
Contents

Preface

page ix

	PART I AREAS OF APPLICATION	1
1	Condensed matter physics	4
	1.1 Fermi–Hubbard model	5
	1.2 Spin models	15
	1.3 SYK model	24
2	Quantum chemistry	29
	2.1 Simulating electrons in molecules and materials	29
	2.2 Simulating vibrations in molecules and materials	45
3	Nuclear and particle physics	51
	3.1 Quantum field theories	51
	3.2 Nuclear physics	57
4	Combinatorial optimization	62
	4.1 Search algorithms à la Grover	63
	4.2 Beyond quadratic speedups in exact combinatorial optimization	68
5	Continuous optimization	78
	5.1 Zero-sum games: Computing Nash equilibria	78
	5.2 Conic programming: Solving LPs, SOCPs, and SDPs	82
	5.3 General convex optimization	90
	5.4 Nonconvex optimization: Escaping saddle points and finding local minima	94
6	Cryptanalysis	98
	6.1 Breaking cryptosystems	99

6.2	Weakening cryptosystems	107
7	Solving differential equations	111
8	Finance	130
8.1	Portfolio optimization	132
8.2	Monte Carlo methods: Option pricing	140
9	Machine learning with classical data	148
9.1	Quantum machine learning via quantum linear algebra	149
9.2	Quantum machine learning via energy-based models	160
9.3	Tensor PCA	169
9.4	Topological data analysis	173
9.5	Quantum neural networks and quantum kernel methods	179
	PART II QUANTUM ALGORITHMIC PRIMITIVES	185
10	Quantum linear algebra	188
10.1	Block-encodings	189
10.2	Manipulating block-encodings	195
10.3	Quantum signal processing	198
10.4	Qubitization	201
10.5	Quantum singular value transformation	205
11	Hamiltonian simulation	210
11.1	Product formulas	211
11.2	qDRIFT	216
11.3	Taylor and Dyson series (linear combination of unitaries)	218
11.4	Quantum signal processing / quantum singular value transformation	222
12	Quantum Fourier transform	225
13	Quantum phase estimation	228
14	Amplitude amplification and estimation	235
14.1	Amplitude amplification	235
14.2	Amplitude estimation	238
15	Gibbs sampling	243
16	Quantum adiabatic algorithm	250
17	Loading classical data	255
17.1	Quantum random access memory	255
17.2	Preparing quantum states from classical data	259
17.3	Block-encoding dense matrices of classical data	266

18	Quantum linear system solvers	270
19	Quantum gradient estimation	276
20	Variational quantum algorithms	281
21	Quantum tomography	286
22	Quantum interior point methods	291
23	Multiplicative weights update method	299
24	Approximate tensor network contraction	305
	 PART III FAULT-TOLERANT QUANTUM COMPUTING	 311
25	Basics of fault tolerance	314
26	Quantum error correction with the surface code	320
27	Logical gates with the surface code	325
<i>Appendix</i>	Background, conventions, and notation	332
	A.1 Quantum systems and bra-ket notation	333
	A.2 The quantum circuit model	336
	A.3 Noise in quantum gates and the NISQ era	338
	A.4 Big- $\mathcal{O}$ notation	339
	A.5 Complexity theory background	341
	 <i>References</i>	 346
	<i>Index</i>	415

