

Index

- o-separable, *see* separable
- \otimes -separable, *see* separable
- abstract tensor system, 75, 146
- adjacency matrix, 165
- adjoint, 103
 - ‘good’ adjoints, 106
 - interpretation, 104
 - linear algebraic, 108
 - matrix, 165
- algebra, 43, 434, 498
 - associativity, 434
 - commutative, 501
 - commutativity, 434
 - semi-simple, 501
 - unitality, 434
- algebraic vs. diagrammatic language, 50
- algorithm, 679
- antipode, 616
- anti spider, 778, 801
- anti-unitary, 353
- automated reasoning, 790
 - proof strategy, 795
- baby, xvi, 29
- balanced function, 706
- ‘bang-box’, 798
- basis, 157
 - of singletons, 158
- Bayesian inversion, 436
- Bayesian updating, 364, 397
- Bell basis, 218
- Bell correction, 332
- Bell inequality, 552
- Bell–Kochen–Specker theorem, 398
- Bell maps, 220
- Bell matrices, 220
- Bell measurement, 332, 362
 - non-demolition, 367
- Bell state/effect, 92, 464
- bialgebra, 565, 616
 - path matrix, 620
- bipartite state, 85
- bit, 2, 443
- bit strings, 53, 443
- Bloch ball, 302
- Bloch sphere, 259
- Born rule, 62
 - generalised, 62
- boxes and wires, 29
- broadcasting, 306, 432
- C*-algebra, 502
 - quantum, 502
- canonical commutation relations, 573
- Cartesian product, 53
- causal structure, 49
- causality
 - causal cq-map, 421
 - causal quantum map, 292
 - causal quantum state, 283
 - causal structure, 311
 - quantum process, 319
- Choi’s theorem, 326
- Choi–Jamiołkowski isomorphism, 90
- circle group $U(1)$, 524
- circuit diagram, 46
 - characterisation, 48
- circuit model, 212
- classical correlation, 473
- classical data copying, 330
- classical map, 424
- classical process, 424
 - deterministic, 426
- classical state
 - copiability of, 427
 - deterministic, 426
 - full support, 437
 - inverse, 436
- classical subgroup, 568
 - closure, 568
- classical wire, 253, 331

- Clifford diagram, 586
 - graph-form, 603
- Clifford maps**, 581
- Clifford+T diagram, 609
 - approximate universality, 609
- coalgebra, 43, 499
 - coassociative, 432
 - cocommutative, 432
 - comonoid homomorphism, 432
 - comultiplication, 432
 - count, 432
- coarse graining, 374
- cobordism, 508
- commutative diagram, 245
- commutative group, 522
- complementary, 529
- complete bipartite diagram, 563
- completely positive map, 291
- completeness
 - of spek ZX-calculus for **spek**, 674
 - of spider diagrams for **linear maps**, 453
 - of string diagrams for **linear maps**, 223
 - of ZX-calculus for **Clifford maps**, 608
 - of ZX-calculus for **single qubit Clifford+T maps**, 609
- complex number, 201
 - conjugation, 201
 - polar form, 202
 - positive definiteness, 203
- composition
 - parallel, 44
 - sequential, 45
- computation, 679
- conjecture synthesis, 800
- conjugate, 108
- constant function, 702
- control qubit, 684
- conversion rate, 743
- convex combination, *see* mixture
- copy spider, 215
- correlations, 657
- cosine-sine decomposition, 696
- covariance, 316
- CP***, 505
- CPM-construction, 339, 344
- criss-cross cups/caps, 100
- cups and caps, 90
 - matrix form, 194
- de Broglie–Bohm theory, 398, 656
- decoherence, 368, 459
 - decoherent state, 461
 - partial, 463
 - time, 463
- decomposition, 47
- dense coding, 485
 - density operator, 257
- depolarizing channel, 748
- derivation, 792
- Deutsch–Jozsa algorithm, 702
- diagonalisation, 182; *see also* spectral theorem
- diagram, 30
 - equation, 38
 - formula, 37
 - only connectivity matters, 35
 - substitution, 42
- dilation, Naimark, 327, 383
- dimension, 157
 - dimension theorem, 157, 209
 - is the circle, 176
- Dirac notation, 70
- direct sum, 622
- directed acyclic, 48
- discarding process, 253, 274, 276
- discarding structure, 340
- disentangled state, 473
- dodo
 - classical, 15
 - quantum, 2
- double slit experiment, 359
- doubling, 253, 338
- doubly stochastic map, 751
- dual type, 146
- Eckmann–Hilton argument, 62
- effect, 60
- eigenstate, 182, 356
- Einstein, Podolsky, and Rosen (EPR) paper, 7
- empty system, 45
- enriched category, 240
- ensembles, 304
- entangled state, 265, 473
- entanglement resource, 602
- entanglement swapping, 370, 486
- entropy, 745
 - Shannon, 756
 - von Neumann, 756
- epistemic state, 675
- EPR, *see* Einstein, Podolsky, and Rosen paper
- equal up to a number, \approx , 68
- equivalence of categories, 200, 243
- equivalent resources, 741
- Euler angles, 584
- Euler decomposition, 584
- expectation value, 380
- folding diagrams, 466
- foliation, 49, 316
- Fourier basis, 517
- free process, 740
- free process theory, 39

- Frobenius algebra, 499
 - dagger special, 500
 - pants algebra, 502
 - symmetric, 502
- full (Schmidt) rank, 128
- functions**, 40, 52
 - are separable, 85
 - states, effects, and numbers, 63
- gates
 - AND, 211
 - CNOT, 212, 264
 - $CX(\alpha)$, 689
 - $CZ(\alpha)$, 687
 - CZ-gate, 685
 - Hadamard, 217, 264, 600
 - NOT, 212, 264, 571
 - phase, 264, 525
 - quantum, 264, 525
 - T, 609
 - Toffoli, 691
 - XOR, 212
- generalised copy rule, 439
- generalised probabilistic theory, 662
- GHZ-state, 465
 - generalised, 465
- global phase, 253, 257
- grammar, 342
- graph state, 601, 719
 - brickwork state, 731
 - cluster state, 721
 - quantum, 721
 - in **spek**, 674
- graphical calculus, 581
- group, 522
 - action, 574
 - commutative, 522
 - cyclic, 579
 - generators, 717
 - group-sum, 522
 - homomorphism, 574, 713
 - inverse, 522
 - unit, 522
- group algebra, 617
- groupoid, 505
- Grover's algorithm, 712
- Hadamard product, 434
- Heisenberg picture, 355
- hidden subgroup problem, 580, 712
- hidden variable, 398, 656
- hidden variable model, *see* refinement
- high-level language, 9
- Hilbert space, 201
 - infinite dimensional, 238
 - set-theoretic definition, 226
- Hopf algebra, 616
- identity, 46
- identity matrix, 174
- impurity, 281, 757
- incompatible measurements, 547
- inner product, 113
 - Hilbert–Schmidt, 222
- interactive theorem prover, *see* proof assistant
- interpretation $\llbracket \cdot \rrbracket$, 224, 407
- interpretations of quantum theory, 397
 - many-worlds, 397
- isometry, 117
- joint system-type, 44
- knot theory, 242
 - Jones polynomial, 243
- Kraus decomposition, 299
- lattice
 - distibutive, 399
 - orthomodular, 401
- LCF paradigm, 803
- light cone, 311
- linear maps**, 201
- local Clifford unitaries, 602
- local complementation, 603
- local exchangeability axiom, 789
- local states, 315
- LOCC maximal, 129, 759, 770
- logic, of interaction, 12
- logic gate, 211
- low-level lanuage, 9
- majorization order, 750
- marginal distribution, 428
- marginalisation, 428
- matrix, 163
 - columns, 177
 - of an isometry, 178
 - Kronecker product, 192
 - process theories of matrices, 198
 - product, 187
 - of a unitary, 179
- matrix calculus, 59, 187
- maximally entangled state, 129
- maximally mixed state, 279
- meaning in context (Wittgenstein), 398
- measure
 - additive, 745
 - supremal, 746
- measurement, 273
 - backaction, 364
 - collapse, 367
 - commuting von Neumann, 379
 - demolition, 350
 - non-demolition, 355
 - ONB, 322, 350

- outcome, 350
- POVM, 380
- von Neumann, 372
- measurement-based quantum computation, 366, 601
 - feed-forward, 720, 724
 - universality, 730
- measurement problem, 397
- measurement scenario, 657
 - GHZ-Mermin, 658
- mixing, 298, 301
- mixture, 301
- models, of quantum computation, 680
- modular law, 404
- monoidal category, 77
 - circuit diagrams, 80
 - coherence, 79
 - compact closed, 150
 - dagger compact closed, 151
 - strict, 54, 77
 - symmetric, 78
 - traced, 80
- mutually unbiased ONBs, 535
 - maximal sets, 538
- natural isomorphism, 245
- no-go theorem, 125
 - cloning, 129
 - cloning (by unitary), 131
 - separability, 125
- noise map, 304, 748
- non-contextuality, 398
- non-determinism, 5
- non-locality, 7, 312, 656
 - GHZ-Mermin, 661
 - local realism, 656
- non-signalling, 312
- normal form, 558, 620
- normalised, 114
- number, 61
 - commutative monoid, 62, 240
- odd-parity function, 577
- one-time pad, 140
- one-way model, *see* measurement-based quantum computation
- ontic state, 675
- ontological model, *see* refinement
- orthonormal basis, 158
 - characterisation, 175
 - non-unique, 159
 - self-conjugate, 165
- parity
 - even-parity function, 577
 - even-parity state, 577
 - generalised parity map, 579
 - map, 577
 - odd-parity state, 578
- partial order, 311, 741
 - antisymmetry, 741
- partial trace, 101
- path counting, 566
- Pauli matrices, *see* Bell matrices
- perfect correlation, 437
- period, of a function, 718
- phase, 515
- phase state, 514
- plain wire, 46
- Planck's constant, 343
- Planck's law, 343
- positive, 118
 - \otimes -positive, 121
- positive number, 203
- positive super-operator, 292
- preorder, 741
- preordered monoid, 742
- probability distribution, 176
 - conditional, 435
 - joint, 435
 - point distribution, 177
 - prior, 435
 - uniform, 427
- process, definition, 29
 - equation, 39
- process theory, 12, 32
 - examples, 33
- process–state duality, 88
- product basis, 189
- projector, 122
 - orthogonal, 374
- promise problem, 703
- proof assistant, 790
- PROP, 622, 623
- pure quantum effect, 256
- pure quantum maps**, 261
- pure quantum state, 256
- purification, 289, 340
 - joint, 325
- purity, 757
- Pusey–Barrett–Rudolph theorem, 397
- quanta, 343
- quantum Bayesianism, 403
- quantum circuit, 264
- quantum circuit model, 680
 - universality, 691
- quantum graph state, 601
- quantum gravity, 13
- quantum group, 617
- quantum information theory, 757
- quantum instrument, 344
- quantum interference, 359

- quantum key distribution, 549
- quantum logic, 380, 399
- quantum maps**, 62, 287
 - states, effects, and numbers, 65
- quantum non-locality, 655
- quantum oracle, 543, 702
 - query, 706
- quantum pictorialism, 14, 83
- quantum process, 318, 331
 - branches and outcomes, 319
 - controlled, 329
 - non-deterministic, 319
- quantum repeater, *see* entanglement swapping
- quantum state, 280
- quantum Turing machine, 736
- quartets, of boxes, 110
- qubit, 2, 210, 258
- quotient group, 713
 - quotient map, 713

- rank, 773
- reduced map, 307, 458
- reduced state, 277
- refinement, 656
- Reichenbach's principle, 657
- relational converse, 107
- relationalism, 399
- relations**, 52
 - are non-separable, 85
 - notation, 56
 - parallel composition, 57
 - sequential composition, 57
 - states, effects, and numbers, 63
 - sums (union), 170
- relativity, 7
- relativity theory/special relativity, 310
- representation theory, 445
- resource, 738
 - convertibility diagram, 774
 - equivalence class, 774
- resource conversion, 738
- resource theory, 305, 738
 - catalysis-free, 744
 - non-interacting, 744
 - quantity-like, 744

- satisfiability problem, 699
- Schmidt decomposition, *see* singular value decomposition
- Schmidt rank, *see* rank
- Schrödinger picture, 355
- Schrödinger's cat, 397
- Schur product, 434
- search problem, 708
- self-conjugate process, 111
- self-transposed process, 99

- separable, 85
- set, 53
- SIC-POVM measurement, 389
- signalling, 312
- simplifier, 794
- singular value decomposition, 448
- SLOCC, 771
- SLOCC-maximal, 128
- space monkeys, 11
- spacetime, 309
- spatial separation, 310
- specification language, 406
- spectral decomposition, 446
- spectral theorem, 204
- spectrum, 206
- spek**, 664
 - spek ZX-calculus, 672
- spider, 439
 - bastard, 466
 - classical, 464
 - copying, 437
 - deleting, 421, 437
 - diagram, 451
 - encode, 416
 - equations, 445
 - fusion, 442
 - isomorphic, 782
 - matching, 437
 - measure, 415
 - phase, 517
 - quantum, 464
- spin, 348
- squared-norm, 114
 - impurity, 285
- state, 60
- Stern–Gerlach device, 347
- stochastic map, *see* classical process
- stochastic matrix, 425
- string diagram, 92
 - logical reading, 135
- strong complementarity, 560
 - generalised rule, 564, 800
 - κ -copy rule, 570
 - κ -eliminate rule, 573
 - κ -map-copy rule, 571
 - κ - κ' -commute rule, 572
- subgroup
 - annihilator of, 717
 - inclusion map, 712
- subtraction, 171
- sums, 167
 - closure of **quantum maps**, 300
 - distributivity, 168, 784
- superposition, 272, 356
- supplementary angles, 596
- swap, 46

- symmetric informationally complete measurement, 388
- system-type, 29
- teleportation, 6
 - classical, 139
 - with classical wires, 482
 - with complementary measurements, 552
 - quantum, 327
 - with string diagrams, 137
- temporal flow, 49
- tensor-style notation, 164
- time-reversal, 134
- tomography, 273, 385
 - local, 390
 - process, 391
 - state, 385
- total order, 744
- trace, 101
 - cyclicity, 102
 - of a matrix, 185
- transpose, 95
 - algebraic, 101
 - involution, 96
 - joint system, 100
 - matrix, 165
 - operator, 149
 - sliding boxes, 98
- trivial system, 45
- type, 29
- unbiased state, 512
- unitary, 117
 - controlled, 690
 - multiplexed, 690
- universal set of gates, 525, 691
- von Neumann, John, 6
- von Neumann algebra, 403
- von Neumann's quantum formalism, 377
- W-state, 775
- weakest precondition semantics, 404
- Wedderburn's theorem, 501
- weight, 283
- Wigner's friend, 397
- Wigner's theorem, 353
- X-basis, 214
- X_α -measurement, 722
- yanking equations, 90
- Z-basis, 210
- Z-measurement, 722
- zero process, 67
- zero relation, 66
- ZX-calculus, 589
 - colour change, 601
 - equivalent presentation, 600
 - general supplementarity, 610
 - local complementation rule, 606
- Y-rule, 589
- $\frac{\pi}{2}$ -supplementarity, 595
- π -commute, 592
- π -copy, 596
- ZX-diagram, 582