MODEL CHECKING QUANTUM SYSTEMS

Model checking is one of the most successful verification techniques and has been widely adopted in traditional computing and communication hardware and software industries.

This book provides the first systematic introduction to model-checking techniques applicable to quantum systems, with broad potential applications in the emerging industry of quantum computing and quantum communication as well as quantum physics.

Suitable for use as a course textbook and for self-study, graduate and senior undergraduate students will appreciate the step-by-step explanations and the exercises included. Researchers and engineers in the related fields can further develop these techniques in their own work, with the final chapter outlining potential future applications.

MINGSHENG YING is Distinguished Professor in the Centre for Quantum Software and Information, University of Technology Sydney; Deputy Director for Research of the Institute of Software, Chinese Academy of Sciences; and Cheung Kong Chair Professor in the Department of Computer Science and Technology, Tsinghua University. His research interests are quantum computing, programming theory and logics in artificial intelligence. He is the author of the books *Foundations of Quantum Programming* (2016) and *Topology in Process Calculus: Approximate Correctness and Infinite Evolution of Concurrent Programs* (2001). Currently, he serves as (Co-)Editor-in-Chief of *ACM Transactions on Quantum Computing*.

YUAN FENG is Professor in the Centre for Quantum Software and Information, University of Technology Sydney. His research interests include formal verification of quantum systems, the theory of quantum programming, quantum information and computation and probabilistic systems. He has published more than 70 research papers in international leading journals and mainstream conferences. He was awarded an ARC (Australian Research Council) Future Fellowship in 2010.

MODEL CHECKING QUANTUM SYSTEMS

Principles and Algorithms

MINGSHENG YING
University of Technology Sydney

YUAN FENG
University of Technology Sydney

CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE
UNIVERSITY PRESS

University Printing House, Cambridge CB2 8BS, 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

79 Anson Road, #06–04/06, Singapore 079906

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning, and research at the highest international levels of excellence.

www.cambridge.org
Information on this title: www.cambridge.org/9781108484305
DOI: 10.1017/9781108613323

First published 2021

Printed in the United Kingdom by TJ Books Limited, Padstow Cornwall

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

Library of Congress Cataloging-in-Publication Data
Names: Ying, Mingsheng, author. | Feng, Yuan, 1977– author.
Title: Model checking quantum systems : principles and algorithms / Mingsheng Ying,
University of Technology, Sydney, Yuan Feng, University of Technology, Sydney.
Description: Cambridge, UK ; New York, NY : Cambridge University Press,
2020. | Includes bibliographical references and index.
Identifiers: LCCN 2020041998 (print) | LCCN 2020041999 (ebook) | ISBN
9781108484305 (hardback) | ISBN 9781108613323 (epub)
Subjects: LCSH: Quantum computing. | Computer systems–Verification.
Classification: LCC QA76.889 .Y564 2020 (print) | LCC QA76.889 (ebook) |
DDC 006.3/843–dc23
LC record available at https://lccn.loc.gov/2020041998
LC ebook record available at https://lccn.loc.gov/2020041999

ISBN 978-1-108-48430-5 Hardback

Cambridge University Press
978-1-108-48430-5 — Model Checking Quantum Systems
Mingsheng Ying , Yuan Feng
Frontmatter
More Information

Contents

Preface

Model checking is an algorithmic technique for verification of dynamic properties of (mainly) finite state systems. After the development of more than 35 years, it has become a prominent verification technique for both hardware and software systems and has found numerous successful applications in the information and communications technology industries. The special attractiveness of model checking is due mainly to the following two features:

- It is completely automatic.
- It provides counterexamples whenever the properties are not satisfied and thus is very useful in debugging.

Since various stochastic phenomena occur in computing and communication systems, model checking has been systematically extended for verifying probabilistic systems, such as Markov chains and Markov decision processes.

With the emergence of quantum computing and quantum communication and, in particular, their rapid progress in the past few years, one may naturally expect to further extend the model-checking technique for verification of quantum systems. Indeed, research on model checking quantum systems has already been conducted for more than 10 years, starting from directly applying probabilistic model checking to quantum systems, in particular, quantum communication protocols. In dealing with more and more general quantum systems, it has been gradually realised that model checking quantum systems requires certain principles fundamentally different from those for classical systems (including probabilistic systems). Some basic principles for model checking quantum systems have been developed in recent research, but they are scattered in various conference and journal papers.

This book attempts to provide a systematic exposition of the principles for model checking quantum systems and the algorithms based on them, which have been proposed up to the writing of this book. Some potential applications and topics for future research are briefly discussed at the end of the book. We hope that the book can serve as an introduction to this new area for researchers and provide a basis for further development of the area.

The book is also intended to serve as a textbook for graduate students. It is therefore organised with a careful pedagogical consideration. Since the students in quantum computing and information may come from either a computer science or physics background, two preliminary chapters are given at the beginning of the book: the first briefly introduces model checking for those from physics, and the second briefly introduces quantum theory for those from computer science. After that, model-checking technique for quantum systems is presented step by step, from simpler models and checked properties to more sophisticated ones.

Acknowledgements

The materials of this book mainly come from a series of articles by the authors and their collaborators. The authors would like to thank Drs Nengkun Yu, Yangjia Li, Shenggang Ying and Ji Guan for pleasant and fruitful collaborations. Without their contributions, this book would not have been possible.

The work presented in this book has been partially supported by the National Key R&D Program of China (Grant No. 2018YFA0306701), the Australian Research Council (Grant Nos. DP160101652 and DP180100691), the National Natural Science Foundation of China (Grant No. 61832015) and the Key Research Program of Frontier Sciences, Chinese Academy of Sciences. All of them are gratefully acknowledged.