

Quantum Algorithms

The 1994 discovery of Shor's quantum algorithm for integer factorization—an important practical problem in the area of cryptography—demonstrated quantum computing's potential for real-world impact. Since then, researchers have worked intensively to expand the list of practical problems that quantum algorithms can solve effectively.

This book surveys the fruits of this effort, covering proposed quantum algorithms for concrete problems in many application areas, including quantum chemistry, optimization, finance, and machine learning. For each quantum algorithm considered, the book clearly states the problem being solved and the full computational complexity of the procedure, making sure to account for the contribution from all the underlying primitive ingredients. Separately, the book provides a detailed, independent summary of the most common algorithmic primitives. It has a modular, encyclopedic format to facilitate navigation of the material and to provide a quick reference for designers of quantum algorithms and quantum computing researchers.

ALEXANDER M. DALZELL is a Research Scientist at the Amazon Web Services Center for Quantum Computing.

SAM McARDLE is a Research Scientist at the Amazon Web Services Center for Quantum Computing.

MARIO BERTA is a Professor of Physics at the Institute for Quantum Information at RWTH Aachen University and a Visiting Reader in the Department of Computing at Imperial College London.

PRZEMYŚLAW BIENIAS is a Research Scientist at the Amazon Web Services Center for Quantum Computing.

CHI-FANG CHEN is a Postdoctoral Scholar in the Department of Electrical Engineering and Computer Sciences at the University of California, Berkeley.

ANDRÁS GILYÉN is a Research Fellow in the Department of Probability and Statistics at the HUN-REN Alfréd Rényi Institute of Mathematics.

CONNOR T. HANN is a Senior Research Scientist at the Amazon Web Services Center for Quantum Computing.

MICHAEL J. KASTORYANO is an Associate Professor of Quantum Computing at the University of Copenhagen and an Amazon Visiting Academic at the Amazon Web Services Center for Quantum Computing.

EMIL T. KHABIBOULLINE is a National Resource Council Postdoctoral Associate at the Joint Center for Quantum Information and Computer Science (QuICS) of the University of Maryland, College Park, and the National Institute of Standards and Technology.

ALEKSANDER KUBICA is an Assistant Professor in the Department of Applied Physics at Yale University.

GRANT SALTON is a Senior Research Scientist at the Amazon Quantum Solutions Lab and the Amazon Web Services Center for Quantum Computing.

SAMSON WANG is a Postdoctoral Scholar at the Institute for Quantum Information and Matter at Caltech.

FERNANDO G. S. L. BRANDÃO is Director of Quantum Applications at the Amazon Web Services Center for Quantum Computing and Bren Professor of Theoretical Physics at Caltech.

Quantum Algorithms

A Survey of Applications and End-to-end Complexities

ALEXANDER M. DALZELL

AWS Center for Quantum Computing

SAM McARDLE

AWS Center for Quantum Computing

MARIO BERTA

RWTH Aachen University and Imperial College London

PRZEMYSŁAW BIENIAS

AWS Center for Quantum Computing

CHI-FANG CHEN

University of California, Berkeley

ANDRÁS GILYÉN

HUN-REN Alfréd Rényi Institute of Mathematics

CONNOR T. HANN

AWS Center for Quantum Computing

MICHAEL J. KASTORYANO

University of Copenhagen and AWS Center for Quantum Computing

EMIL T. KHABIBOULLINE

*National Institute of Standards and Technology and University
of Maryland, College Park*

ALEKSANDER KUBICA

Yale University

GRANT SALTON

Amazon Quantum Solutions Lab and AWS Center for Quantum Computing

SAMSON WANG

Caltech

FERNANDO G. S. L. BRANDÃO

AWS Center for Quantum Computing and Caltech



CAMBRIDGE
UNIVERSITY PRESS



Shaftesbury Road, Cambridge CB2 8EA, United Kingdom

One Liberty Plaza, 20th Floor, New York, NY 10006, USA

477 Williamstown Road, Port Melbourne, VIC 3207, Australia

314–321, 3rd Floor, Plot 3, Splendor Forum, Jasola District Centre,
New Delhi – 110025, India

103 Penang Road, #05–06/07, Visioncrest Commercial, Singapore 238467

Cambridge University Press is part of Cambridge University Press & Assessment,
a department of the University of Cambridge.

We share the University's mission to contribute to society through the pursuit of
education, learning and research at the highest international levels of excellence.

www.cambridge.org

Information on this title: www.cambridge.org/9781009639644

DOI: [10.1017/9781009639651](https://doi.org/10.1017/9781009639651)

© Amazon Technologies, Inc., California Institute of Technology, and Alfréd Rényi
Institute of Mathematics 2025

This publication is in copyright. Subject to statutory exception and to the provisions
of relevant collective licensing agreements, no reproduction of any part may take
place without the written permission of Cambridge University Press & Assessment.

An online version of this work is published at doi.org/10.1017/9781009639651 under
a Creative Commons Open Access license CC-BY-NC-ND 4.0 which permits re-use,
distribution and reproduction in any medium for non-commercial purposes providing
appropriate credit to the original work is given. You may not distribute derivative
works without permission. To view a copy of this license, visit

<https://creativecommons.org/licenses/by-nc-nd/4.0>

When citing this work, please include a reference to the DOI [10.1017/9781009639651](https://doi.org/10.1017/9781009639651)

First published 2025

Cover image: [ArtHead/Shutterstock.com](https://www.arthead.com)

A catalogue record for this publication is available from the British Library

*A Cataloging-in-Publication data record for this book is available from the Library
of Congress*

ISBN 978-1-009-63964-4 Hardback

ISBN 978-1-009-63966-8 Paperback

Cambridge University Press & Assessment has no responsibility for the persistence
or accuracy of URLs for external or third-party internet websites referred to in this
publication and does not guarantee that any content on such websites is, or will
remain, accurate or appropriate.

For EU product safety concerns, contact us at Calle de José Abascal, 56, 1º, 28003
Madrid, Spain, or email eugpsr@cambridge.org.