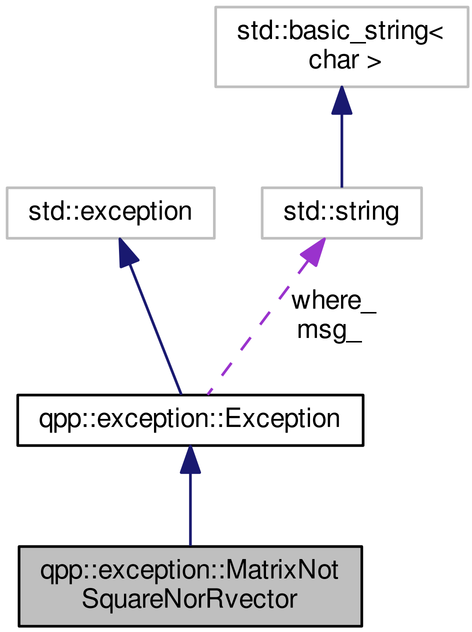
Matrix is not square nor row vector exception.

```
#include <classes/exception.h>
```

Inheritance diagram for qpp::exception::MatrixNotSquareNorRvector:



Collaboration diagram for qpp::exception::MatrixNotSquareNorRvector:




## Public Member Functions

- std::string type_description () const override

    *Exception type description.*

### 7.31.1 Detailed Description

Matrix is not square nor row vector exception.

Eigen::Matrix is not a square matrix nor a row vector

### 7.31.2 Member Function Documentation

#### 7.31.2.1 type_description()

`std::string qpp::exception::MatrixNotSquareNorRvector::type_description ( ) const [inline], [override], [virtual]`

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

The documentation for this class was generated from the following file:

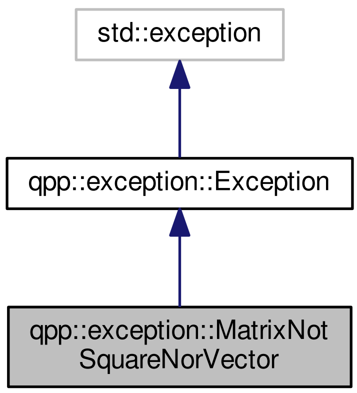
- classes/exception.h

## 7.32 qpp::exception::MatrixNotSquareNorVector Class Reference

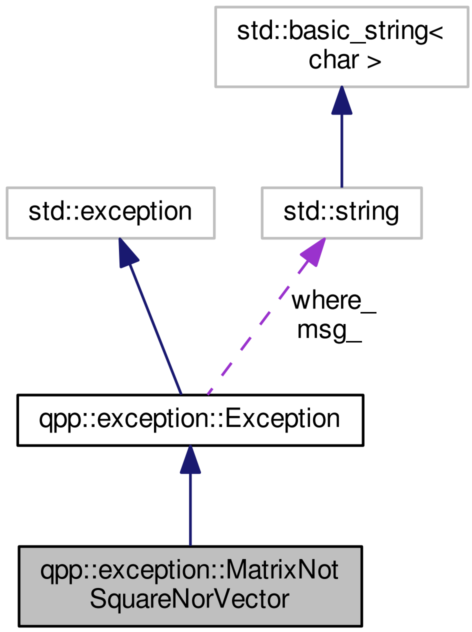
Matrix is not square nor vector exception.

`#include <classes/exception.h>`

Inheritance diagram for qpp::exception::MatrixNotSquareNorVector:



Collaboration diagram for qpp::exception::MatrixNotSquareNorVector:




### Public Member Functions

- std::string type_description () const override

  *Exception type description.*

### 7.32.1 Detailed Description

Matrix is not square nor vector exception.

Eigen::Matrix is not a square matrix nor a row/column vector

### 7.32.2 Member Function Documentation

#### 7.32.2.1 type_description()

```
std::string qpp::exception::MatrixNotSquareNorVector::type_description ( ) const [inline],
[override], [virtual]
```

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

The documentation for this class was generated from the following file:

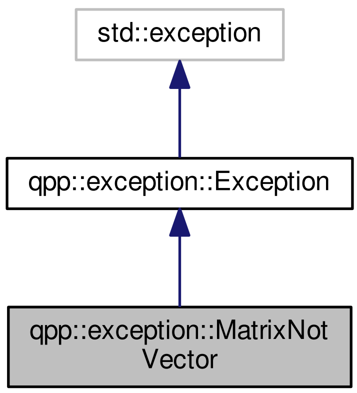
- classes/exception.h

## 7.33 qpp::exception::MatrixNotVector Class Reference

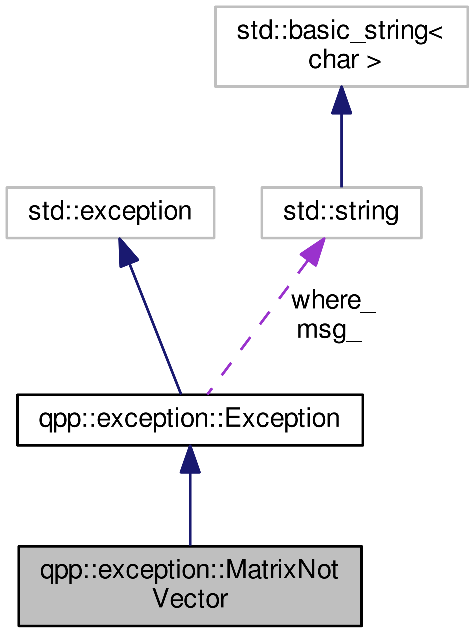
Matrix is not a vector exception.

```
#include <classes/exception.h>
```

Inheritance diagram for qpp::exception::MatrixNotVector:



Collaboration diagram for qpp::exception::MatrixNotVector:




### Public Member Functions

- std::string type_description () const override

    *Exception type description.*

### 7.33.1 Detailed Description

Matrix is not a vector exception.

Eigen::Matrix is not a row or column vector

### 7.33.2 Member Function Documentation

#### 7.33.2.1 type_description()

```
std::string qpp::exception::MatrixNotVector::type_description ( ) const  [inline], [override],
[virtual]
```

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

The documentation for this class was generated from the following file:

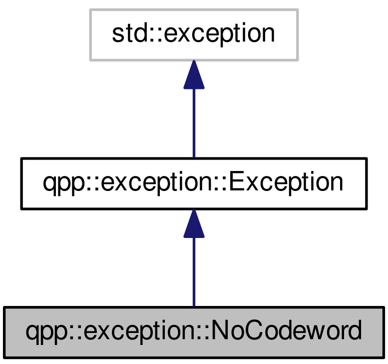
- classes/exception.h

## 7.34 qpp::exception::NoCodeword Class Reference

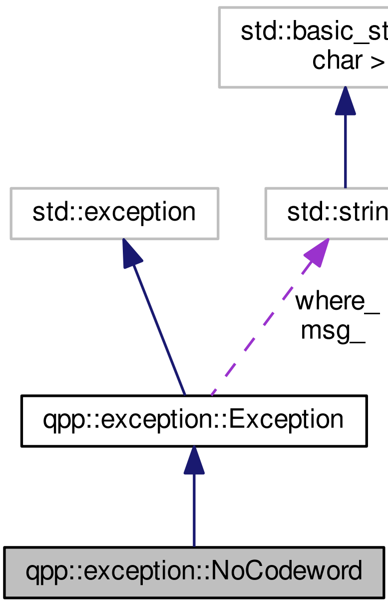
Codeword does not exist exception.

```
#include <classes/exception.h>
```

Inheritance diagram for qpp::exception::NoCodeword:



Collaboration diagram for qpp::exception::NoCodeword:




## Public Member Functions

- std::string type_description () const override
  *Exception type description.*

## 7.34.1 Detailed Description

Codeword does not exist exception.

Codeword does not exist, thrown when calling qpp::Codes::codeword() with an invalid index

## 7.34.2 Member Function Documentation

### 7.34.2.1 type_description()

```
std::string qpp::exception::NoCodeword::type_description ( ) const [inline], [override],
[virtual]
```

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

The documentation for this class was generated from the following file:

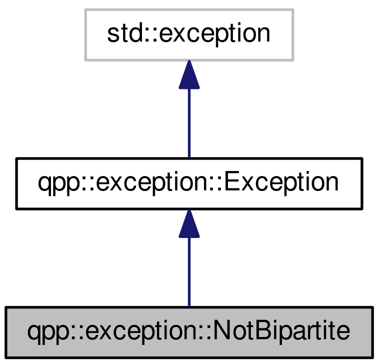
- classes/exception.h

## 7.35 qpp::exception::NotBipartite Class Reference

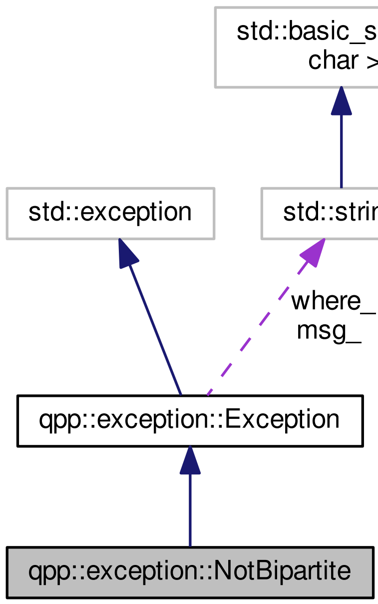
Not bi-partite exception.

`#include <classes/exception.h>`

Inheritance diagram for qpp::exception::NotBipartite:



Collaboration diagram for qpp::exception::NotBipartite:




## Public Member Functions

- std::string type_description () const override

  *Exception type description.*

### 7.35.1 Detailed Description

Not bi-partite exception.

std::vector<idx> of dimensions has size different from 2

### 7.35.2 Member Function Documentation

#### 7.35.2.1 type_description()

`std::string qpp::exception::NotBipartite::type_description ( ) const [inline], [override], [virtual]`

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

The documentation for this class was generated from the following file:

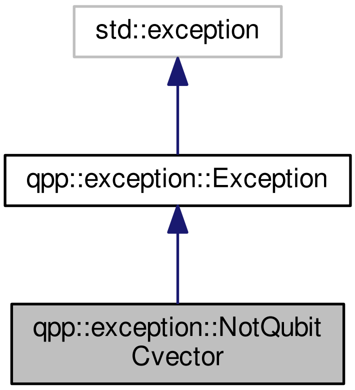
- classes/exception.h

## 7.36 qpp::exception::NotQubitCvector Class Reference

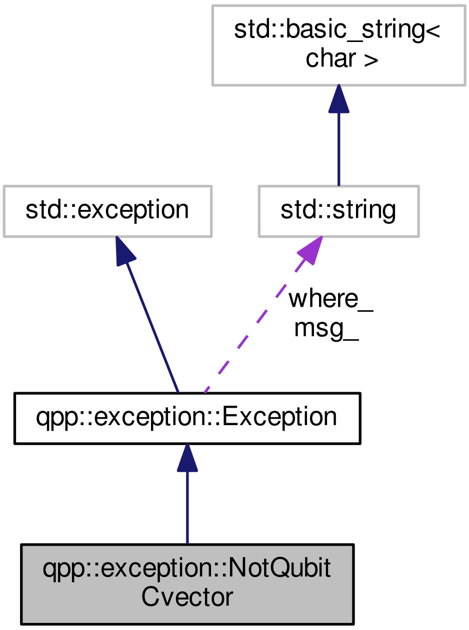
Column vector is not 2 x 1 exception.

`#include <classes/exception.h>`

Inheritance diagram for qpp::exception::NotQubitCvector:



Collaboration diagram for qpp::exception::NotQubitCvector:




## Public Member Functions

- std::string type_description () const override

  *Exception type description.*

### 7.36.1 Detailed Description

Column vector is not 2 x 1 exception.

Eigen::Matrix is not 2 x 1

### 7.36.2 Member Function Documentation

#### 7.36.2.1 type_description()

```
std::string qpp::exception::NotQubitCvector::type_description ( ) const  [inline], [override],
[virtual]
```

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

The documentation for this class was generated from the following file:

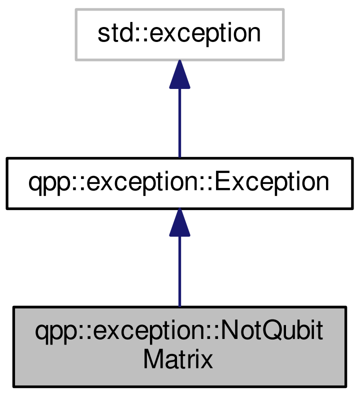
- classes/exception.h

## 7.37 qpp::exception::NotQubitMatrix Class Reference

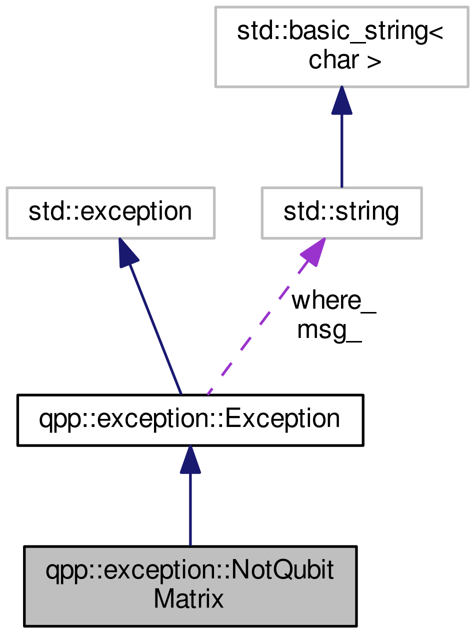
Matrix is not 2 x 2 exception.

```
#include <classes/exception.h>
```

Inheritance diagram for qpp::exception::NotQubitMatrix:



Collaboration diagram for qpp::exception::NotQubitMatrix:




## Public Member Functions

- std::string type_description () const override

  *Exception type description.*

### 7.37.1 Detailed Description

Matrix is not 2 x 2 exception.

Eigen::Matrix is not 2 x 2

### 7.37.2 Member Function Documentation

#### 7.37.2.1 type_description()

```
std::string qpp::exception::NotQubitMatrix::type_description ( ) const  [inline], [override],
[virtual]
```

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

The documentation for this class was generated from the following file:

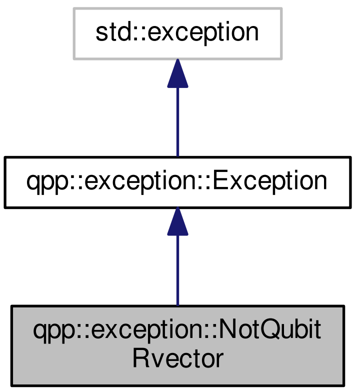
- classes/exception.h

## 7.38 qpp::exception::NotQubitRvector Class Reference

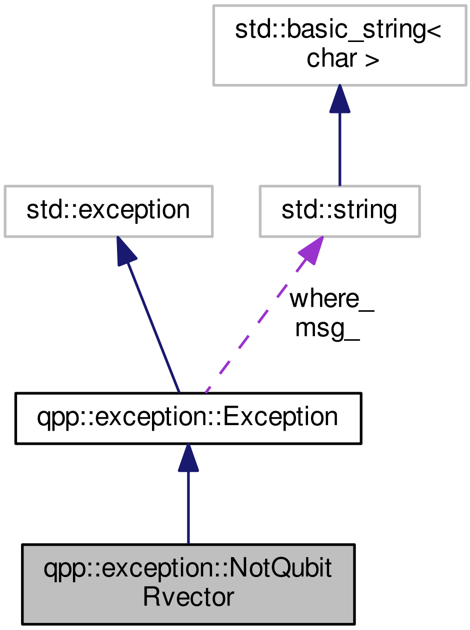
Row vector is not 1 x 2 exception.

```
#include <classes/exception.h>
```

Inheritance diagram for qpp::exception::NotQubitRvector:



Collaboration diagram for qpp::exception::NotQubitRvector:




## Public Member Functions

- std::string type_description () const override

    *Exception type description.*

### 7.38.1 Detailed Description

Row vector is not 1 x 2 exception.

Eigen::Matrix is not 1 x 2

### 7.38.2 Member Function Documentation

#### 7.38.2.1 type_description()

```
std::string qpp::exception::NotQubitRvector::type_description ( ) const  [inline], [override],
[virtual]
```

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

The documentation for this class was generated from the following file:

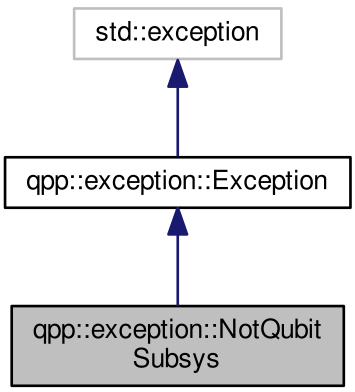
- classes/exception.h

## 7.39 qpp::exception::NotQubitSubsys Class Reference

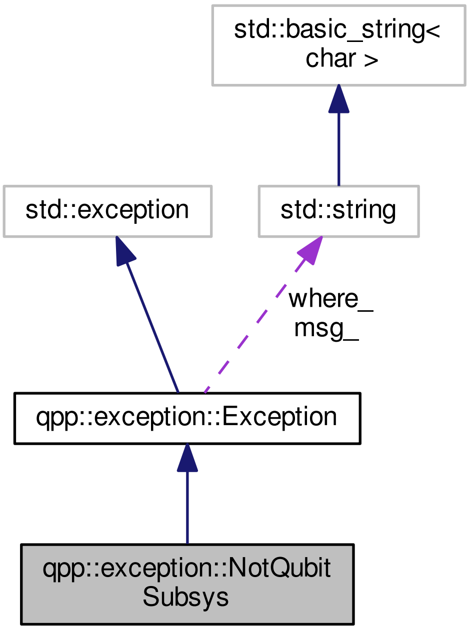
Subsystems are not qubits exception.

```
#include <classes/exception.h>
```

Inheritance diagram for qpp::exception::NotQubitSubsys:



Collaboration diagram for qpp::exception::NotQubitSubsys:




## Public Member Functions

- std::string type_description () const override

  *Exception type description.*

### 7.39.1 Detailed Description

Subsystems are not qubits exception.

Subsystems are not 2-dimensional (qubits)

### 7.39.2 Member Function Documentation

#### 7.39.2.1 type_description()

```
std::string qpp::exception::NotQubitSubsys::type_description ( ) const  [inline], [override],
[virtual]
```

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

The documentation for this class was generated from the following file:

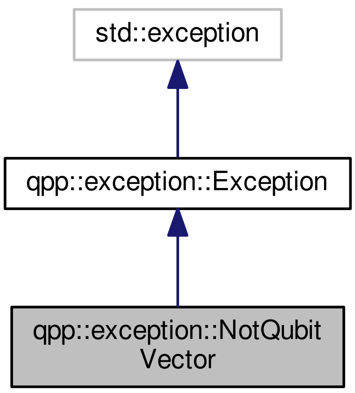
- classes/exception.h

## 7.40 qpp::exception::NotQubitVector Class Reference

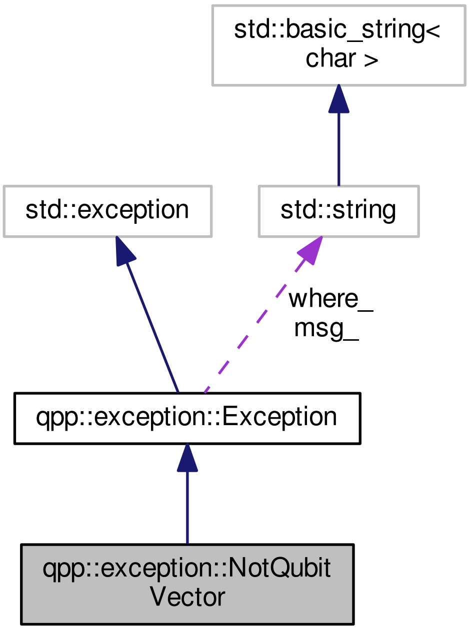
Vector is not 2 x 1 nor 1 x 2 exception.

```
#include <classes/exception.h>
```

Inheritance diagram for qpp::exception::NotQubitVector:



Collaboration diagram for qpp::exception::NotQubitVector:




## Public Member Functions

- std::string type_description () const override

    *Exception type description.*

### 7.40.1 Detailed Description

Vector is not 2 x 1 nor 1 x 2 exception.

Eigen::Matrix is not 2 x 1 nor 1 x 2

### 7.40.2 Member Function Documentation

#### 7.40.2.1 type_description()

```
std::string qpp::exception::NotQubitVector::type_description ( ) const [inline], [override],
[virtual]
```

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

The documentation for this class was generated from the following file:

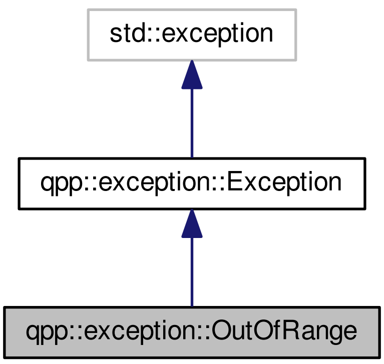
- classes/exception.h

## 7.41 qpp::exception::OutOfRange Class Reference

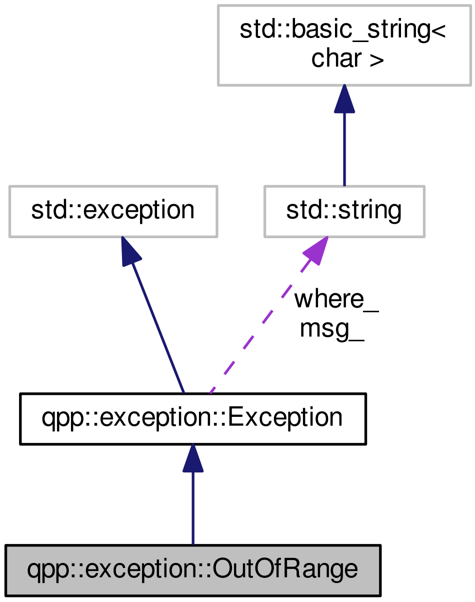
Parameter out of range exception.

```
#include <classes/exception.h>
```

Inheritance diagram for qpp::exception::OutOfRange:



Collaboration diagram for qpp::exception::OutOfRange:




## Public Member Functions

- std::string type_description () const override

  *Exception type description.*

### 7.41.1 Detailed Description

Parameter out of range exception.

Parameter out of range

### 7.41.2 Member Function Documentation

#### 7.41.2.1 type_description()

```
std::string qpp::exception::OutOfRange::type_description ( ) const  [inline], [override],
[virtual]
```

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

The documentation for this class was generated from the following file:

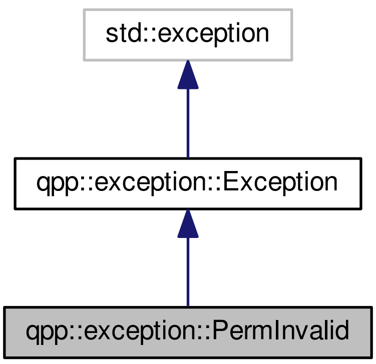
- classes/exception.h

## 7.42 qpp::exception::PermInvalid Class Reference

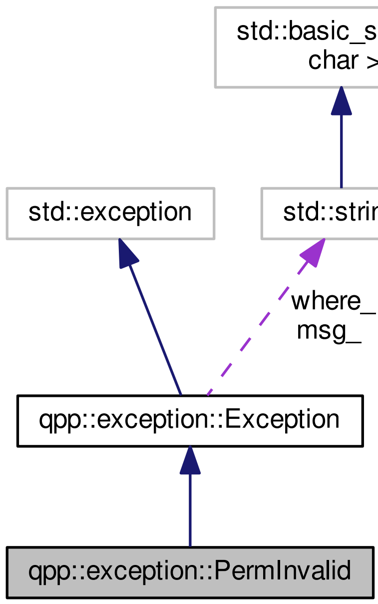
Invalid permutation exception.

```
#include <classes/exception.h>
```

Inheritance diagram for qpp::exception::PermInvalid:



Collaboration diagram for qpp::exception::PermInvalid:




## Public Member Functions

- std::string type_description () const override

    *Exception type description.*

### 7.42.1 Detailed Description

Invalid permutation exception.

std::vector<idx> does note represent a valid permutation

### 7.42.2 Member Function Documentation

#### 7.42.2.1 type_description()

```
std::string qpp::exception::PermInvalid::type_description ( ) const  [inline], [override],
[virtual]
```

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

The documentation for this class was generated from the following file:

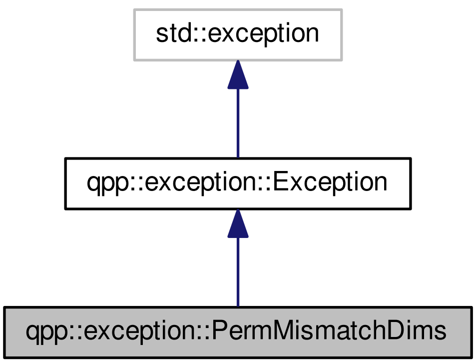
- classes/exception.h

## 7.43 qpp::exception::PermMismatchDims Class Reference

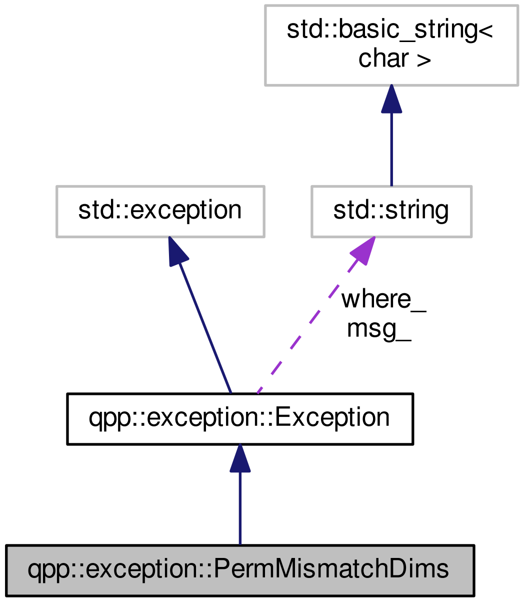
Permutation mismatch dimensions exception.

```
#include <classes/exception.h>
```

Inheritance diagram for qpp::exception::PermMismatchDims:



Collaboration diagram for qpp::exception::PermMismatchDims:




## Public Member Functions

- std::string type_description () const override

  *Exception type description.*

### 7.43.1 Detailed Description

Permutation mismatch dimensions exception.

Size of the std::vector<idx> representing the permutation is different from the size of the std::vector<idx> of dimensions

### 7.43.2 Member Function Documentation

#### 7.43.2.1 type_description()

```
std::string qpp::exception::PermMismatchDims::type_description ( ) const  [inline], [override],
[virtual]
```

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

The documentation for this class was generated from the following file:

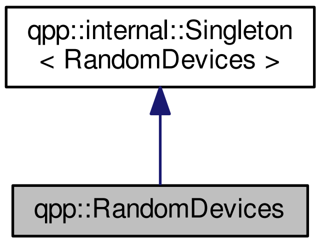
- classes/exception.h

## 7.44 qpp::RandomDevices Class Reference

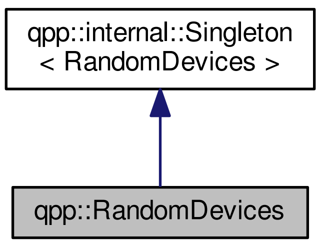
Singleton class that manages the source of randomness in the library.

```
#include <classes/random_devices.h>
```

Inheritance diagram for qpp::RandomDevices:




Collaboration diagram for qpp::RandomDevices:



### Public Member Functions

- std::mt19937 & get_prng ()
  *Returns a reference to the internal PRNG object.*
- std::istream & load (std::istream &is)
  *Loads the state of the PRNG from an input stream.*
- std::ostream & save (std::ostream &os) const
  *Saves the state of the PRNG to an output stream.*

### Private Member Functions

- RandomDevices ()
  *Initializes and seeds the random number generators.*
- ∼RandomDevices ()=default
  *Default destructor.*

### Private Attributes

- std::random_device rd_
  *used to seed std::mt19937 prng_*
- std::mt19937 prng_
  *Mersenne twister random number generator.*

### Friends

- class internal::Singleton< RandomDevices >

### Additional Inherited Members

## 7.44.1 Detailed Description

Singleton class that manages the source of randomness in the library.

Consists of a wrapper around an std::mt19937 Mersenne twister random number generator engine and an std↩ ::random_device engine. The latter is used to seed the Mersenne twister.

**Warning**

This class DOES NOT seed the standard C number generator used by Eigen::Matrix::Random(), since it is not thread safe. Do not use Eigen::Matrix::Random() or functions that depend on the C style random number engine, but use qpp::rand() instead!

## 7.44.2 Constructor & Destructor Documentation

#### 7.44.2.1 RandomDevices()

```
qpp::RandomDevices::RandomDevices ( ) [inline], [private]
```

Initializes and seeds the random number generators.

#### 7.44.2.2 ∼RandomDevices()

```
qpp::RandomDevices::∼RandomDevices ( ) [private], [default]
```

Default destructor.

### 7.44.3 Member Function Documentation

#### 7.44.3.1 get_prng()

```
std::mt19937& qpp::RandomDevices::get_prng ( ) [inline]
```

Returns a reference to the internal PRNG object.

**Returns**

Reference to the internal PRNG object

#### 7.44.3.2 load()

```
std::istream& qpp::RandomDevices::load (
            std::istream & is ) [inline]
```

Loads the state of the PRNG from an input stream.

**Parameters**

| | |
|---|---|
| *is* | Input stream |

**Returns**

The input stream

#### 7.44.3.3 save()

```
std::ostream& qpp::RandomDevices::save (
            std::ostream & os ) const  [inline]
```

Saves the state of the PRNG to an output stream.

**Parameters**

| | |
|---|---|
| *os* | Output stream |

**Returns**

The output stream

### 7.44.4 Friends And Related Function Documentation

#### 7.44.4.1 internal::Singleton< RandomDevices >

```
friend class internal::Singleton< RandomDevices >  [friend]
```

### 7.44.5 Member Data Documentation

#### 7.44.5.1 prng_

```
std::mt19937 qpp::RandomDevices::prng_  [private]
```

Mersenne twister random number generator.

#### 7.44.5.2 rd_

```
std::random_device qpp::RandomDevices::rd_  [private]
```

used to seed std::mt19937 prng_

The documentation for this class was generated from the following file:

- classes/random_devices.h

## 7.45 qpp::internal::Singleton< T > Class Template Reference

Singleton policy class, used internally to implement the singleton pattern via CRTP (Curiously recurring template pattern)

`#include <internal/classes/singleton.h>`

### Static Public Member Functions

- static T & get_instance () noexcept(std::is_nothrow_constructible< T >::value)
- static T & get_thread_local_instance () noexcept(std::is_nothrow_constructible< T >::value)

### Protected Member Functions

- Singleton () noexcept=default
- Singleton (const Singleton &)=delete
- Singleton & operator= (const Singleton &)=delete
- virtual ~Singleton ()=default

### 7.45.1 Detailed Description

**template<typename T>**
**class qpp::internal::Singleton< T >**

Singleton policy class, used internally to implement the singleton pattern via CRTP (Curiously recurring template pattern)

To implement a singleton, derive your class from qpp::internal::Singleton, make qpp::internal::Singleton a friend of your class, then declare the constructor and destructor of your class as private. To get an instance, use the static member function qpp::internal::Singleton::get_instance() (qpp::internal::Singleton::get_thread_local_instance()), which returns a reference (thread_local reference) to your newly created singleton (thread-safe in C++11).

Example:

```
class MySingleton: public qpp::internal::Singleton<MySingleton>
{
       friend class qpp::internal::Singleton<MySingleton>;
public:
    // Declare all public members here
private:
    MySingleton()
    {
        // Implement the constructor here
    }
    ~MySingleton()
    {
        // Implement the destructor here
    }
};

MySingleton& mySingleton = MySingleton::get_instance(); // Get an instance
thread_local MySingleton& tls = MySingleton::get_thread_local_instance();
// Get a thread_local instance
```

**See also**

Code of qpp::Codes, qpp::Gates, qpp::Init, qpp::RandomDevices, qpp::States or qpp.h for real world examples of usage.

### 7.45.2 Constructor & Destructor Documentation

#### 7.45.2.1 Singleton() [1/2]

```
template<typename T>
qpp::internal::Singleton< T >::Singleton ( )  [protected], [default], [noexcept]
```

#### 7.45.2.2 Singleton() [2/2]

```
template<typename T>
qpp::internal::Singleton< T >::Singleton (
            const Singleton< T > &  )  [protected], [delete]
```

#### 7.45.2.3 ∼Singleton()

```
template<typename T>
virtual qpp::internal::Singleton< T >::~Singleton ( )  [protected], [virtual], [default]
```

### 7.45.3 Member Function Documentation

#### 7.45.3.1 get_instance()

```
template<typename T>
static T& qpp::internal::Singleton< T >::get_instance ( )  [inline], [static], [noexcept]
```

#### 7.45.3.2 get_thread_local_instance()

```
template<typename T>
static T& qpp::internal::Singleton< T >::get_thread_local_instance ( )  [inline], [static],
[noexcept]
```

#### 7.45.3.3 operator=()

```
template<typename T>
Singleton& qpp::internal::Singleton< T >::operator= (
            const Singleton< T > &  )  [protected], [delete]
```

The documentation for this class was generated from the following file:

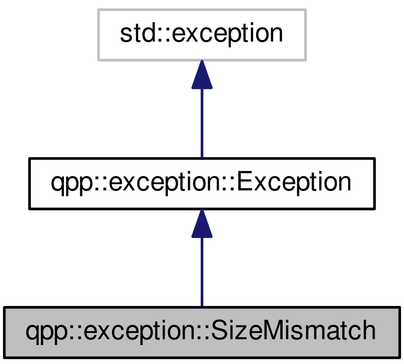
- internal/classes/singleton.h

## 7.46 qpp::exception::SizeMismatch Class Reference

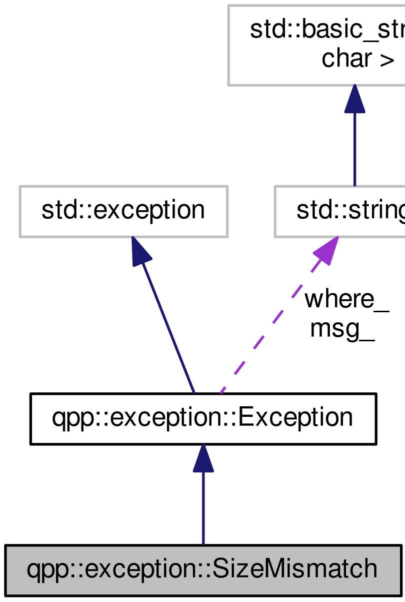
Size mismatch exception.

```
#include <classes/exception.h>
```

Inheritance diagram for qpp::exception::SizeMismatch:



Collaboration diagram for qpp::exception::SizeMismatch:




## Public Member Functions

- std::string type_description () const override
  *Exception type description.*

### 7.46.1 Detailed Description

Size mismatch exception.

Sizes do not match

### 7.46.2 Member Function Documentation

#### 7.46.2.1 type_description()

`std::string qpp::exception::SizeMismatch::type_description ( ) const [inline], [override], [virtual]`

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

The documentation for this class was generated from the following file:

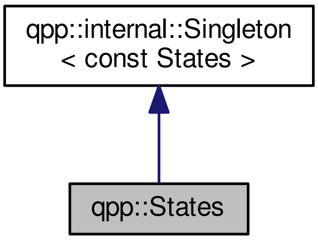
- classes/exception.h

## 7.47 qpp::States Class Reference

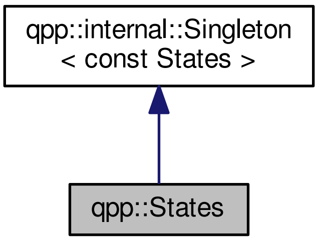
const Singleton class that implements most commonly used states

`#include <classes/states.h>`

Inheritance diagram for qpp::States:




Collaboration diagram for qpp::States:



## Public Member Functions

- ket mes (idx d=2) const

  *Maximally entangled state of 2 qudits.*
- ket zero (idx n, idx d=2) const

  *Zero state of n qudits.*
- ket one (idx n, idx d=2) const

  *One state of n qudits.*
- ket jn (idx j, idx n, idx d=2) const

  $|j\rangle^{\otimes n}$ *state of n qudits*
- ket plus (idx n) const

  *Plus state of n qubits.*
- ket minus (idx n) const

  *Minus state of n qubits.*

## Public Attributes

- ket x0 {ket::Zero(2)}

  *Pauli Sigma-X 0-eigenstate |+>*
- ket x1 {ket::Zero(2)}

  *Pauli Sigma-X 1-eigenstate |->*
- ket y0 {ket::Zero(2)}

  *Pauli Sigma-Y 0-eigenstate |y+>*
- ket y1 {ket::Zero(2)}

  *Pauli Sigma-Y 1-eigenstate |y->*
- ket z0 {ket::Zero(2)}

  *Pauli Sigma-Z 0-eigenstate |0>*
- ket z1 {ket::Zero(2)}

  *Pauli Sigma-Z 1-eigenstate |1>*
- cmat px0 {cmat::Zero(2, 2)}

  *Projector onto the Pauli Sigma-X 0-eigenstate |+><+|.*
- cmat px1 {cmat::Zero(2, 2)}

  *Projector onto the Pauli Sigma-X 1-eigenstate |-><-|.*
- cmat py0 {cmat::Zero(2, 2)}

  *Projector onto the Pauli Sigma-Y 0-eigenstate |y+><y+|.*
- cmat py1 {cmat::Zero(2, 2)}

  *Projector onto the Pauli Sigma-Y 1-eigenstate |y-><y-|.*
- cmat pz0 {cmat::Zero(2, 2)}

  *Projector onto the Pauli Sigma-Z 0-eigenstate |0><0|.*
- cmat pz1 {cmat::Zero(2, 2)}

  *Projector onto the Pauli Sigma-Z 1-eigenstate |1><1|.*
- ket b00 {ket::Zero(4)}

  *Bell-00 state (following the convention in Nielsen and Chuang)*
- ket b01 {ket::Zero(4)}

  *Bell-01 state (following the convention in Nielsen and Chuang)*
- ket b10 {ket::Zero(4)}

  *Bell-10 state (following the convention in Nielsen and Chuang)*
- ket b11 {ket::Zero(4)}

  *Bell-11 state (following the convention in Nielsen and Chuang)*
- cmat pb00 {cmat::Zero(4, 4)}

Projector onto the Bell-00 state.
- cmat pb01 {cmat::Zero(4, 4)}

  *Projector onto the Bell-01 state.*
- cmat pb10 {cmat::Zero(4, 4)}

  *Projector onto the Bell-10 state.*
- cmat pb11 {cmat::Zero(4, 4)}

  *Projector onto the Bell-11 state.*
- ket GHZ {ket::Zero(8)}

  *GHZ state.*
- ket W {ket::Zero(8)}

  *W state.*
- cmat pGHZ {cmat::Zero(8, 8)}

  *Projector onto the GHZ state.*
- cmat pW {cmat::Zero(8, 8)}

  *Projector onto the W state.*

## Private Member Functions

- States ()
- ∼States ()=default

  *Default destructor.*

## Friends

- class internal::Singleton< const States >

## Additional Inherited Members

### 7.47.1 Detailed Description

const Singleton class that implements most commonly used states

### 7.47.2 Constructor & Destructor Documentation

#### 7.47.2.1 States()

```
qpp::States::States ( )  [inline], [private]
```

Initialize the states

#### 7.47.2.2 ∼States()

```
qpp::States::∼States ( )  [private], [default]
```

Default destructor.

### 7.47.3 Member Function Documentation

#### 7.47.3.1 jn()

```
ket qpp::States::jn (
            idx j,
            idx n,
            idx d = 2 ) const [inline]
```

$|j\rangle^{\otimes n}$ state of *n* qudits

**Parameters**

| | |
|---|---|
| *j* | Non-negative integer |
| *n* | Non-negative integer |
| *d* | Subsystem dimensions |

**Returns**

$|j\rangle^{\otimes n}$ state of *n* qudits

#### 7.47.3.2 mes()

```
ket qpp::States::mes (
            idx d = 2 ) const [inline]
```

Maximally entangled state of 2 qudits.

**Parameters**

| | |
|---|---|
| *d* | Subsystem dimensions |

**Returns**

Maximally entangled state $\frac{1}{\sqrt{d}}\sum_{j=0}^{d-1}|jj\rangle$ of 2 qudits

#### 7.47.3.3 minus()

```
ket qpp::States::minus (
            idx n ) const [inline]
```

Minus state of *n* qubits.

**Parameters**

| | |
|---|---|
| *n* | Non-negative integer |

**Returns**

Minus state $|-\rangle^{\otimes n}$ of *n* qubits

#### 7.47.3.4 one()

```
ket qpp::States::one (
            idx n,
            idx d = 2 ) const  [inline]
```

One state of *n* qudits.

**Parameters**

| | |
|---|---|
| *n* | Non-negative integer |
| *d* | Subsystem dimensions |

**Returns**

One state $|1\rangle^{\otimes n}$ of *n* qudits

#### 7.47.3.5 plus()

```
ket qpp::States::plus (
            idx n ) const  [inline]
```

Plus state of *n* qubits.

**Parameters**

| | |
|---|---|
| *n* | Non-negative integer |

**Returns**

Plus state $|+\rangle^{\otimes n}$ of *n* qubits

#### 7.47.3.6 zero()

```
ket qpp::States::zero (
            idx n,
            idx d = 2 ) const  [inline]
```

Zero state of *n* qudits.

**Parameters**

| | |
|---|---|
| *n* | Non-negative integer |
| *d* | Subsystem dimensions |

**Returns**

Zero state $|0\rangle^{\otimes n}$ of *n* qudits

### 7.47.4 Friends And Related Function Documentation

#### 7.47.4.1 internal::Singleton< const States >

```
friend class internal::Singleton< const States >  [friend]
```

### 7.47.5 Member Data Documentation

#### 7.47.5.1 b00

```
ket qpp::States::b00 {ket::Zero(4)}
```

Bell-00 state (following the convention in Nielsen and Chuang)

#### 7.47.5.2 b01

```
ket qpp::States::b01 {ket::Zero(4)}
```

Bell-01 state (following the convention in Nielsen and Chuang)

#### 7.47.5.3 b10

```
ket qpp::States::b10 {ket::Zero(4)}
```

Bell-10 state (following the convention in Nielsen and Chuang)

#### 7.47.5.4 b11

```
ket qpp::States::b11 {ket::Zero(4)}
```

Bell-11 state (following the convention in Nielsen and Chuang)

#### 7.47.5.5 GHZ

```
ket qpp::States::GHZ {ket::Zero(8)}
```

GHZ state.

#### 7.47.5.6 pb00

```
cmat qpp::States::pb00 {cmat::Zero(4, 4)}
```

Projector onto the Bell-00 state.

#### 7.47.5.7 pb01

```
cmat qpp::States::pb01 {cmat::Zero(4, 4)}
```

Projector onto the Bell-01 state.

#### 7.47.5.8 pb10

```
cmat qpp::States::pb10 {cmat::Zero(4, 4)}
```

Projector onto the Bell-10 state.

#### 7.47.5.9 pb11

```
cmat qpp::States::pb11 {cmat::Zero(4, 4)}
```

Projector onto the Bell-11 state.

#### 7.47.5.10 pGHZ

```
cmat qpp::States::pGHZ {cmat::Zero(8, 8)}
```

Projector onto the GHZ state.

#### 7.47.5.11 pW

```
cmat qpp::States::pW {cmat::Zero(8, 8)}
```

Projector onto the W state.

#### 7.47.5.12 px0

```
cmat qpp::States::px0 {cmat::Zero(2, 2)}
```

Projector onto the Pauli Sigma-X 0-eigenstate |+><+|.

#### 7.47.5.13 px1

```
cmat qpp::States::px1 {cmat::Zero(2, 2)}
```

Projector onto the Pauli Sigma-X 1-eigenstate |-><-|.

#### 7.47.5.14 py0

```
cmat qpp::States::py0 {cmat::Zero(2, 2)}
```

Projector onto the Pauli Sigma-Y 0-eigenstate |y+><y+|.

#### 7.47.5.15 py1

```
cmat qpp::States::py1 {cmat::Zero(2, 2)}
```

Projector onto the Pauli Sigma-Y 1-eigenstate |y-><y-|.

#### 7.47.5.16 pz0

```
cmat qpp::States::pz0 {cmat::Zero(2, 2)}
```

Projector onto the Pauli Sigma-Z 0-eigenstate |0><0|.

#### 7.47.5.17 pz1

```
cmat qpp::States::pz1 {cmat::Zero(2, 2)}
```

Projector onto the Pauli Sigma-Z 1-eigenstate |1><1|.

#### 7.47.5.18 W

```
ket qpp::States::W {ket::Zero(8)}
```

W state.

#### 7.47.5.19 x0

```
ket qpp::States::x0 {ket::Zero(2)}
```

Pauli Sigma-X 0-eigenstate |+>

#### 7.47.5.20 x1

```
ket qpp::States::x1 {ket::Zero(2)}
```

Pauli Sigma-X 1-eigenstate |->

#### 7.47.5.21 y0

```
ket qpp::States::y0 {ket::Zero(2)}
```

Pauli Sigma-Y 0-eigenstate |y+>

#### 7.47.5.22 y1

```
ket qpp::States::y1 {ket::Zero(2)}
```

Pauli Sigma-Y 1-eigenstate |y->

#### 7.47.5.23 z0

```
ket qpp::States::z0 {ket::Zero(2)}
```

Pauli Sigma-Z 0-eigenstate |0>

#### 7.47.5.24 z1

```
ket qpp::States::z1 {ket::Zero(2)}
```

Pauli Sigma-Z 1-eigenstate |1>

The documentation for this class was generated from the following file:

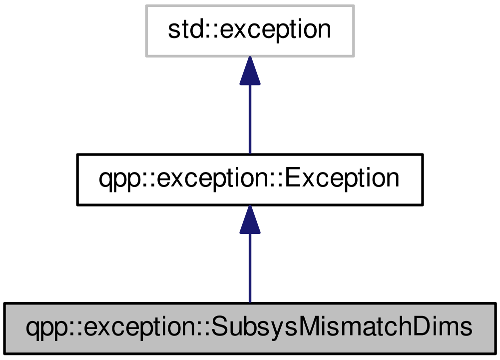
- classes/states.h

## 7.48 qpp::exception::SubsysMismatchDims Class Reference

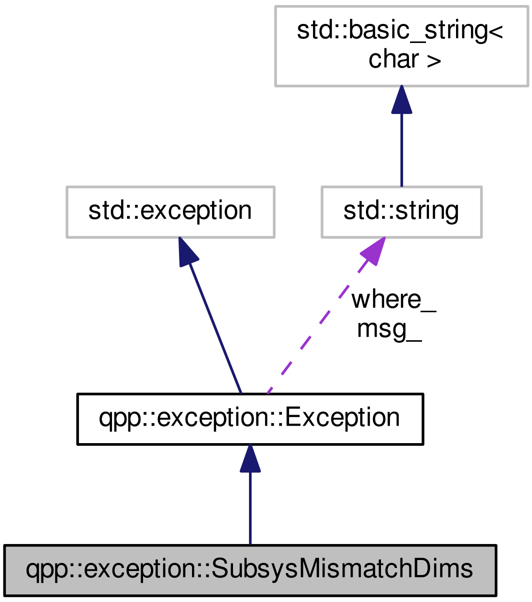
Subsystems mismatch dimensions exception.

```
#include <classes/exception.h>
```

Inheritance diagram for qpp::exception::SubsysMismatchDims:




Collaboration diagram for qpp::exception::SubsysMismatchDims:



### Public Member Functions

- std::string type_description () const override
  *Exception type description.*

## 7.48.1 Detailed Description

Subsystems mismatch dimensions exception.

std::vector<idx> of subsystem labels has duplicates, or has entries that are larger than the size of the std↩ ::vector<idx> of dimensions

## 7.48.2 Member Function Documentation

### 7.48.2.1 type_description()

```
std::string qpp::exception::SubsysMismatchDims::type_description ( ) const  [inline], [override],
[virtual]
```

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

The documentation for this class was generated from the following file:

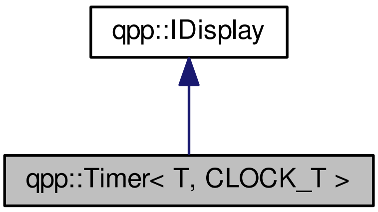
- classes/exception.h

# 7.49 qpp::Timer< T, CLOCK_T > Class Template Reference

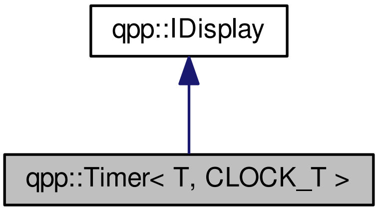
Chronometer.

```
#include <classes/timer.h>
```

Inheritance diagram for qpp::Timer< T, CLOCK_T >:



Collaboration diagram for qpp::Timer< T, CLOCK_T >:




## Public Member Functions

- Timer () noexcept
  *Constructs an instance with the current time as the starting point.*
- void tic () noexcept
  *Resets the chronometer.*
- const Timer & toc () noexcept
  *Stops the chronometer.*
- double tics () const noexcept
  *Time passed in the duration specified by T.*
- template<typename U = T>
  U get_duration () const noexcept
  *Duration specified by U.*
- Timer (const Timer &)=default
  *Default copy constructor.*
- Timer (Timer &&)=default
  *Default move constructor.*
- Timer & operator= (const Timer &)=default
  *Default copy assignment operator.*
- Timer & operator= (Timer &&)=default
  *Default move assignment operator.*
- virtual ~Timer ()=default
  *Default virtual destructor.*

## Protected Attributes

- CLOCK_T::time_point start_
- CLOCK_T::time_point end_

## Private Member Functions

- std::ostream & display (std::ostream &os) const override
  *qpp::IDisplay::display() override*

### 7.49.1 Detailed Description

**template<typename T = std::chrono::duration<double>, typename CLOCK_T = std::chrono::steady_clock>**
**class qpp::Timer< T, CLOCK_T >**

Chronometer.

**Template Parameters**

| | |
|---|---|
| *T* | Tics duration, default is std::chrono::duration<double, 1>, i.e. seconds in double precision |
| *CLOCK←_T* | Clock's type, default is std::chrono::steady_clock, not affected by wall clock changes during runtime |

### 7.49.2 Constructor & Destructor Documentation

#### 7.49.2.1 Timer() [1/3]

```
template<typename T = std::chrono::duration<double>, typename CLOCK_T = std::chrono::steady↩
_clock>
qpp::Timer< T, CLOCK_T >::Timer ( ) [inline], [noexcept]
```

Constructs an instance with the current time as the starting point.

#### 7.49.2.2 Timer() [2/3]

```
template<typename T = std::chrono::duration<double>, typename CLOCK_T = std::chrono::steady↩
_clock>
qpp::Timer< T, CLOCK_T >::Timer (
             const Timer< T, CLOCK_T > & ) [default]
```

Default copy constructor.

#### 7.49.2.3 Timer() [3/3]

```
template<typename T = std::chrono::duration<double>, typename CLOCK_T = std::chrono::steady↩
_clock>
qpp::Timer< T, CLOCK_T >::Timer (
             Timer< T, CLOCK_T > && ) [default]
```

Default move constructor.

#### 7.49.2.4 ∼Timer()

```
template<typename T = std::chrono::duration<double>, typename CLOCK_T = std::chrono::steady↩
_clock>
virtual qpp::Timer< T, CLOCK_T >::∼Timer ( )  [virtual], [default]
```

Default virtual destructor.

### 7.49.3 Member Function Documentation

#### 7.49.3.1 display()

```
template<typename T = std::chrono::duration<double>, typename CLOCK_T = std::chrono::steady↩
_clock>
std::ostream& qpp::Timer< T, CLOCK_T >::display (
            std::ostream & os ) const  [inline], [override], [private], [virtual]
```

qpp::IDisplay::display() override

**Parameters**

| | |
|---|---|
| *os* | Output stream |

**Returns**

Writes to the output stream the number of tics (specified by T) that passed between the instantiation/reset and invocation of qpp::Timer::toc().

Implements qpp::IDisplay.

#### 7.49.3.2 get_duration()

```
template<typename T = std::chrono::duration<double>, typename CLOCK_T = std::chrono::steady↩
_clock>
template<typename U = T>
U qpp::Timer< T, CLOCK_T >::get_duration ( ) const  [inline], [noexcept]
```

Duration specified by U.

**Template Parameters**

| | |
|---|---|
| *U* | Duration, default is T, which defaults to std::chrono::duration<double, 1>, i.e. seconds in double precision |

**Returns**

Duration that passed between the instantiation/reset and invocation of qpp::Timer::toc()

#### 7.49.3.3 operator=() [1/2]

```
template<typename T = std::chrono::duration<double>, typename CLOCK_T = std::chrono::steady↩
_clock>
Timer& qpp::Timer< T, CLOCK_T >::operator= (
             const Timer< T, CLOCK_T > &  )  [default]
```

Default copy assignment operator.

#### 7.49.3.4 operator=() [2/2]

```
template<typename T = std::chrono::duration<double>, typename CLOCK_T = std::chrono::steady↩
_clock>
Timer& qpp::Timer< T, CLOCK_T >::operator= (
             Timer< T, CLOCK_T > &&  )  [default]
```

Default move assignment operator.

#### 7.49.3.5 tic()

```
template<typename T = std::chrono::duration<double>, typename CLOCK_T = std::chrono::steady↩
_clock>
void qpp::Timer< T, CLOCK_T >::tic ( )  [inline], [noexcept]
```

Resets the chronometer.

Resets the starting/ending point to the current time

#### 7.49.3.6 tics()

```
template<typename T = std::chrono::duration<double>, typename CLOCK_T = std::chrono::steady↩
_clock>
double qpp::Timer< T, CLOCK_T >::tics ( ) const  [inline], [noexcept]
```

Time passed in the duration specified by T.

**Returns**

Number of tics (specified by T) that passed between the instantiation/reset and invocation of qpp::Timer::toc()

#### 7.49.3.7 toc()

```
template<typename T = std::chrono::duration<double>, typename CLOCK_T = std::chrono::steady↩
_clock>
const Timer& qpp::Timer< T, CLOCK_T >::toc ( )  [inline], [noexcept]
```

Stops the chronometer.

Set the current time as the ending point

**Returns**

Reference to the current instance

### 7.49.4 Member Data Documentation

#### 7.49.4.1 end_

```
template<typename T = std::chrono::duration<double>, typename CLOCK_T = std::chrono::steady↩
_clock>
CLOCK_T::time_point qpp::Timer< T, CLOCK_T >::end_  [protected]
```

#### 7.49.4.2 start_

```
template<typename T = std::chrono::duration<double>, typename CLOCK_T = std::chrono::steady↩
_clock>
CLOCK_T::time_point qpp::Timer< T, CLOCK_T >::start_  [protected]
```

The documentation for this class was generated from the following file:

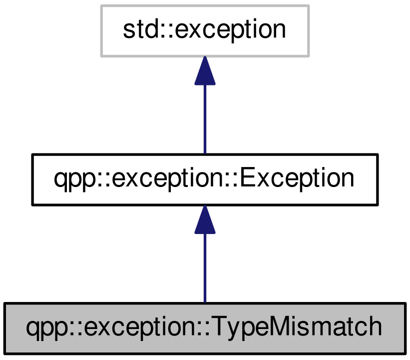
- classes/timer.h

## 7.50 qpp::exception::TypeMismatch Class Reference

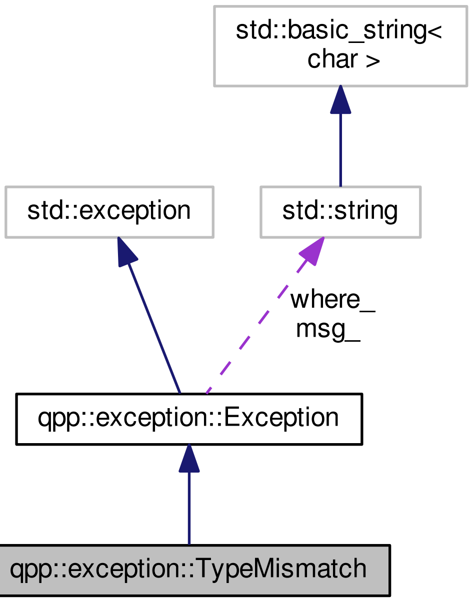
Type mismatch exception.

`#include <classes/exception.h>`

Inheritance diagram for qpp::exception::TypeMismatch:




Collaboration diagram for qpp::exception::TypeMismatch:



### Public Member Functions

- std::string type_description () const override

  *Exception type description.*

### 7.50.1 Detailed Description

Type mismatch exception.

Scalar types do not match

### 7.50.2 Member Function Documentation

#### 7.50.2.1 type_description()

```
std::string qpp::exception::TypeMismatch::type_description ( ) const  [inline], [override],
[virtual]
```

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

The documentation for this class was generated from the following file:

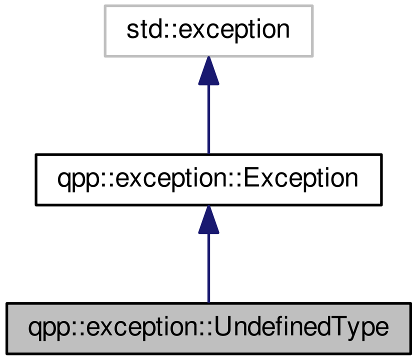
- classes/exception.h

## 7.51 qpp::exception::UndefinedType Class Reference

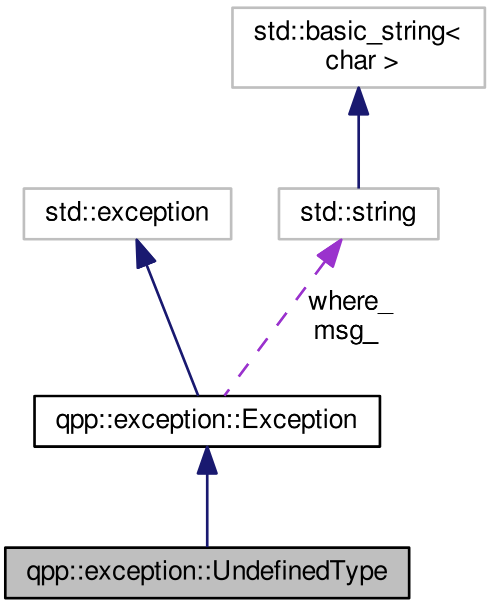
Not defined for this type exception.

```
#include <classes/exception.h>
```

Inheritance diagram for qpp::exception::UndefinedType:




Collaboration diagram for qpp::exception::UndefinedType:




## Public Member Functions

- std::string type_description () const override
  *Exception type description.*

### 7.51.1 Detailed Description

Not defined for this type exception.

Templated specialization is not defined for this type

### 7.51.2 Member Function Documentation

#### 7.51.2.1 type_description()

`std::string qpp::exception::UndefinedType::type_description ( ) const [inline], [override], [virtual]`

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

The documentation for this class was generated from the following file:

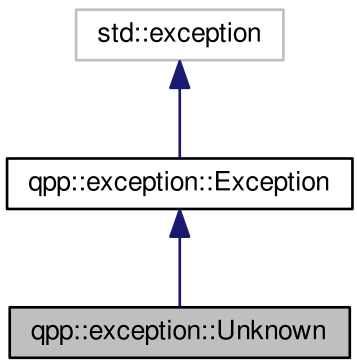
- classes/exception.h

## 7.52 qpp::exception::Unknown Class Reference

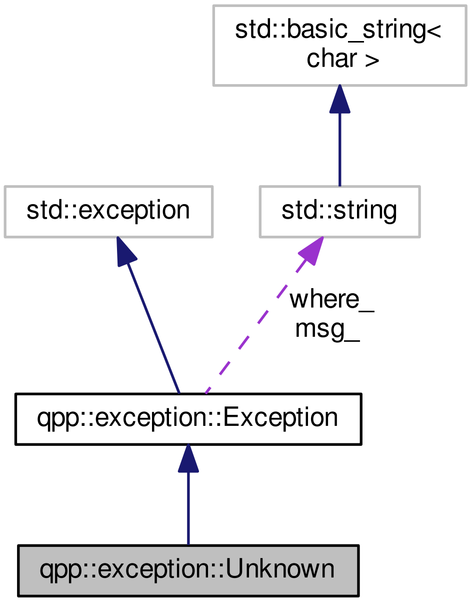
Unknown exception.

`#include <classes/exception.h>`

Inheritance diagram for qpp::exception::Unknown:



Collaboration diagram for qpp::exception::Unknown:




### Public Member Functions

- std::string type_description () const override
  *Exception type description.*

## 7.52.1 Detailed Description

Unknown exception.

Thrown when no other exception is suitable (not recommended, it is better to define another suitable exception type)

## 7.52.2 Member Function Documentation

### 7.52.2.1 type_description()

```
std::string qpp::exception::Unknown::type_description ( ) const  [inline], [override], [virtual]
```

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

The documentation for this class was generated from the following file:

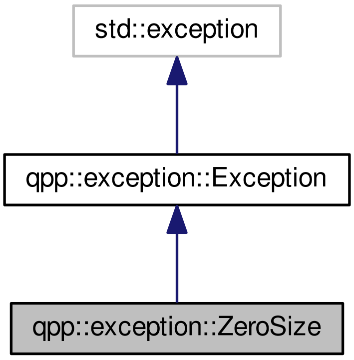
- classes/exception.h

## 7.53 qpp::exception::ZeroSize Class Reference

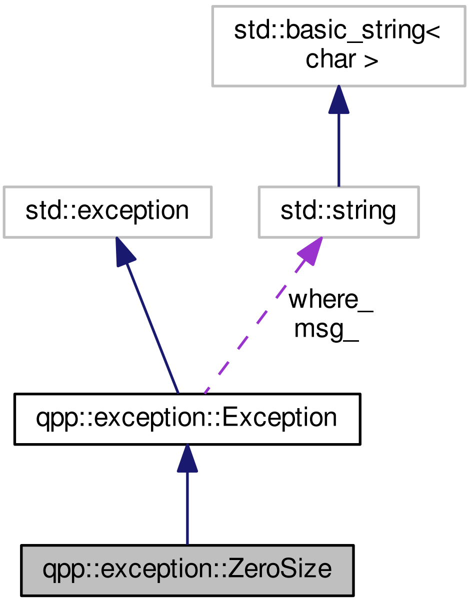
Object has zero size exception.

```
#include <classes/exception.h>
```

Inheritance diagram for qpp::exception::ZeroSize:




Collaboration diagram for qpp::exception::ZeroSize:



## Public Member Functions

- std::string type_description () const override

  *Exception type description.*

### 7.53.1 Detailed Description

Object has zero size exception.

Zero sized object, e.g. empty Eigen::Matrix or std::vector with no elements

### 7.53.2 Member Function Documentation

#### 7.53.2.1 type_description()

```
std::string qpp::exception::ZeroSize::type_description ( ) const  [inline], [override], [virtual]
```

Exception type description.

**Returns**

Exception type description

Implements qpp::exception::Exception.

The documentation for this class was generated from the following file:

- classes/exception.h

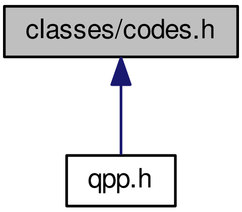
# Chapter 8

# File Documentation

## 8.1 classes/codes.h File Reference

Quantum error correcting codes.

This graph shows which files directly or indirectly include this file:




### Classes

- class qpp::Codes

    *const Singleton class that defines quantum error correcting codes*

### Namespaces

- qpp

    *Quantum++ main namespace.*

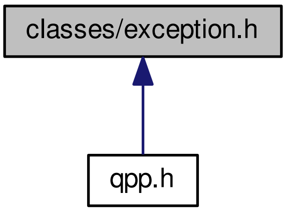
### 8.1.1 Detailed Description

Quantum error correcting codes.

## 8.2 classes/exception.h File Reference

Exceptions.

This graph shows which files directly or indirectly include this file:




### Classes

- class qpp::exception::Exception

  *Base class for generating Quantum++ custom exceptions.*
- class qpp::exception::Unknown

  *Unknown exception.*
- class qpp::exception::ZeroSize

  *Object has zero size exception.*
- class qpp::exception::MatrixNotSquare

  *Matrix is not square exception.*
- class qpp::exception::MatrixNotCvector

  *Matrix is not a column vector exception.*
- class qpp::exception::MatrixNotRvector

  *Matrix is not a row vector exception.*
- class qpp::exception::MatrixNotVector

  *Matrix is not a vector exception.*
- class qpp::exception::MatrixNotSquareNorCvector

  *Matrix is not square nor column vector exception.*
- class qpp::exception::MatrixNotSquareNorRvector

  *Matrix is not square nor row vector exception.*
- class qpp::exception::MatrixNotSquareNorVector

  *Matrix is not square nor vector exception.*
- class qpp::exception::MatrixMismatchSubsys

  *Matrix mismatch subsystems exception.*
- class qpp::exception::DimsInvalid

  *Invalid dimension(s) exception.*
- class qpp::exception::DimsNotEqual

  *Dimensions not equal exception.*
- class qpp::exception::DimsMismatchMatrix

  *Dimension(s) mismatch matrix size exception.*
- class qpp::exception::DimsMismatchCvector

*Dimension(s) mismatch column vector size exception.*
- class qpp::exception::DimsMismatchRvector

  *Dimension(s) mismatch row vector size exception.*
- class qpp::exception::DimsMismatchVector

  *Dimension(s) mismatch vector size exception.*
- class qpp::exception::SubsysMismatchDims

  *Subsystems mismatch dimensions exception.*
- class qpp::exception::PermInvalid

  *Invalid permutation exception.*
- class qpp::exception::PermMismatchDims

  *Permutation mismatch dimensions exception.*
- class qpp::exception::NotQubitMatrix

  *Matrix is not 2 x 2 exception.*
- class qpp::exception::NotQubitCvector

  *Column vector is not 2 x 1 exception.*
- class qpp::exception::NotQubitRvector

  *Row vector is not 1 x 2 exception.*
- class qpp::exception::NotQubitVector

  *Vector is not 2 x 1 nor 1 x 2 exception.*
- class qpp::exception::NotQubitSubsys

  *Subsystems are not qubits exception.*
- class qpp::exception::NotBipartite

  *Not bi-partite exception.*
- class qpp::exception::NoCodeword

  *Codeword does not exist exception.*
- class qpp::exception::OutOfRange

  *Parameter out of range exception.*
- class qpp::exception::TypeMismatch

  *Type mismatch exception.*
- class qpp::exception::SizeMismatch

  *Size mismatch exception.*
- class qpp::exception::UndefinedType

  *Not defined for this type exception.*
- class qpp::exception::CustomException

  *Custom exception.*

## Namespaces

- qpp

  *Quantum++ main namespace.*
- qpp::exception

  *Quantum++ exception hierarchy namespace.*

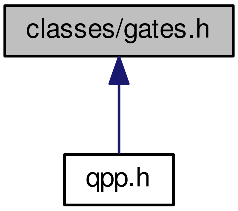
### 8.2.1 Detailed Description

Exceptions.

## 8.3 classes/gates.h File Reference

Quantum gates.

This graph shows which files directly or indirectly include this file:




### Classes

- class qpp::Gates

  *const Singleton class that implements most commonly used gates*

### Namespaces

- qpp

  *Quantum++ main namespace.*

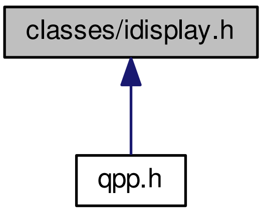
### 8.3.1 Detailed Description

Quantum gates.

## 8.4 classes/idisplay.h File Reference

Display interface via the non-virtual interface (NVI)

This graph shows which files directly or indirectly include this file:



### Classes

- class qpp::IDisplay

    *Abstract class (interface) that mandates the definition of virtual std::ostream& display(std::ostream& os) const.*

### Namespaces

- qpp

    *Quantum++ main namespace.*

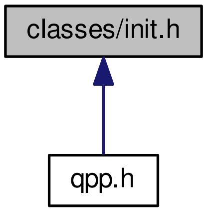
### 8.4.1 Detailed Description

Display interface via the non-virtual interface (NVI)

## 8.5 classes/init.h File Reference

Initialization.

This graph shows which files directly or indirectly include this file:




### Classes

- class qpp::Init

    *const Singleton class that performs additional initializations/cleanups*

### Namespaces

- qpp

    *Quantum++ main namespace.*

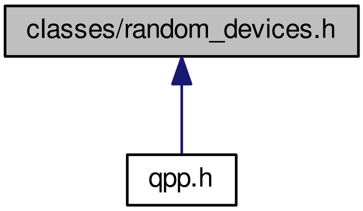
### 8.5.1 Detailed Description

Initialization.

## 8.6 classes/random_devices.h File Reference

Random devices.

This graph shows which files directly or indirectly include this file:




### Classes

- class qpp::RandomDevices

    *Singleton class that manages the source of randomness in the library.*

### Namespaces

- qpp

    *Quantum++ main namespace.*

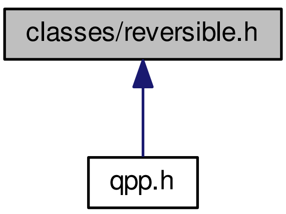
### 8.6.1 Detailed Description

Random devices.

## 8.7 classes/reversible.h File Reference

Support for classical reversible circuits.

This graph shows which files directly or indirectly include this file:



### Classes

- class qpp::Dynamic_bitset

    *Dynamic bitset class, allows the specification of the number of bits at runtime (unlike std::bitset<N>)*
- class qpp::Bit_circuit

    *Classical reversible circuit simulator.*
- struct qpp::Bit_circuit::Gate_count

### Namespaces

- qpp

    *Quantum++ main namespace.*

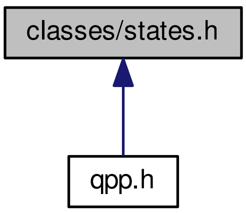
### 8.7.1 Detailed Description

Support for classical reversible circuits.

## 8.8 classes/states.h File Reference

Quantum states.

This graph shows which files directly or indirectly include this file:




### Classes

- class qpp::States

    *const Singleton class that implements most commonly used states*

### Namespaces

- qpp

    *Quantum++ main namespace.*

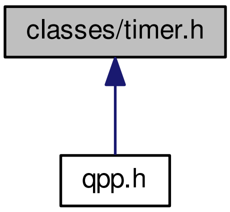
### 8.8.1 Detailed Description

Quantum states.

## 8.9 classes/timer.h File Reference

Timing.

This graph shows which files directly or indirectly include this file:




### Classes

- class qpp::Timer< T, CLOCK_T >

  *Chronometer.*

### Namespaces

- qpp

  *Quantum++ main namespace.*

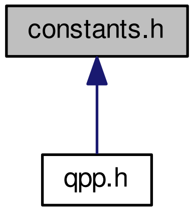
### 8.9.1 Detailed Description

Timing.

## 8.10 constants.h File Reference

Constants.

This graph shows which files directly or indirectly include this file:




### Namespaces

- qpp

  *Quantum++ main namespace.*
- qpp::literals

### Functions

- constexpr cplx qpp::literals::operator"" _i (unsigned long long int x) noexcept

  *User-defined literal for complex* $i = \sqrt{-1}$ *(integer overload)*
- constexpr cplx qpp::operator"" _i (long double x) noexcept

  *User-defined literal for complex* $i = \sqrt{-1}$ *(real overload)*
- cplx qpp::omega (idx D)

  *D-th root of unity.*

### Variables

- constexpr double qpp::chop = 1e-10

  *Used in qpp::disp() for setting to zero numbers that have their absolute value smaller than qpp::chop.*
- constexpr double qpp::eps = 1e-12

  *Used to decide whether a number or expression in double precision is zero or not.*
- constexpr idx qpp::maxn = 64

  *Maximum number of allowed qubits/qudits (subsystems)*
- constexpr double qpp::pi = 3.141592653589793238462643383279502884

  $\pi$
- constexpr double qpp::ee = 2.718281828459045235360287471352662497

  *Base of natural logarithm,* $e$.
- constexpr double qpp::infty = std::numeric_limits<double>::max()

  *Used to denote infinity in double precision.*

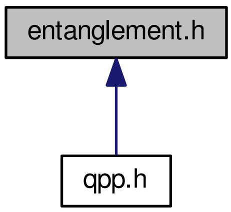
### 8.10.1 Detailed Description

Constants.

## 8.11 entanglement.h File Reference

Entanglement functions.

This graph shows which files directly or indirectly include this file:




### Namespaces

- qpp
  *Quantum++ main namespace.*

### Functions

- template<typename Derived >
  dyn_col_vect< double > qpp::schmidtcoeffs (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &dims)
  *Schmidt coefficients of the bi-partite pure state A.*
- template<typename Derived >
  dyn_col_vect< double > qpp::schmidtcoeffs (const Eigen::MatrixBase< Derived > &A, idx d=2)
  *Schmidt coefficients of the bi-partite pure state A.*
- template<typename Derived >
  cmat qpp::schmidtA (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &dims)
  *Schmidt basis on Alice side.*
- template<typename Derived >
  cmat qpp::schmidtA (const Eigen::MatrixBase< Derived > &A, idx d=2)
  *Schmidt basis on Alice side.*
- template<typename Derived >
  cmat qpp::schmidtB (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &dims)
  *Schmidt basis on Bob side.*
- template<typename Derived >
  cmat qpp::schmidtB (const Eigen::MatrixBase< Derived > &A, idx d=2)

*Schmidt basis on Bob side.*

- template<typename Derived >
std::vector< double > qpp::schmidtprobs (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &dims)

    *Schmidt probabilities of the bi-partite pure state A.*

- template<typename Derived >
std::vector< double > qpp::schmidtprobs (const Eigen::MatrixBase< Derived > &A, idx d=2)

    *Schmidt probabilities of the bi-partite pure state A.*

- template<typename Derived >
double qpp::entanglement (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &dims)

    *Entanglement of the bi-partite pure state A.*

- template<typename Derived >
double qpp::entanglement (const Eigen::MatrixBase< Derived > &A, idx d=2)

    *Entanglement of the bi-partite pure state A.*

- template<typename Derived >
double qpp::gconcurrence (const Eigen::MatrixBase< Derived > &A)

    *G-concurrence of the bi-partite pure state A.*

- template<typename Derived >
double qpp::negativity (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &dims)

    *Negativity of the bi-partite mixed state A.*

- template<typename Derived >
double qpp::negativity (const Eigen::MatrixBase< Derived > &A, idx d=2)

    *Negativity of the bi-partite mixed state A.*

- template<typename Derived >
double qpp::lognegativity (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &dims)

    *Logarithmic negativity of the bi-partite mixed state A.*

- template<typename Derived >
double qpp::lognegativity (const Eigen::MatrixBase< Derived > &A, idx d=2)

    *Logarithmic negativity of the bi-partite mixed state A.*

- template<typename Derived >
double qpp::concurrence (const Eigen::MatrixBase< Derived > &A)

    *Wootters concurrence of the bi-partite qubit mixed state A.*

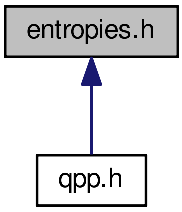
### 8.11.1 Detailed Description

Entanglement functions.

## 8.12 entropies.h File Reference

Entropy functions.

This graph shows which files directly or indirectly include this file:




### Namespaces

- qpp

  *Quantum++ main namespace.*

### Functions

- template$<$typename Derived $>$
  double qpp::entropy (const Eigen::MatrixBase$<$ Derived $>$ &A)

  *von-Neumann entropy of the density matrix A*
- double qpp::entropy (const std::vector$<$ double $>$ &prob)

  *Shannon entropy of the probability distribution prob.*
- template$<$typename Derived $>$
  double qpp::renyi (const Eigen::MatrixBase$<$ Derived $>$ &A, double alpha)

  *Renyi- $\alpha$ entropy of the density matrix A, for $\alpha \geq 0$.*
- double qpp::renyi (const std::vector$<$ double $>$ &prob, double alpha)

  *Renyi- $\alpha$ entropy of the probability distribution prob, for $\alpha \geq 0$.*
- template$<$typename Derived $>$
  double qpp::tsallis (const Eigen::MatrixBase$<$ Derived $>$ &A, double q)

  *Tsallis- $q$ entropy of the density matrix A, for $q \geq 0$.*
- double qpp::tsallis (const std::vector$<$ double $>$ &prob, double q)

  *Tsallis- $q$ entropy of the probability distribution prob, for $q \geq 0$.*
- template$<$typename Derived $>$
  double qpp::qmutualinfo (const Eigen::MatrixBase$<$ Derived $>$ &A, const std::vector$<$ idx $>$ &subsysA, const std::vector$<$ idx $>$ &subsysB, const std::vector$<$ idx $>$ &dims)

  *Quantum mutual information between 2 subsystems of a composite system.*
- template$<$typename Derived $>$
  double qpp::qmutualinfo (const Eigen::MatrixBase$<$ Derived $>$ &A, const std::vector$<$ idx $>$ &subsysA, const std::vector$<$ idx $>$ &subsysB, idx d=2)

  *Quantum mutual information between 2 subsystems of a composite system.*

### 8.12.1 Detailed Description

Entropy functions.

## 8.13 experimental/experimental.h File Reference

Experimental/test functions/classes.

### Namespaces

- qpp

  *Quantum++ main namespace.*
- qpp::experimental

  *Experimental/test functions/classes, do not use or modify.*

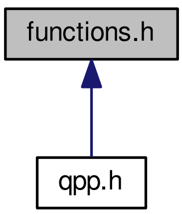
### 8.13.1 Detailed Description

Experimental/test functions/classes.

## 8.14 functions.h File Reference

Generic quantum computing functions.

This graph shows which files directly or indirectly include this file:




### Namespaces

- qpp

  *Quantum++ main namespace.*
- qpp::literals

## Functions

- template< typename Derived >
  dyn_mat< typename Derived::Scalar > qpp::transpose (const Eigen::MatrixBase< Derived > &A)
  
  *Transpose.*
- template< typename Derived >
  dyn_mat< typename Derived::Scalar > qpp::conjugate (const Eigen::MatrixBase< Derived > &A)
  
  *Complex conjugate.*
- template< typename Derived >
  dyn_mat< typename Derived::Scalar > qpp::adjoint (const Eigen::MatrixBase< Derived > &A)
  
  *Adjoint.*
- template< typename Derived >
  dyn_mat< typename Derived::Scalar > qpp::inverse (const Eigen::MatrixBase< Derived > &A)
  
  *Inverse.*
- template< typename Derived >
  Derived::Scalar qpp::trace (const Eigen::MatrixBase< Derived > &A)
  
  *Trace.*
- template< typename Derived >
  Derived::Scalar qpp::det (const Eigen::MatrixBase< Derived > &A)
  
  *Determinant.*
- template< typename Derived >
  Derived::Scalar qpp::logdet (const Eigen::MatrixBase< Derived > &A)
  
  *Logarithm of the determinant.*
- template< typename Derived >
  Derived::Scalar qpp::sum (const Eigen::MatrixBase< Derived > &A)
  
  *Element-wise sum of A.*
- template< typename Derived >
  Derived::Scalar qpp::prod (const Eigen::MatrixBase< Derived > &A)
  
  *Element-wise product of A.*
- template< typename Derived >
  double qpp::norm (const Eigen::MatrixBase< Derived > &A)
  
  *Frobenius norm.*
- template< typename Derived >
  std::pair< dyn_col_vect< cplx >, cmat > qpp::eig (const Eigen::MatrixBase< Derived > &A)
  
  *Full eigen decomposition.*
- template< typename Derived >
  dyn_col_vect< cplx > qpp::evals (const Eigen::MatrixBase< Derived > &A)
  
  *Eigenvalues.*
- template< typename Derived >
  cmat qpp::evects (const Eigen::MatrixBase< Derived > &A)
  
  *Eigenvectors.*
- template< typename Derived >
  std::pair< dyn_col_vect< double >, cmat > qpp::heig (const Eigen::MatrixBase< Derived > &A)
  
  *Full eigen decomposition of Hermitian expression.*
- template< typename Derived >
  dyn_col_vect< double > qpp::hevals (const Eigen::MatrixBase< Derived > &A)
  
  *Hermitian eigenvalues.*
- template< typename Derived >
  cmat qpp::hevects (const Eigen::MatrixBase< Derived > &A)
  
  *Hermitian eigenvectors.*
- template< typename Derived >
  std::tuple< cmat, dyn_col_vect< double >, cmat > qpp::svd (const Eigen::MatrixBase< Derived > &A)
  
  *Full singular value decomposition.*

- template<typename Derived >
  dyn_col_vect< double > qpp::svals (const Eigen::MatrixBase< Derived > &A)

  *Singular values.*
- template<typename Derived >
  cmat qpp::svdU (const Eigen::MatrixBase< Derived > &A)

  *Left singular vectors.*
- template<typename Derived >
  cmat qpp::svdV (const Eigen::MatrixBase< Derived > &A)

  *Right singular vectors.*
- template<typename Derived >
  cmat qpp::funm (const Eigen::MatrixBase< Derived > &A, cplx(*f)(const cplx &))

  *Functional calculus f(A)*
- template<typename Derived >
  cmat qpp::sqrtm (const Eigen::MatrixBase< Derived > &A)

  *Matrix square root.*
- template<typename Derived >
  cmat qpp::absm (const Eigen::MatrixBase< Derived > &A)

  *Matrix absolute value.*
- template<typename Derived >
  cmat qpp::expm (const Eigen::MatrixBase< Derived > &A)

  *Matrix exponential.*
- template<typename Derived >
  cmat qpp::logm (const Eigen::MatrixBase< Derived > &A)

  *Matrix logarithm.*
- template<typename Derived >
  cmat qpp::sinm (const Eigen::MatrixBase< Derived > &A)

  *Matrix sin.*
- template<typename Derived >
  cmat qpp::cosm (const Eigen::MatrixBase< Derived > &A)

  *Matrix cos.*
- template<typename Derived >
  cmat qpp::spectralpowm (const Eigen::MatrixBase< Derived > &A, const cplx z)

  *Matrix power.*
- template<typename Derived >
  dyn_mat< typename Derived::Scalar > qpp::powm (const Eigen::MatrixBase< Derived > &A, idx n)

  *Fast matrix power based on the SQUARE-AND-MULTIPLY algorithm.*
- template<typename Derived >
  double qpp::schatten (const Eigen::MatrixBase< Derived > &A, double p)

  *Schatten matrix norm.*
- template<typename OutputScalar , typename Derived >
  dyn_mat< OutputScalar > qpp::cwise (const Eigen::MatrixBase< Derived > &A, OutputScalar(*f)(const typename Derived::Scalar &))

  *Functor.*
- template<typename T >
  dyn_mat< typename T::Scalar > qpp::kron (const T &head)

  *Kronecker product.*
- template<typename T , typename... Args>
  dyn_mat< typename T::Scalar > qpp::kron (const T &head, const Args &... tail)

  *Kronecker product.*
- template<typename Derived >
  dyn_mat< typename Derived::Scalar > qpp::kron (const std::vector< Derived > &As)

  *Kronecker product.*

- template< typename Derived >
dyn_mat< typename Derived::Scalar > qpp::kron (const std::initializer_list< Derived > &As)

    *Kronecker product.*
- template< typename Derived >
dyn_mat< typename Derived::Scalar > qpp::kronpow (const Eigen::MatrixBase< Derived > &A, idx n)

    *Kronecker power.*
- template< typename T >
dyn_mat< typename T::Scalar > qpp::dirsum (const T &head)

    *Direct sum.*
- template< typename T , typename... Args>
dyn_mat< typename T::Scalar > qpp::dirsum (const T &head, const Args &... tail)

    *Direct sum.*
- template< typename Derived >
dyn_mat< typename Derived::Scalar > qpp::dirsum (const std::vector< Derived > &As)

    *Direct sum.*
- template< typename Derived >
dyn_mat< typename Derived::Scalar > qpp::dirsum (const std::initializer_list< Derived > &As)

    *Direct sum.*
- template< typename Derived >
dyn_mat< typename Derived::Scalar > qpp::dirsumpow (const Eigen::MatrixBase< Derived > &A, idx n)

    *Direct sum power.*
- template< typename Derived >
dyn_mat< typename Derived::Scalar > qpp::reshape (const Eigen::MatrixBase< Derived > &A, idx rows, idx cols)

    *Reshape.*
- template< typename Derived1 , typename Derived2 >
dyn_mat< typename Derived1::Scalar > qpp::comm (const Eigen::MatrixBase< Derived1 > &A, const Eigen::MatrixBase< Derived2 > &B)

    *Commutator.*
- template< typename Derived1 , typename Derived2 >
dyn_mat< typename Derived1::Scalar > qpp::anticomm (const Eigen::MatrixBase< Derived1 > &A, const Eigen::MatrixBase< Derived2 > &B)

    *Anti-commutator.*
- template< typename Derived >
dyn_mat< typename Derived::Scalar > qpp::prj (const Eigen::MatrixBase< Derived > &A)

    *Projector.*
- template< typename Derived >
dyn_mat< typename Derived::Scalar > qpp::grams (const std::vector< Derived > &As)

    *Gram-Schmidt orthogonalization.*
- template< typename Derived >
dyn_mat< typename Derived::Scalar > qpp::grams (const std::initializer_list< Derived > &As)

    *Gram-Schmidt orthogonalization.*
- template< typename Derived >
dyn_mat< typename Derived::Scalar > qpp::grams (const Eigen::MatrixBase< Derived > &A)

    *Gram-Schmidt orthogonalization.*
- std::vector< idx > qpp::n2multiidx (idx n, const std::vector< idx > &dims)

    *Non-negative integer index to multi-index.*
- idx qpp::multiidx2n (const std::vector< idx > &midx, const std::vector< idx > &dims)

    *Multi-index to non-negative integer index.*
- ket qpp::mket (const std::vector< idx > &mask, const std::vector< idx > &dims)

    *Multi-partite qudit ket.*
- ket qpp::mket (const std::vector< idx > &mask, idx d=2)

    *Multi-partite qudit ket.*

- cmat qpp::mprj (const std::vector< idx > &mask, const std::vector< idx > &dims)

    *Projector onto multi-partite qudit ket.*
- cmat qpp::mprj (const std::vector< idx > &mask, idx d=2)

    *Projector onto multi-partite qudit ket.*
- template<typename InputIterator >
  std::vector< double > qpp::abssq (InputIterator first, InputIterator last)

    *Computes the absolute values squared of an STL-like range of complex numbers.*
- template<typename Container >
  std::vector< double > qpp::abssq (const Container &c, typename std::enable_if< is_iterable< Container >::value >::type ∗=nullptr)

    *Computes the absolute values squared of an STL-like container.*
- template<typename Derived >
  std::vector< double > qpp::abssq (const Eigen::MatrixBase< Derived > &A)

    *Computes the absolute values squared of an Eigen expression.*
- template<typename InputIterator >
  std::iterator_traits< InputIterator >::value_type qpp::sum (InputIterator first, InputIterator last)

    *Element-wise sum of an STL-like range.*
- template<typename Container >
  Container::value_type qpp::sum (const Container &c, typename std::enable_if< is_iterable< Container >↩ ::value >::type ∗=nullptr)

    *Element-wise sum of the elements of an STL-like container.*
- template<typename InputIterator >
  std::iterator_traits< InputIterator >::value_type qpp::prod (InputIterator first, InputIterator last)

    *Element-wise product of an STL-like range.*
- template<typename Container >
  Container::value_type qpp::prod (const Container &c, typename std::enable_if< is_iterable< Container >↩ ::value >::type ∗=nullptr)

    *Element-wise product of the elements of an STL-like container.*
- template<typename Derived >
  dyn_col_vect< typename Derived::Scalar > qpp::rho2pure (const Eigen::MatrixBase< Derived > &A)

    *Finds the pure state representation of a matrix proportional to a projector onto a pure state.*
- template<typename T >
  std::vector< T > qpp::complement (std::vector< T > subsys, idx N)

    *Constructs the complement of a subsystem vector.*
- template<typename Derived >
  std::vector< double > qpp::rho2bloch (const Eigen::MatrixBase< Derived > &A)

    *Computes the 3-dimensional real Bloch vector corresponding to the qubit density matrix A.*
- cmat qpp::bloch2rho (const std::vector< double > &r)

    *Computes the density matrix corresponding to the 3-dimensional real Bloch vector r.*
- template<char... Bits>
  ket qpp::literals::operator"" _ket ()

    *Multi-partite qubit ket user-defined literal.*
- template<char... Bits>
  bra qpp::literals::operator"" _bra ()

    *Multi-partite qubit bra user-defined literal.*
- template<char... Bits>
  cmat qpp::literals::operator"" _prj ()

    *Multi-partite qubit projector user-defined literal.*

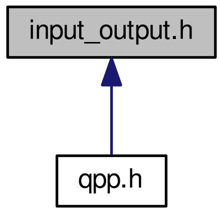
### 8.14.1 Detailed Description

Generic quantum computing functions.

## 8.15 input_output.h File Reference

Input/output functions.

This graph shows which files directly or indirectly include this file:




### Namespaces

- qpp

    *Quantum++ main namespace.*

### Functions

- template< typename Derived >
  internal::IOManipEigen qpp::disp (const Eigen::MatrixBase< Derived > &A, double chop=qpp::chop)

    *Eigen expression ostream manipulator.*
- internal::IOManipEigen qpp::disp (cplx z, double chop=qpp::chop)

    *Complex number ostream manipulator.*
- template< typename InputIterator >
  internal::IOManipRange< InputIterator > qpp::disp (InputIterator first, InputIterator last, const std::string &separator, const std::string &start="[", const std::string &end="]")

    *Range ostream manipulator.*
- template< typename Container >
  internal::IOManipRange< typename Container::const_iterator > qpp::disp (const Container &c, const std↩ ::string &separator, const std::string &start="[", const std::string &end="]", typename std::enable_if< is_↩ iterable< Container >::value >::type *=nullptr)

    *Standard container ostream manipulator. The container must support std::begin(), std::end() and forward iteration.*
- template< typename PointerType >
  internal::IOManipPointer< PointerType > qpp::disp (const PointerType *p, idx N, const std::string &separator, const std::string &start="[", const std::string &end="]")

    *C-style pointer ostream manipulator.*
- template< typename Derived >
  void qpp::save (const Eigen::MatrixBase< Derived > &A, const std::string &fname)

    *Saves Eigen expression to a binary file (internal format) in double precision.*
- template< typename Derived >
  dyn_mat< typename Derived::Scalar > qpp::load (const std::string &fname)

    *Loads Eigen matrix from a binary file (internal format) in double precision.*

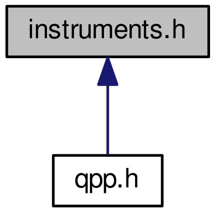
### 8.15.1 Detailed Description

Input/output functions.

## 8.16 instruments.h File Reference

Measurement functions.

This graph shows which files directly or indirectly include this file:




### Namespaces

- qpp

  *Quantum++ main namespace.*

### Functions

- template< typename Derived >
  dyn_col_vect< typename Derived::Scalar > qpp::ip (const Eigen::MatrixBase< Derived > &phi, const Eigen::MatrixBase< Derived > &psi, const std::vector< idx > &subsys, const std::vector< idx > &dims)

  *Generalized inner product.*
- template< typename Derived >
  dyn_col_vect< typename Derived::Scalar > qpp::ip (const Eigen::MatrixBase< Derived > &phi, const Eigen::MatrixBase< Derived > &psi, const std::vector< idx > &subsys, idx d=2)

  *Generalized inner product.*
- template< typename Derived >
  std::tuple< idx, std::vector< double >, std::vector< cmat > > qpp::measure (const Eigen::MatrixBase< Derived > &A, const std::vector< cmat > &Ks)

  *Measures the state A using the set of Kraus operators Ks.*
- template< typename Derived >
  std::tuple< idx, std::vector< double >, std::vector< cmat > > qpp::measure (const Eigen::MatrixBase< Derived > &A, const std::initializer_list< cmat > &Ks)

  *Measures the state A using the set of Kraus operators Ks.*
- template< typename Derived >
  std::tuple< idx, std::vector< double >, std::vector< cmat > > qpp::measure (const Eigen::MatrixBase< Derived > &A, const cmat &U)

*Measures the state A in the orthonormal basis specified by the unitary matrix U.*

- template<typename Derived >
  std::tuple< idx, std::vector< double >, std::vector< cmat > > qpp::measure (const Eigen::MatrixBase< Derived > &A, const std::vector< cmat > &Ks, const std::vector< idx > &subsys, const std::vector< idx > &dims)

  *Measures the part subsys of the multi-partite state vector or density matrix A using the set of Kraus operators Ks.*
- template<typename Derived >
  std::tuple< idx, std::vector< double >, std::vector< cmat > > qpp::measure (const Eigen::MatrixBase< Derived > &A, const std::initializer_list< cmat > &Ks, const std::vector< idx > &subsys, const std::vector< idx > &dims)

  *Measures the part subsys of the multi-partite state vector or density matrix A using the set of Kraus operators Ks.*
- template<typename Derived >
  std::tuple< idx, std::vector< double >, std::vector< cmat > > qpp::measure (const Eigen::MatrixBase< Derived > &A, const std::vector< cmat > &Ks, const std::vector< idx > &subsys, idx d=2)

  *Measures the part subsys of the multi-partite state vector or density matrix A using the set of Kraus operators Ks.*
- template<typename Derived >
  std::tuple< idx, std::vector< double >, std::vector< cmat > > qpp::measure (const Eigen::MatrixBase< Derived > &A, const std::initializer_list< cmat > &Ks, const std::vector< idx > &subsys, idx d=2)

  *Measures the part subsys of the multi-partite state vector or density matrix A using the set of Kraus operators Ks.*
- template<typename Derived >
  std::tuple< idx, std::vector< double >, std::vector< cmat > > qpp::measure (const Eigen::MatrixBase< Derived > &A, const cmat &V, const std::vector< idx > &subsys, const std::vector< idx > &dims)

  *Measures the part subsys of the multi-partite state vector or density matrix A in the orthonormal basis or rank-1 POVM specified by the matrix V.*
- template<typename Derived >
  std::tuple< idx, std::vector< double >, std::vector< cmat > > qpp::measure (const Eigen::MatrixBase< Derived > &A, const cmat &V, const std::vector< idx > &subsys, idx d=2)

  *Measures the part subsys of the multi-partite state vector or density matrix A in the orthonormal basis or rank-1 POVM specified by the matrix V.*
- template<typename Derived >
  std::tuple< std::vector< idx >, double, cmat > qpp::measure_seq (const Eigen::MatrixBase< Derived > &A, std::vector< idx > subsys, std::vector< idx > dims)

  *Sequentially measures the part subsys of the multi-partite state vector or density matrix A in the computational basis.*
- template<typename Derived >
  std::tuple< std::vector< idx >, double, cmat > qpp::measure_seq (const Eigen::MatrixBase< Derived > &A, std::vector< idx > subsys, idx d=2)

  *Sequentially measures the part subsys of the multi-partite state vector or density matrix A in the computational basis.*

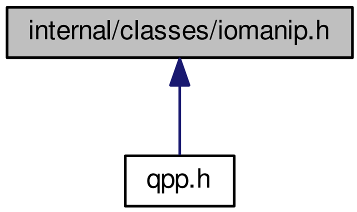
### 8.16.1 Detailed Description

Measurement functions.

## 8.17 internal/classes/iomanip.h File Reference

Input/output manipulators.

This graph shows which files directly or indirectly include this file:




## Classes

- class qpp::internal::IOManipRange< InputIterator >
- class qpp::internal::IOManipPointer< PointerType >
- class qpp::internal::IOManipEigen

## Namespaces

- qpp

  *Quantum++ main namespace.*
- qpp::internal

  *Internal utility functions, do not use them directly or modify them.*

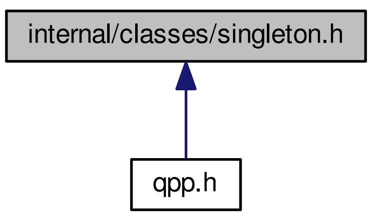
### 8.17.1 Detailed Description

Input/output manipulators.

## 8.18 internal/classes/singleton.h File Reference

Singleton pattern via CRTP.

This graph shows which files directly or indirectly include this file:



### Classes

- class qpp::internal::Singleton< T >

  *Singleton policy class, used internally to implement the singleton pattern via CRTP (Curiously recurring template pattern)*

### Namespaces

- qpp

  *Quantum++ main namespace.*
- qpp::internal

  *Internal utility functions, do not use them directly or modify them.*

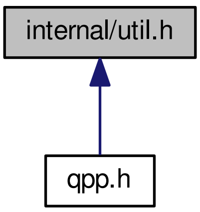
### 8.18.1 Detailed Description

Singleton pattern via CRTP.

## 8.19 internal/util.h File Reference

Internal utility functions.

This graph shows which files directly or indirectly include this file:




### Classes

- struct qpp::internal::Display_Impl_

### Namespaces

- qpp

  *Quantum++ main namespace.*
- qpp::internal

  *Internal utility functions, do not use them directly or modify them.*

## Functions

- void qpp::internal::n2multiidx (idx n, idx numdims, const idx ∗const dims, idx ∗result) noexcept
- idx qpp::internal::multiidx2n (const idx ∗const midx, idx numdims, const idx ∗const dims) noexcept
- template< typename Derived >
  bool qpp::internal::check_square_mat (const Eigen::MatrixBase< Derived > &A)
- template< typename Derived >
  bool qpp::internal::check_vector (const Eigen::MatrixBase< Derived > &A)
- template< typename Derived >
  bool qpp::internal::check_rvector (const Eigen::MatrixBase< Derived > &A)
- template< typename Derived >
  bool qpp::internal::check_cvector (const Eigen::MatrixBase< Derived > &A)
- template< typename T >
  bool qpp::internal::check_nonzero_size (const T &x) noexcept
- template< typename T1 , typename T2 >
  bool qpp::internal::check_matching_sizes (const T1 &lhs, const T2 &rhs) noexcept
- bool qpp::internal::check_dims (const std::vector< idx > &dims)
- template< typename Derived >
  bool qpp::internal::check_dims_match_mat (const std::vector< idx > &dims, const Eigen::MatrixBase< Derived > &A)
- template< typename Derived >
  bool qpp::internal::check_dims_match_cvect (const std::vector< idx > &dims, const Eigen::MatrixBase< Derived > &A)
- template< typename Derived >
  bool qpp::internal::check_dims_match_rvect (const std::vector< idx > &dims, const Eigen::MatrixBase< Derived > &A)
- bool qpp::internal::check_eq_dims (const std::vector< idx > &dims, idx dim) noexcept
- bool qpp::internal::check_subsys_match_dims (const std::vector< idx > &subsys, const std::vector< idx > &dims)
- template< typename Derived >
  bool qpp::internal::check_qubit_matrix (const Eigen::MatrixBase< Derived > &A) noexcept
- template< typename Derived >
  bool qpp::internal::check_qubit_cvector (const Eigen::MatrixBase< Derived > &A) noexcept
- template< typename Derived >
  bool qpp::internal::check_qubit_rvector (const Eigen::MatrixBase< Derived > &A) noexcept
- template< typename Derived >
  bool qpp::internal::check_qubit_vector (const Eigen::MatrixBase< Derived > &A) noexcept
- bool qpp::internal::check_perm (const std::vector< idx > &perm)
- template< typename Derived1 , typename Derived2 >
  dyn_mat< typename Derived1::Scalar > qpp::internal::kron2 (const Eigen::MatrixBase< Derived1 > &A, const Eigen::MatrixBase< Derived2 > &B)
- template< typename Derived1 , typename Derived2 >
  dyn_mat< typename Derived1::Scalar > qpp::internal::dirsum2 (const Eigen::MatrixBase< Derived1 > &A, const Eigen::MatrixBase< Derived2 > &B)
- template< typename T >
  void qpp::internal::variadic_vector_emplace (std::vector< T > &)
- template< typename T , typename First , typename... Args>
  void qpp::internal::variadic_vector_emplace (std::vector< T > &v, First &&first, Args &&... args)
- idx qpp::internal::get_num_subsys (idx sz, idx d)
- idx qpp::internal::get_dim_subsys (idx sz, idx N)

### 8.19.1 Detailed Description

Internal utility functions.

## 8.20 MATLAB/matlab.h File Reference

Input/output interfacing with MATLAB.

```
#include "mat.h"
#include "mex.h"
```

### Namespaces

- qpp

  *Quantum++ main namespace.*

### Functions

- template< typename Derived >
  std::enable_if< std::is_same< typename Derived::Scalar, cplx >::value, dyn_mat< cplx > >::type qpp↩ ::loadMATLAB (const std::string &mat_file, const std::string &var_name)

  *Loads a complex Eigen dynamic matrix from a MATLAB .mat file,.*
- template< typename Derived >
  std::enable_if<!std::is_same< typename Derived::Scalar, cplx >::value, dyn_mat< typename Derived::↩ Scalar > >::type qpp::loadMATLAB (const std::string &mat_file, const std::string &var_name)

  *Loads a non-complex Eigen dynamic matrix from a MATLAB .mat file,.*
- template< typename Derived >
  std::enable_if< std::is_same< typename Derived::Scalar, cplx >::value >::type qpp::saveMATLAB (const Eigen::MatrixBase< Derived > &A, const std::string &mat_file, const std::string &var_name, const std::string &mode)

  *Saves a complex Eigen dynamic matrix to a MATLAB .mat file,.*
- template< typename Derived >
  std::enable_if< !std::is_same< typename Derived::Scalar, cplx >::value >::type qpp::saveMATLAB (const Eigen::MatrixBase< Derived > &A, const std::string &mat_file, const std::string &var_name, const std::string &mode)

  *Saves a non-complex Eigen dynamic matrix to a MATLAB .mat file,.*

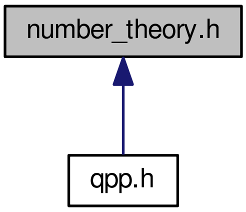
### 8.20.1 Detailed Description

Input/output interfacing with MATLAB.

## 8.21 number_theory.h File Reference

Number theory functions.

This graph shows which files directly or indirectly include this file:




## Namespaces

- qpp

  *Quantum++ main namespace.*

## Functions

- std::vector< int > qpp::x2contfrac (double x, idx N, idx cut=1e5)

  *Simple continued fraction expansion.*
- double qpp::contfrac2x (const std::vector< int > &cf, idx N=idx(-1))

  *Real representation of a simple continued fraction.*
- bigint qpp::gcd (bigint a, bigint b)

  *Greatest common divisor of two integers.*
- bigint qpp::gcd (const std::vector< bigint > &as)

  *Greatest common divisor of a list of integers.*
- bigint qpp::lcm (bigint a, bigint b)

  *Least common multiple of two integers.*
- bigint qpp::lcm (const std::vector< bigint > &as)

  *Least common multiple of a list of integers.*
- std::vector< idx > qpp::invperm (const std::vector< idx > &perm)

  *Inverse permutation.*
- std::vector< idx > qpp::compperm (const std::vector< idx > &perm, const std::vector< idx > &sigma)

  *Compose permutations.*
- std::vector< bigint > qpp::factors (bigint a)

  *Prime factor decomposition.*
- bigint qpp::modmul (bigint a, bigint b, bigint p)

  *Modular multiplication without overflow.*
- bigint qpp::modpow (bigint a, bigint n, bigint p)

  *Fast integer power modulo p based on the SQUARE-AND-MULTIPLY algorithm.*
- std::tuple< bigint, bigint, bigint > qpp::egcd (bigint a, bigint b)

  *Extended greatest common divisor of two integers.*
- bigint qpp::modinv (bigint a, bigint p)

  *Modular inverse of a mod p.*
- bool qpp::isprime (bigint p, idx k=80)

  *Primality test based on the Miller-Rabin's algorithm.*
- bigint qpp::randprime (bigint a, bigint b, idx N=1000)

  *Generates a random big prime uniformly distributed in the interval [a, b].*

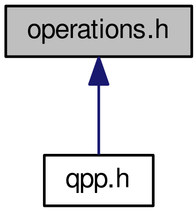
### 8.21.1 Detailed Description

Number theory functions.

## 8.22 operations.h File Reference

Quantum operation functions.

This graph shows which files directly or indirectly include this file:




### Namespaces

- qpp

  *Quantum++ main namespace.*

### Functions

- template<typename Derived1 , typename Derived2 >
  dyn_mat< typename Derived1::Scalar > qpp::applyCTRL (const Eigen::MatrixBase< Derived1 > &state, const Eigen::MatrixBase< Derived2 > &A, const std::vector< idx > &ctrl, const std::vector< idx > &subsys, const std::vector< idx > &dims)

  *Applies the controlled-gate A to the part subsys of the multi-partite state vector or density matrix state.*
- template<typename Derived1 , typename Derived2 >
  dyn_mat< typename Derived1::Scalar > qpp::applyCTRL (const Eigen::MatrixBase< Derived1 > &state, const Eigen::MatrixBase< Derived2 > &A, const std::vector< idx > &ctrl, const std::vector< idx > &subsys, idx d=2)

  *Applies the controlled-gate A to the part subsys of the multi-partite state vector or density matrix state.*
- template<typename Derived1 , typename Derived2 >
  dyn_mat< typename Derived1::Scalar > qpp::apply (const Eigen::MatrixBase< Derived1 > &state, const Eigen::MatrixBase< Derived2 > &A, const std::vector< idx > &subsys, const std::vector< idx > &dims)

  *Applies the gate A to the part subsys of the multi-partite state vector or density matrix state.*
- template<typename Derived1 , typename Derived2 >
  dyn_mat< typename Derived1::Scalar > qpp::apply (const Eigen::MatrixBase< Derived1 > &state, const Eigen::MatrixBase< Derived2 > &A, const std::vector< idx > &subsys, idx d=2)

  *Applies the gate A to the part subsys of the multi-partite state vector or density matrix state.*

- template< typename Derived >
  cmat qpp::apply (const Eigen::MatrixBase< Derived > &A, const std::vector< cmat > &Ks)

  *Applies the channel specified by the set of Kraus operators Ks to the density matrix A.*
- template< typename Derived >
  cmat qpp::apply (const Eigen::MatrixBase< Derived > &A, const std::vector< cmat > &Ks, const std::vector< idx > &subsys, const std::vector< idx > &dims)

  *Applies the channel specified by the set of Kraus operators Ks to the part subsys of the multi-partite density matrix A.*
- template< typename Derived >
  cmat qpp::apply (const Eigen::MatrixBase< Derived > &A, const std::vector< cmat > &Ks, const std::vector< idx > &subsys, idx d=2)

  *Applies the channel specified by the set of Kraus operators Ks to the part subsys of the multi-partite density matrix A.*
- cmat qpp::kraus2super (const std::vector< cmat > &Ks)

  *Superoperator matrix.*
- cmat qpp::kraus2choi (const std::vector< cmat > &Ks)

  *Choi matrix.*
- std::vector< cmat > qpp::choi2kraus (const cmat &A)

  *Orthogonal Kraus operators from Choi matrix.*
- cmat qpp::choi2super (const cmat &A)

  *Converts Choi matrix to superoperator matrix.*
- cmat qpp::super2choi (const cmat &A)

  *Converts superoperator matrix to Choi matrix.*
- template< typename Derived >
  dyn_mat< typename Derived::Scalar > qpp::ptrace1 (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &dims)

  *Partial trace.*
- template< typename Derived >
  dyn_mat< typename Derived::Scalar > qpp::ptrace1 (const Eigen::MatrixBase< Derived > &A, idx d=2)

  *Partial trace.*
- template< typename Derived >
  dyn_mat< typename Derived::Scalar > qpp::ptrace2 (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &dims)

  *Partial trace.*
- template< typename Derived >
  dyn_mat< typename Derived::Scalar > qpp::ptrace2 (const Eigen::MatrixBase< Derived > &A, idx d=2)

  *Partial trace.*
- template< typename Derived >
  dyn_mat< typename Derived::Scalar > qpp::ptrace (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &subsys, const std::vector< idx > &dims)

  *Partial trace.*
- template< typename Derived >
  dyn_mat< typename Derived::Scalar > qpp::ptrace (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &subsys, idx d=2)

  *Partial trace.*
- template< typename Derived >
  dyn_mat< typename Derived::Scalar > qpp::ptranspose (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &subsys, const std::vector< idx > &dims)

  *Partial transpose.*
- template< typename Derived >
  dyn_mat< typename Derived::Scalar > qpp::ptranspose (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &subsys, idx d=2)

  *Partial transpose.*
- template< typename Derived >
  dyn_mat< typename Derived::Scalar > qpp::syspermute (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &perm, const std::vector< idx > &dims)

*Subsystem permutation.*

- template<typename Derived >
  dyn_mat< typename Derived::Scalar > qpp::syspermute (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &perm, idx d=2)

  *Subsystem permutation.*
- template<typename Derived >
  dyn_mat< typename Derived::Scalar > qpp::applyQFT (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &subsys, idx d=2, bool swap=true)

  *Applies the qudit quantum Fourier transform to the part subsys of the multi-partite state vector or density matrix A.*
- template<typename Derived >
  dyn_mat< typename Derived::Scalar > qpp::applyINVQFT (const Eigen::MatrixBase< Derived > &A, const std::vector< idx > &subsys, idx d=2, bool swap=true)

  *Applies the inverse (adjoint) qudit quantum Fourier transform to the part subsys of the multi-partite state vector or density matrix A.*
- template<typename Derived >
  dyn_col_vect< typename Derived::Scalar > qpp::INVQFT (const Eigen::MatrixBase< Derived > &A, idx d=2, bool swap=true)

  *Inverse (adjoint) qudit quantum Fourier transform.*
- template<typename Derived >
  dyn_col_vect< typename Derived::Scalar > qpp::QFT (const Eigen::MatrixBase< Derived > &A, idx d=2, bool swap=true)

  *Qudit quantum Fourier transform.*

### 8.22.1 Detailed Description

Quantum operation functions.

## 8.23 qpp.h File Reference

Quantum++ main header file, includes all other necessary headers.

```
#include <algorithm>
#include <cassert>
#include <chrono>
#include <cmath>
#include <complex>
#include <cstdlib>
#include <cstring>
#include <exception>
#include <fstream>
#include <functional>
#include <initializer_list>
#include <iomanip>
#include <iterator>
#include <limits>
#include <memory>
#include <numeric>
#include <ostream>
#include <random>
#include <sstream>
#include <stdexcept>
#include <string>
```

```
#include <tuple>
#include <type_traits>
#include <utility>
#include <vector>
#include <Eigen/Dense>
#include <Eigen/SVD>
#include "types.h"
#include "classes/exception.h"
#include "constants.h"
#include "traits.h"
#include "classes/idisplay.h"
#include "internal/util.h"
#include "internal/classes/iomanip.h"
#include "input_output.h"
#include "internal/classes/singleton.h"
#include "classes/init.h"
#include "functions.h"
#include "classes/codes.h"
#include "classes/gates.h"
#include "classes/states.h"
#include "classes/random_devices.h"
#include "statistics.h"
#include "operations.h"
#include "entropies.h"
#include "entanglement.h"
#include "random.h"
#include "classes/timer.h"
#include "instruments.h"
#include "number_theory.h"
#include "classes/reversible.h"
```

## Namespaces

- qpp

  *Quantum++ main namespace.*

## Macros

- #define QPP_UNUSED_

### 8.23.1 Detailed Description

Quantum++ main header file, includes all other necessary headers.

### 8.23.2 Macro Definition Documentation

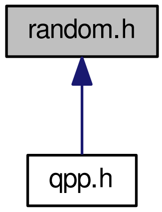
#### 8.23.2.1 QPP_UNUSED_

```
#define QPP_UNUSED_
```

## 8.24 random.h File Reference

Randomness-related functions.

This graph shows which files directly or indirectly include this file:




### Namespaces

- qpp

    *Quantum++ main namespace.*

### Functions

- double qpp::rand (double a, double b)

    *Generates a random real number uniformly distributed in the interval [a, b)*
- bigint qpp::rand (bigint a, bigint b)

    *Generates a random big integer uniformly distributed in the interval [a, b].*
- idx qpp::randidx (idx a=std::numeric_limits< idx >::min(), idx b=std::numeric_limits< idx >::max())

    *Generates a random index (idx) uniformly distributed in the interval [a, b].*
- template<typename Derived >
  Derived qpp::rand (idx rows, idx cols, double a=0, double b=1)

    *Generates a random matrix with entries uniformly distributed in the interval [a, b)*
- template<>
  dmat qpp::rand (idx rows, idx cols, double a, double b)

    *Generates a random real matrix with entries uniformly distributed in the interval [a, b), specialization for double matrices (qpp::dmat)*
- template<>
  cmat qpp::rand (idx rows, idx cols, double a, double b)

    *Generates a random complex matrix with entries (both real and imaginary) uniformly distributed in the interval [a, b), specialization for complex matrices (qpp::cmat)*
- template<typename Derived >
  Derived qpp::randn (idx rows, idx cols, double mean=0, double sigma=1)

    *Generates a random matrix with entries normally distributed in N(mean, sigma)*
- template<>
  dmat qpp::randn (idx rows, idx cols, double mean, double sigma)

    *Generates a random real matrix with entries normally distributed in N(mean, sigma), specialization for double matrices (qpp::dmat)*

- template<>
  cmat qpp::randn (idx rows, idx cols, double mean, double sigma)

  *Generates a random complex matrix with entries (both real and imaginary) normally distributed in N(mean, sigma), specialization for complex matrices (qpp::cmat)*
- double qpp::randn (double mean=0, double sigma=1)

  *Generates a random real number (double) normally distributed in N(mean, sigma)*
- cmat qpp::randU (idx D=2)

  *Generates a random unitary matrix.*
- cmat qpp::randV (idx Din, idx Dout)

  *Generates a random isometry matrix.*
- std::vector< cmat > qpp::randkraus (idx N, idx D=2)

  *Generates a set of random Kraus operators.*
- cmat qpp::randH (idx D=2)

  *Generates a random Hermitian matrix.*
- ket qpp::randket (idx D=2)

  *Generates a random normalized ket (pure state vector)*
- cmat qpp::randrho (idx D=2)

  *Generates a random density matrix.*
- std::vector< idx > qpp::randperm (idx N)

  *Generates a random uniformly distributed permutation.*
- std::vector< double > qpp::randprob (idx N)

  *Generates a random probability vector uniformly distributed over the probability simplex.*

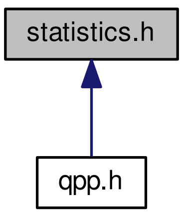
### 8.24.1 Detailed Description

Randomness-related functions.

## 8.25 statistics.h File Reference

Statistics functions.

This graph shows which files directly or indirectly include this file:



## Namespaces

- qpp

  *Quantum++ main namespace.*

## Functions

- std::vector< double > qpp::uniform (idx N)

  *Uniform probability distribution vector.*
- std::vector< double > qpp::marginalX (const dmat &probXY)

  *Marginal distribution.*
- std::vector< double > qpp::marginalY (const dmat &probXY)

  *Marginal distribution.*
- template<typename Container >
  double qpp::avg (const std::vector< double > &prob, const Container &X, typename std::enable_if< is_↩
  iterable< Container >::value >::type ∗=nullptr)

  *Average.*
- template<typename Container >
  double qpp::cov (const dmat &probXY, const Container &X, const Container &Y, typename std::enable_if<
  is_iterable< Container >::value >::type ∗=nullptr)

  *Covariance.*
- template<typename Container >
  double qpp::var (const std::vector< double > &prob, const Container &X, typename std::enable_if< is_↩
  iterable< Container >::value >::type ∗=nullptr)

  *Variance.*
- template<typename Container >
  double qpp::sigma (const std::vector< double > &prob, const Container &X, typename std::enable_if< is_↩
  iterable< Container >::value >::type ∗=nullptr)

  *Standard deviation.*
- template<typename Container >
  double qpp::cor (const dmat &probXY, const Container &X, const Container &Y, typename std::enable_if<
  is_iterable< Container >::value >::type ∗=nullptr)

  *Correlation.*

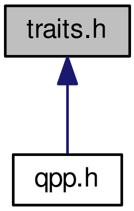
### 8.25.1 Detailed Description

Statistics functions.

## 8.26 traits.h File Reference

Type traits.

This graph shows which files directly or indirectly include this file:




## Classes

- struct qpp::make_void< Ts >

  *Helper for qpp::to_void<> alias template.*
- struct qpp::is_iterable< T, typename >

  *Checks whether T is compatible with an STL-like iterable container.*
- struct qpp::is_iterable< T, to_void< decltype(std::declval< T >().begin()), decltype(std::declval< T >().↩
  end()), typename T::value_type > >

  *Checks whether T is compatible with an STL-like iterable container, specialization for STL-like iterable containers.*
- struct qpp::is_matrix_expression< Derived >

  *Checks whether the type is an Eigen matrix expression.*
- struct qpp::is_complex< T >

  *Checks whether the type is a complex type.*
- struct qpp::is_complex< std::complex< T > >

  *Checks whether the type is a complex number type, specialization for complex types.*

## Namespaces

- qpp

  *Quantum++ main namespace.*

## Typedefs

- template<typename... Ts>
  using qpp::to_void = typename make_void< Ts... >::type

  *Alias template that implements the proposal for void_t.*

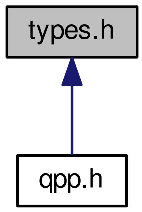
### 8.26.1 Detailed Description

Type traits.

## 8.27 types.h File Reference

Type aliases.

This graph shows which files directly or indirectly include this file:




### Namespaces

- qpp

  *Quantum++ main namespace.*

### Typedefs

- using qpp::idx = std::size_t

  *Non-negative integer index.*
- using qpp::bigint = long long int

  *Big integer.*
- using qpp::cplx = std::complex< double >

  *Complex number in double precision.*
- using qpp::ket = Eigen::VectorXcd

  *Complex (double precision) dynamic Eigen column vector.*
- using qpp::bra = Eigen::RowVectorXcd

  *Complex (double precision) dynamic Eigen row vector.*
- using qpp::cmat = Eigen::MatrixXcd

  *Complex (double precision) dynamic Eigen matrix.*
- using qpp::dmat = Eigen::MatrixXd

  *Real (double precision) dynamic Eigen matrix.*
- template< typename Scalar >
  using qpp::dyn_mat = Eigen::Matrix< Scalar, Eigen::Dynamic, Eigen::Dynamic >

  *Dynamic Eigen matrix over the field specified by Scalar.*
- template< typename Scalar >
  using qpp::dyn_col_vect = Eigen::Matrix< Scalar, Eigen::Dynamic, 1 >

  *Dynamic Eigen column vector over the field specified by Scalar.*
- template< typename Scalar >
  using qpp::dyn_row_vect = Eigen::Matrix< Scalar, 1, Eigen::Dynamic >

  *Dynamic Eigen row vector over the field specified by Scalar.*

### 8.27.1 Detailed Description

Type aliases.

## 8.28 /home/vlad/qpp/README.md File Reference

# Index


/home/vlad/qpp/README.md, 299
~Codes
 qpp::Codes, 132
~Gates
 qpp::Gates, 168
~IDisplay
 qpp::IDisplay, 179
~Init
 qpp::Init, 182
~RandomDevices
 qpp::RandomDevices, 235
~Singleton
 qpp::internal::Singleton, 238
~States
 qpp::States, 243
~Timer
 qpp::Timer, 254

A_
 qpp::internal::IOManipEigen, 184
absm
 qpp, 28
abssq
 qpp, 28, 29
adjoint
 qpp, 29
all
 qpp::Dynamic_bitset, 151
anticomm
 qpp, 30
any
 qpp::Dynamic_bitset, 151
apply
 qpp, 30–32
applyCTRL
 qpp, 33, 34
applyINVQFT
 qpp, 34
applyQFT
 qpp, 35
avg
 qpp, 35

b00
 qpp::States, 246
b01
 qpp::States, 246
b10
 qpp::States, 246
b11
 qpp::States, 247
bigint
 qpp, 26
Bit_circuit
 qpp::Bit_circuit, 127
bloch2rho
 qpp, 36
bra
 qpp, 26

CNOTba
 qpp::Gates, 175
CNOT
 qpp::Bit_circuit, 127
 qpp::Bit_circuit::Gate_count, 164
 qpp::Gates, 175
CTRL
 qpp::Gates, 168
check_cvector
 qpp::internal, 117
check_dims
 qpp::internal, 118
check_dims_match_cvect
 qpp::internal, 118
check_dims_match_mat
 qpp::internal, 118
check_dims_match_rvect
 qpp::internal, 118
check_eq_dims
 qpp::internal, 118
check_matching_sizes
 qpp::internal, 118
check_nonzero_size
 qpp::internal, 119
check_perm
 qpp::internal, 119
check_qubit_cvector
 qpp::internal, 119
check_qubit_matrix
 qpp::internal, 119
check_qubit_rvector
 qpp::internal, 119
check_qubit_vector
 qpp::internal, 119
check_rvector
 qpp::internal, 120
check_square_mat
 qpp::internal, 120
check_subsys_match_dims
 qpp::internal, 120

check_vector
qpp::internal, 120
choi2kraus
qpp, 36
choi2super
qpp, 37
chop
qpp, 113
chop_
qpp::internal::IOManipEigen, 185
classes/codes.h, 265
classes/exception.h, 266
classes/gates.h, 268
classes/idisplay.h, 268
classes/init.h, 269
classes/random_devices.h, 270
classes/reversible.h, 270
classes/states.h, 271
classes/timer.h, 272
cmat
qpp, 26
Codes
qpp::Codes, 132
codeword
qpp::Codes, 132
comm
qpp, 37
complement
qpp, 38
compperm
qpp, 38
concurrence
qpp, 38
conjugate
qpp, 40
constants.h, 273
contfrac2x
qpp, 40
cor
qpp, 41
cosm
qpp, 41
count
qpp::Dynamic_bitset, 151
cov
qpp, 41
cplx
qpp, 26
CustomException
qpp::exception::CustomException, 134
cwise
qpp, 42
CZ
qpp::Gates, 175

data
qpp::Dynamic_bitset, 151
det
qpp, 42
dirsum
qpp, 43, 44
dirsum2
qpp::internal, 120
dirsumpow
qpp, 45
disp
qpp, 45–47
display
qpp::Dynamic_bitset, 152
qpp::IDisplay, 179
qpp::Timer, 255
qpp::internal::IOManipEigen, 184
qpp::internal::IOManipPointer, 187
qpp::internal::IOManipRange, 190
display_impl_
qpp::internal::Display_Impl_, 147
dmat
qpp, 26
dyn_col_vect
qpp, 26
dyn_mat
qpp, 27
dyn_row_vect
qpp, 27
Dynamic_bitset
qpp::Dynamic_bitset, 150

ee
qpp, 113
egcd
qpp, 47
eig
qpp, 48
end_
qpp::Timer, 257
qpp::internal::IOManipPointer, 187
qpp::internal::IOManipRange, 191
entanglement
qpp, 48, 49
entanglement.h, 274
entropies.h, 275
entropy
qpp, 49, 50
eps
qpp, 113
evals
qpp, 50
evects
qpp, 51
Exception
qpp::exception::Exception, 163
expandout
qpp::Gates, 169, 170
experimental/experimental.h, 277
expm
qpp, 51

FRED

qpp::Bit_circuit, 127
qpp::Bit_circuit::Gate_count, 165
qpp::Gates, 176
factors
qpp, 51
Fd
qpp::Gates, 171
first_
qpp::internal::IOManipRange, 191
flip
qpp::Dynamic_bitset, 153
functions.h, 277
funm
qpp, 52

GHZ
qpp::States, 247
gate_count
qpp::Bit_circuit, 130
Gates
qpp::Gates, 168
gcd
qpp, 52, 53
gconcurrence
qpp, 53
get
qpp::Dynamic_bitset, 153
get_dim_subsys
qpp::internal, 120
get_duration
qpp::Timer, 255
get_instance
qpp::internal::Singleton, 238
get_num_subsys
qpp::internal, 121
get_prng
qpp::RandomDevices, 235
get_thread_local_instance
qpp::internal::Singleton, 238
grams
qpp, 54

H
qpp::Gates, 176
heig
qpp, 55
hevals
qpp, 55
hevects
qpp, 56

IDisplay
qpp::IDisplay, 179
INVQFT
qpp, 57
IOManipEigen
qpp::internal::IOManipEigen, 184
IOManipPointer
qpp::internal::IOManipPointer, 186, 187
IOManipRange
qpp::internal::IOManipRange, 190
Id
qpp::Gates, 172
Id2
qpp::Gates, 176
idx
qpp, 27
index_
qpp::Dynamic_bitset, 154
infty
qpp, 114
Init
qpp::Init, 182
input_output.h, 282
instruments.h, 283
internal/classes/iomanip.h, 284
internal/classes/singleton.h, 285
internal/util.h, 286
internal::Singleton< const Codes >
qpp::Codes, 132
internal::Singleton< const Gates >
qpp::Gates, 175
internal::Singleton< const Init >
qpp::Init, 182
internal::Singleton< const States >
qpp::States, 246
internal::Singleton< RandomDevices >
qpp::RandomDevices, 236
inverse
qpp, 56
invperm
qpp, 56
ip
qpp, 57, 58
isprime
qpp, 58

jn
qpp::States, 244

ket
qpp, 27
kraus2choi
qpp, 59
kraus2super
qpp, 59
kron
qpp, 60, 61
kron2
qpp::internal, 121
kronpow
qpp, 62

last_
qpp::internal::IOManipRange, 191
lcm
qpp, 62, 63
load

qpp, 63
qpp::RandomDevices, 235
loadMATLAB
qpp, 64
logdet
qpp, 65
logm
qpp, 65
lognegativity
qpp, 66

MATLAB/matlab.h, 288
MODMUL
qpp::Gates, 172
marginalX
qpp, 67
marginalY
qpp, 67
maxn
qpp, 114
measure
qpp, 67–72
measure_seq
qpp, 73
mes
qpp::States, 244
minus
qpp::States, 244
mket
qpp, 74
modinv
qpp, 75
modmul
qpp, 76
modpow
qpp, 76
mprj
qpp, 77
msg_
qpp::exception::Exception, 164
multiidx2n
qpp, 78
qpp::internal, 121

n2multiidx
qpp, 78
qpp::internal, 121
N_
qpp::Dynamic_bitset, 160
qpp::internal::IOManipPointer, 188
NOT
qpp::Bit_circuit, 128
qpp::Bit_circuit::Gate_count, 165
negativity
qpp, 79
none
qpp::Dynamic_bitset, 154
norm
qpp, 79
number_theory.h, 288

offset_
qpp::Dynamic_bitset, 154
omega
qpp, 80
one
qpp::States, 245
operations.h, 290
operator!=
qpp::Dynamic_bitset, 155
operator<<
qpp::IDisplay, 180
operator-
qpp::Dynamic_bitset, 155
operator=
qpp::IDisplay, 180
qpp::Timer, 256
qpp::internal::IOManipPointer, 187
qpp::internal::IOManipRange, 190
qpp::internal::Singleton, 238
operator==
qpp::Dynamic_bitset, 155
operator"" _bra
qpp::literals, 122
operator"" _i
qpp, 80
qpp::literals, 123
operator"" _ket
qpp::literals, 123
operator"" _prj
qpp::literals, 123

p_
qpp::internal::IOManipPointer, 188
pGHZ
qpp::States, 248
pb00
qpp::States, 247
pb01
qpp::States, 247
pb10
qpp::States, 247
pb11
qpp::States, 247
pi
qpp, 114
plus
qpp::States, 245
powm
qpp, 80
prj
qpp, 81
prng_
qpp::RandomDevices, 236
prod
qpp, 81, 82
ptrace
qpp, 82, 83

ptrace1
qpp, 83, 84
ptrace2
qpp, 84, 85
ptranspose
qpp, 85, 86
pW
qpp::States, 248
px0
qpp::States, 248
px1
qpp::States, 248
py0
qpp::States, 248
py1
qpp::States, 248
pz0
qpp::States, 249
pz1
qpp::States, 249

QFT
qpp, 86
QPP_UNUSED_
qpp.h, 293
qmutualinfo
qpp, 87
qpp, 13
absm, 28
abssq, 28, 29
adjoint, 29
anticomm, 30
apply, 30–32
applyCTRL, 33, 34
applyINVQFT, 34
applyQFT, 35
avg, 35
bigint, 26
bloch2rho, 36
bra, 26
choi2kraus, 36
choi2super, 37
chop, 113
cmat, 26
comm, 37
complement, 38
compperm, 38
concurrence, 38
conjugate, 40
contfrac2x, 40
cor, 41
cosm, 41
cov, 41
cplx, 26
cwise, 42
det, 42
dirsum, 43, 44
dirsumpow, 45
disp, 45–47
dmat, 26
dyn_col_vect, 26
dyn_mat, 27
dyn_row_vect, 27
ee, 113
egcd, 47
eig, 48
entanglement, 48, 49
entropy, 49, 50
eps, 113
evals, 50
evects, 51
expm, 51
factors, 51
funm, 52
gcd, 52, 53
gconcurrence, 53
grams, 54
heig, 55
hevals, 55
hevects, 56
INVQFT, 57
idx, 27
infty, 114
inverse, 56
invperm, 56
ip, 57, 58
isprime, 58
ket, 27
kraus2choi, 59
kraus2super, 59
kron, 60, 61
kronpow, 62
lcm, 62, 63
load, 63
loadMATLAB, 64
logdet, 65
logm, 65
lognegativity, 66
marginalX, 67
marginalY, 67
maxn, 114
measure, 67–72
measure_seq, 73
mket, 74
modinv, 75
modmul, 76
modpow, 76
mprj, 77
multiidx2n, 78
n2multiidx, 78
negativity, 79
norm, 79
omega, 80
operator"" _i, 80
pi, 114
powm, 80
prj, 81

prod, 81, 82
ptrace, 82, 83
ptrace1, 83, 84
ptrace2, 84, 85
ptranspose, 85, 86
QFT, 86
qmutualinfo, 87
rand, 88–90
randH, 90
randidx, 91
randket, 91
randkraus, 91
randn, 92, 93
randperm, 94
randprime, 94
randprob, 95
randrho, 95
randU, 95
randV, 96
renyi, 96, 97
reshape, 97
rho2bloch, 98
rho2pure, 98
save, 99
saveMATLAB, 99, 100
schatten, 100
schmidtA, 101
schmidtB, 101, 102
schmidtcoeffs, 102, 103
schmidtprobs, 103, 104
sigma, 104
sinm, 105
spectralpowm, 105
sqrtm, 106
sum, 106, 107
super2choi, 107
svals, 108
svd, 108
svdU, 108
svdV, 109
syspermute, 109, 110
to_void, 28
trace, 110
transpose, 110
tsallis, 111
uniform, 112
var, 112
x2contfrac, 113

qpp.h, 292
QPP_UNUSED_, 293

qpp::Bit_circuit, 125
Bit_circuit, 127
CNOT, 127
FRED, 127
gate_count, 130
NOT, 128
reset, 128
SWAP, 128
TOF, 129
X, 129

qpp::Bit_circuit::Gate_count, 164
CNOT, 164
FRED, 165
NOT, 165
SWAP, 165
TOF, 165
X, 165

qpp::Codes, 130
∼Codes, 132
Codes, 132
codeword, 132
internal::Singleton< const Codes >, 132
Type, 131

qpp::Dynamic_bitset, 148
all, 151
any, 151
count, 151
data, 151
display, 152
Dynamic_bitset, 150
flip, 153
get, 153
index_, 154
N_, 160
none, 154
offset_, 154
operator!=, 155
operator-, 155
operator==, 155
rand, 157
reset, 157, 158
set, 158
size, 159
storage_size, 159
storage_size_, 160
storage_type, 150
to_string, 159
v_, 160
value_type, 150

qpp::Gates, 166
∼Gates, 168
CNOTba, 175
CNOT, 175
CTRL, 168
CZ, 175
expandout, 169, 170
FRED, 176
Fd, 171
Gates, 168
H, 176
Id, 172
Id2, 176
internal::Singleton< const Gates >, 175
MODMUL, 172
Rn, 172
RX, 173

  RY, 173
  RZ, 173
  S, 176
  SWAPd, 174
  SWAP, 176
  T, 176
  TOF, 177
  X, 177
  Xd, 174
  Y, 177
  Z, 177
  Zd, 174
qpp::IDisplay, 178
  ∼IDisplay, 179
  display, 179
  IDisplay, 179
  operator<<, 180
  operator=, 180
qpp::Init, 181
  ∼Init, 182
  Init, 182
  internal::Singleton< const Init >, 182
qpp::RandomDevices, 233
  ∼RandomDevices, 235
  get_prng, 235
  internal::Singleton< RandomDevices >, 236
  load, 235
  prng_, 236
  RandomDevices, 234
  rd_, 236
  save, 235
qpp::States, 241
  ∼States, 243
  b00, 246
  b01, 246
  b10, 246
  b11, 247
  GHZ, 247
  internal::Singleton< const States >, 246
  jn, 244
  mes, 244
  minus, 244
  one, 245
  pGHZ, 248
  pb00, 247
  pb01, 247
  pb10, 247
  pb11, 247
  plus, 245
  pW, 248
  px0, 248
  px1, 248
  py0, 248
  py1, 248
  pz0, 249
  pz1, 249
  States, 243
  W, 249
  x0, 249
  x1, 249
  y0, 249
  y1, 250
  z0, 250
  z1, 250
  zero, 245
qpp::Timer
  ∼Timer, 254
  display, 255
  end_, 257
  get_duration, 255
  operator=, 256
  start_, 257
  tic, 256
  tics, 256
  Timer, 254
  toc, 256
qpp::Timer< T, CLOCK_T >, 252
qpp::exception, 114
qpp::exception::CustomException, 133
  CustomException, 134
  type_description, 135
  what_, 135
qpp::exception::DimsInvalid, 136
  type_description, 137
qpp::exception::DimsMismatchCvector, 137
  type_description, 139
qpp::exception::DimsMismatchMatrix, 139
  type_description, 140
qpp::exception::DimsMismatchRvector, 141
  type_description, 142
qpp::exception::DimsMismatchVector, 143
  type_description, 144
qpp::exception::DimsNotEqual, 145
  type_description, 146
qpp::exception::Exception, 161
  Exception, 163
  msg_, 164
  type_description, 163
  what, 163
  where_, 164
qpp::exception::MatrixMismatchSubsys, 198
  type_description, 199
qpp::exception::MatrixNotCvector, 199
  type_description, 201
qpp::exception::MatrixNotRvector, 201
  type_description, 202
qpp::exception::MatrixNotSquare, 203
  type_description, 204
qpp::exception::MatrixNotSquareNorCvector, 205
  type_description, 206
qpp::exception::MatrixNotSquareNorRvector, 207
  type_description, 208
qpp::exception::MatrixNotSquareNorVector, 209
  type_description, 210
qpp::exception::MatrixNotVector, 211
  type_description, 212

qpp::exception::NoCodeword, 213
type_description, 214
qpp::exception::NotBipartite, 215
type_description, 216
qpp::exception::NotQubitCvector, 217
type_description, 218
qpp::exception::NotQubitMatrix, 219
type_description, 220
qpp::exception::NotQubitRvector, 221
type_description, 222
qpp::exception::NotQubitSubsys, 223
type_description, 224
qpp::exception::NotQubitVector, 225
type_description, 226
qpp::exception::OutOfRange, 227
type_description, 228
qpp::exception::PermInvalid, 229
type_description, 230
qpp::exception::PermMismatchDims, 231
type_description, 232
qpp::exception::SizeMismatch, 239
type_description, 240
qpp::exception::SubsysMismatchDims, 251
type_description, 252
qpp::exception::TypeMismatch, 258
type_description, 259
qpp::exception::UndefinedType, 259
type_description, 261
qpp::exception::Unknown, 261
type_description, 262
qpp::exception::ZeroSize, 263
type_description, 264
qpp::experimental, 116
qpp::internal, 116
check_cvector, 117
check_dims, 118
check_dims_match_cvect, 118
check_dims_match_mat, 118
check_dims_match_rvect, 118
check_eq_dims, 118
check_matching_sizes, 118
check_nonzero_size, 119
check_perm, 119
check_qubit_cvector, 119
check_qubit_matrix, 119
check_qubit_rvector, 119
check_qubit_vector, 119
check_rvector, 120
check_square_mat, 120
check_subsys_match_dims, 120
check_vector, 120
dirsum2, 120
get_dim_subsys, 120
get_num_subsys, 121
kron2, 121
multiidx2n, 121
n2multiidx, 121
variadic_vector_emplace, 121
qpp::internal::Display_Impl_, 147
display_impl_, 147
qpp::internal::IOManipEigen, 183
A_, 184
chop_, 185
display, 184
IOManipEigen, 184
qpp::internal::IOManipPointer
display, 187
end_, 187
IOManipPointer, 186, 187
N_, 188
operator=, 187
p_, 188
separator_, 188
start_, 188
qpp::internal::IOManipPointer< PointerType >, 185
qpp::internal::IOManipRange
display, 190
end_, 191
first_, 191
IOManipRange, 190
last_, 191
operator=, 190
separator_, 191
start_, 191
qpp::internal::IOManipRange< InputIterator >, 189
qpp::internal::Singleton
~Singleton, 238
get_instance, 238
get_thread_local_instance, 238
operator=, 238
Singleton, 238
qpp::internal::Singleton< T >, 237
qpp::is_complex< std::complex< T > >, 193
qpp::is_complex< T >, 192
qpp::is_iterable< T, to_void< decltype(std::declval< T >().begin()), decltype(std::declval< T >().←end()), typename T::value_type > >, 195
qpp::is_iterable< T, typename >, 194
qpp::is_matrix_expression< Derived >, 196
qpp::literals, 122
operator"" _bra, 122
operator"" _i, 123
operator"" _ket, 123
operator"" _prj, 123
qpp::make_void
type, 197
qpp::make_void< Ts >, 197

rand
qpp, 88–90
qpp::Dynamic_bitset, 157
randH
qpp, 90
randidx
qpp, 91
randket
qpp, 91

randkraus
qpp, 91
randn
qpp, 92, 93
random.h, 294
RandomDevices
qpp::RandomDevices, 234
randperm
qpp, 94
randprime
qpp, 94
randprob
qpp, 95
randrho
qpp, 95
randU
qpp, 95
randV
qpp, 96
rd_
qpp::RandomDevices, 236
renyi
qpp, 96, 97
reset
qpp::Bit_circuit, 128
qpp::Dynamic_bitset, 157, 158
reshape
qpp, 97
rho2bloch
qpp, 98
rho2pure
qpp, 98
Rn
qpp::Gates, 172
RX
qpp::Gates, 173
RY
qpp::Gates, 173
RZ
qpp::Gates, 173

S
qpp::Gates, 176
SWAPd
qpp::Gates, 174
SWAP
qpp::Bit_circuit, 128
qpp::Bit_circuit::Gate_count, 165
qpp::Gates, 176
save
qpp, 99
qpp::RandomDevices, 235
saveMATLAB
qpp, 99, 100
schatten
qpp, 100
schmidtA
qpp, 101
schmidtB
qpp, 101, 102
schmidtcoeffs
qpp, 102, 103
schmidtprobs
qpp, 103, 104
separator_
qpp::internal::IOManipPointer, 188
qpp::internal::IOManipRange, 191
set
qpp::Dynamic_bitset, 158
sigma
qpp, 104
Singleton
qpp::internal::Singleton, 238
sinm
qpp, 105
size
qpp::Dynamic_bitset, 159
spectralpowm
qpp, 105
sqrtm
qpp, 106
start_
qpp::Timer, 257
qpp::internal::IOManipPointer, 188
qpp::internal::IOManipRange, 191
States
qpp::States, 243
statistics.h, 295
storage_size
qpp::Dynamic_bitset, 159
storage_size_
qpp::Dynamic_bitset, 160
storage_type
qpp::Dynamic_bitset, 150
sum
qpp, 106, 107
super2choi
qpp, 107
svals
qpp, 108
svd
qpp, 108
svdU
qpp, 108
svdV
qpp, 109
syspermute
qpp, 109, 110

T
qpp::Gates, 176
TOF
qpp::Bit_circuit, 129
qpp::Bit_circuit::Gate_count, 165
qpp::Gates, 177
tic
qpp::Timer, 256
tics

qpp::Timer, 256
Timer
qpp::Timer, 254
to_string
qpp::Dynamic_bitset, 159
to_void
qpp, 28
toc
qpp::Timer, 256
trace
qpp, 110
traits.h, 296
transpose
qpp, 110
tsallis
qpp, 111
Type
qpp::Codes, 131
type
qpp::make_void, 197
type_description
qpp::exception::CustomException, 135
qpp::exception::DimsInvalid, 137
qpp::exception::DimsMismatchCvector, 139
qpp::exception::DimsMismatchMatrix, 140
qpp::exception::DimsMismatchRvector, 142
qpp::exception::DimsMismatchVector, 144
qpp::exception::DimsNotEqual, 146
qpp::exception::Exception, 163
qpp::exception::MatrixMismatchSubsys, 199
qpp::exception::MatrixNotCvector, 201
qpp::exception::MatrixNotRvector, 202
qpp::exception::MatrixNotSquare, 204
qpp::exception::MatrixNotSquareNorCvector, 206
qpp::exception::MatrixNotSquareNorRvector, 208
qpp::exception::MatrixNotSquareNorVector, 210
qpp::exception::MatrixNotVector, 212
qpp::exception::NoCodeword, 214
qpp::exception::NotBipartite, 216
qpp::exception::NotQubitCvector, 218
qpp::exception::NotQubitMatrix, 220
qpp::exception::NotQubitRvector, 222
qpp::exception::NotQubitSubsys, 224
qpp::exception::NotQubitVector, 226
qpp::exception::OutOfRange, 228
qpp::exception::PermInvalid, 230
qpp::exception::PermMismatchDims, 232
qpp::exception::SizeMismatch, 240
qpp::exception::SubsysMismatchDims, 252
qpp::exception::TypeMismatch, 259
qpp::exception::UndefinedType, 261
qpp::exception::Unknown, 262
qpp::exception::ZeroSize, 264
types.h, 298

uniform
qpp, 112

v_
qpp::Dynamic_bitset, 160
value_type
qpp::Dynamic_bitset, 150
var
qpp, 112
variadic_vector_emplace
qpp::internal, 121

W
qpp::States, 249
what
qpp::exception::Exception, 163
what_
qpp::exception::CustomException, 135
where_
qpp::exception::Exception, 164

X
qpp::Bit_circuit, 129
qpp::Bit_circuit::Gate_count, 165
qpp::Gates, 177
x0
qpp::States, 249
x1
qpp::States, 249
x2contfrac
qpp, 113
Xd
qpp::Gates, 174

Y
qpp::Gates, 177
y0
qpp::States, 249
y1
qpp::States, 250

Z
qpp::Gates, 177
z0
qpp::States, 250
z1
qpp::States, 250
Zd
qpp::Gates, 174
zero
qpp::States, 245