

Preface

Quantum computation provides a new way of computation based on so-called quantum bits (qubits). In contrast to the conventional bits used in Boolean logic, qubits do not only allow to represent the basis states 0 and 1, but also superpositions of both. By this, qubits can represent multiple states at the same time which enables massive parallelism. Additionally, exploiting further quantum-mechanical phenomena such as phase shifts or entanglement allows for the design of algorithms with an asymptotic speed-up for many relevant computational problems such as database search, integer factorization, or graph and algebraic problems.

Motivated by these prospects, researchers from various domains investigated this emerging technology. While, originally, the exploitation of quantum-mechanical phenomena has been discussed in a purely theoretical fashion, in the past decade also the consideration of physical realizations has gained significant interest. In fact, building a quantum computer is a very challenging task. Nonetheless and despite the severe physical challenges, suitable technologies for the modelling and design of powerful, large-scale quantum computers composed of dozens of usable qubits are in the range of vision.

However, for quantum systems of larger size, the manual design of quantum circuits which realize a given (quantum) functionality in technology is no longer an option. In order to keep up with the technological progress, methods need to be provided which, similar to the design and synthesis of conventional circuits, automatically generate a circuit description of the desired (quantum) functionality—finally leading to *Computer-Aided Design* (CAD) of quantum circuits.

But in order to formalize the quantum-mechanical phenomena, states of qubits are modelled as vectors in high-dimensional Hilbert spaces and are manipulated by quantum operations which are described by unitary matrices—possibly including complex numbers. This poses serious challenges to the representation, but even more to the development of proper and efficient methods for quantum circuit synthesis that would scale to quantum systems of considerable size. Hence, an efficient representation of the desired quantum functionality is of the essence.

In this book, we provide a comprehensive analysis of the challenges for a compact representation of quantum functionality, extensively review the

state-of-the-art in this area as well as describe in detail a proper solution in terms of *Quantum Multiple-Valued Decision Diagrams* (QMDDs). Based on QMDDs, we demonstrate applications where this compact representation can be exploited in order to develop scalable and automated methods for quantum circuit synthesis and verification. The book is written in order to be comprehensible for computer scientists as well as computer architects with little background in quantum logic and, thus, does not require previous knowledge about the underlying physics. The respective concepts as well as the used models are briefly introduced. All approaches are described in a self-contained manner. The content of the book does not only convey a coherent overview about current research results but also build the basis for future work on quantum logic CAD.

This book is the result of several years of intensive research in the area of quantum logic at the University of Bremen, Germany, and the Johannes Kepler University Linz, Austria. During this time, we experienced broad support from many people for which we would like to thank them very much.

Most importantly, we would like to thank Prof. Dr. *Rolf Drechsler* for his continuous support in all these years and for providing a comfortable and inspirational environment from which both authors benefit until today. We are also indebted to thank Prof. *D. Michael Miller* from the University of Victoria, Canada—one of the “fathers” of QMDDs—for many fruitful collaborations which laid the foundation of his book. The numerous inspiring discussions, the helpful comments and suggestions, and the thorough reading and review of this manuscript made this book possible. In this context, the German Academic Exchange Service (DAAD) earns our thanks for funding the close contact with Prof. Miller’s group. Beyond that, we are very thankful for the support by the European Union through the COST Action IC1405.

Many thanks also go to Prof. *Mitch Thornton* (Southern Methodist University, Texas, USA) and *Alwin Zulehner* (Johannes Kepler University Linz, Austria) for the very productive collaboration that resulted in some research papers which form the basis of this book.

Finally, we would like to thank the many people who contributed in further, more or less indirect ways to the completion of this book: In particular, the whole Group for Computer Architecture at the University of Bremen as well as the Institute for Integrated Circuits at the Johannes Kepler University earn many thanks for providing a comfortable and inspirational environment. Particularly, very special thanks go to *Oliver Keszöcze* with whom the first author of this book does not only share the same wavelength, but also a rather green office. Finally, we would like to thank *Arne Grenzebach* for proofreading the manuscript as well as for establishing the contact to *Sabine Lehr* (Associate Editor at Springer).

Bremen, Germany
Linz, Austria
June 2017

Philipp Niemann
Robert Wille

Compact Representations for the Design of Quantum
Logic

Niemann, P.; Wille, R.

2017, VIII, 125 p. 43 illus., 1 illus. in color., Softcover

ISBN: 978-3-319-63723-5