Jaroslaw Adam Miszczak

High-level Structures for Quantum Computing

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Nathaniel Cabot Thomas

High Level Structures For Quantum Computing Jaroslaw Miszczak:

High-level Structures for Quantum Computing Jaroslaw Adam Miszczak,2012 This book is concerned with the models of quantum computation Information processing based on the rules of quantum mechanics provides us with new opportunities for developing more efficient algorithms and protocols However to harness the power offered by quantum information processing it is essential to control the behavior of quantum mechanical objects in a precise manner As this seems to be conceptually difficult at the level of quantum states and unitary gates high level quantum programming languages have been proposed for this purpose The aim of this book is to provide an introduction to abstract models of computation used in quantum information theory Starting from the abstract models of Turing machine and finite automata we introduce the models of Boolean circuits and Random Access Machine and use them to present quantum programming techniques and quantum programming languages Table of Contents Introduction Turing machines Quantum Finite State Automata Computational Circuits Random Access Machines Quantum Programming Environment Quantum Programming Languages Imperative quantum programming Functional Quantum Programming Outlook *High Level Structures for Quantum Computing* Jaroslaw Miszczak,2022-05-31 This book is concerned with the models of quantum computation Information processing based on the rules of quantum mechanics provides us with new opportunities for developing more efficient algorithms and protocols However to harness the power offered by quantum information processing it is essential to control the behavior of quantum mechanical objects in a precise manner As this seems to be conceptually difficult at the level of quantum states and unitary gates high level quantum programming languages have been proposed for this purpose The aim of this book is to provide an introduction to abstract models of computation used in quantum information theory Starting from the abstract models of Turing machine and finite automata we introduce the models of Boolean circuits and Random Access Machine and use them to present quantum programming techniques and quantum programming languages Table of Contents Introduction Turing machines Quantum Finite State Automata Computational Circuits Random Access Machines Quantum Programming Environment Quantum Programming Languages Imperative quantum programming Functional Quantum Programming Outlook Approximability of Optimization Problems through Adiabatic Quantum Computation William Cruz-Santos,Guillermo Morales-Luna,2022-05-31 The adiabatic quantum computation AQC is based on the adiabatic theorem to approximate solutions of the Schr dinger equation The design of an AQC algorithm involves the construction of a Hamiltonian that describes the behavior of the quantum system This Hamiltonian is expressed as a linear interpolation of an initial Hamiltonian whose ground state is easy to compute and a final Hamiltonian whose ground state corresponds to the solution of a given combinatorial optimization problem The adiabatic theorem asserts that if the time evolution of a quantum system described by a Hamiltonian is large enough then the system remains close to its ground state An AQC algorithm uses the adiabatic theorem to approximate the ground state of the final Hamiltonian that corresponds to the solution of the given

optimization problem In this book we investigate the computational simulation of AQC algorithms applied to the MAX SAT problem A symbolic analysis of the AQC solution is given in order to understand the involved computational complexity of AQC algorithms This approach can be extended to other combinatorial optimization problems and can be used for the classical simulation of an AQC algorithm where a Hamiltonian problem is constructed This construction requires the computation of a sparse matrix of dimension 2n 2n by means of tensor products where n is the dimension of the quantum system Also a general scheme to design AQC algorithms is proposed based on a natural correspondence between optimization Boolean variables and quantum bits Combinatorial graph problems are in correspondence with pseudo Boolean maps that are reduced in polynomial time to quadratic maps Finally the relation among NP hard problems is investigated as well as its logical representability and is applied to the design of AQC algorithms It is shown that every monadic second order logic MSOL expression has associated pseudo Boolean maps that can be obtained by expanding the given expression and also can be reduced to quadratic forms Table of Contents Preface Acknowledgments Introduction Approximability of NP hard Problems Adiabatic Quantum Computing Efficient Hamiltonian Construction AQC for Pseudo Boolean Optimization A General Strategy to Solve NP Hard Problems Conclusions Bibliography Authors Biographies **Adiabatic Quantum Computation and Quantum Annealing** Catherine C. McGeoch,2022-06-01 Adiabatic quantum computation AQC is an alternative to the better known gate model of quantum computation The two models are polynomially equivalent but otherwise quite dissimilar one property that distinguishes AQC from the gate model is its analog nature Quantum annealing QA describes a type of heuristic search algorithm that can be implemented to run in the native instruction set of an AQC platform D Wave Systems Inc manufactures quantum annealing processor chips that exploit quantum properties to realize QA computations in hardware The chips form the centerpiece of a novel computing platform designed to solve NP hard optimization problems Starting with a 16 qubit prototype announced in 2007 the company has launched and sold increasingly larger models the 128 qubit D Wave One system was announced in 2010 and the 512 qubit D Wave Two system arrived on the scene in 2013 A 1 000 qubit model is expected to be available in 2014 This monograph presents an introductory overview of this unusual and rapidly developing approach to computation We start with a survey of basic principles of quantum computation and what is known about the AQC model and the QA algorithm paradigm Next we review the D Wave technology stack and discuss some challenges to building and using quantum computing systems at a commercial scale The last chapter reviews some experimental efforts to understand the properties and capabilities of these unusual platforms The discussion throughout is aimed at an audience of computer scientists with little background in quantum computation or in physics Table of Contents Acknowledgments Introduction Adiabatic Quantum Computation Quantum Annealing The D Wave Platform Computational Experience Bibliography Author s Biography **Quantum Robotics** Prateek Tandon,Stanley Lam,Ben Shih,Tanay Mehta,Alex Mitev,Zhiyang Ong,2022-05-31 Quantum robotics is an emerging engineering and scientific research discipline

that explores the application of quantum mechanics quantum computing quantum algorithms and related fields to robotics This work broadly surveys advances in our scientific understanding and engineering of quantum mechanisms and how these developments are expected to impact the technical capability for robots to sense plan learn and act in a dynamic environment It also discusses the new technological potential that quantum approaches may unlock for sensing and control especially for exploring and manipulating quantum scale environments Finally the work surveys the state of the art in current implementations along with their benefits and limitations and provides a roadmap for the future **Negative Quantum Channels** James M. McCracken,2022-05-31 This book is a brief introduction to negative quantum channels i e linear trace preserving and consistent quantum maps that are not completely positive The flat and sharp operators are introduced and explained Complete positivity is presented as a mathematical property but it is argued that complete positivity is not a physical requirement of all quantum operations Negativity a measure of the lack of complete positivity is proposed as a tool for empirically testing complete positivity assumptions Table of Contents Preface Acknowledgments Introduction and Definition of Terms Tomography Non Positive Reduced Dynamics Complete Positivity Physical Motivation of Complete Positivity Measures of Complete Positivity Negative Channels Negative Climates with Diagonal Composite Dynamics Rabi Channels Physical Motivations for Sharp Operations Negative Qubit Channel Examples with Multi Qubit Baths Proposed Experimental Demonstration of Negativity Implications of Negative Channels Uses for Negative Channels Conclusions Bibliography Author s Biography **Quantum Computer Architecture** Umar Farooq,2014-10-29 Seminar paper from the year 2014 in the subject Computer Science Applied grade A course Advance Computer Architecture language English abstract Quantum Computers are evolving for more than a decade and they are closer to reality The field of quantum computing is too big to be described in one paper but the real motivation for the quantum computers is its architecture Firstly it is believed that classical computers can t use the quantum algorithms and operations secondly the programs running on the quantum computers can t run on traditional computer which is due to architecture and system The quantum computer architecture is the key to build a quantum computer The quantum computers are more complex than traditional computers This research paper will discuss the quantum computer architecture **Quantum Computing for Computer Architects** Tzvetan S. Metodi,Frederic T. Chong,2022-12-06 Quantum computation may seem to be a topic for science fiction but small quantum computers have existed for several years and larger machines are on the drawing table These efforts have been fueled by a tantalizing property while conventional computers employ a binary representation that allows computational power to scale linearly with resources at best quantum computations employ quantum phenomena that can interact to allow computational power that is exponential in the number of quantum bits in the system Quantum devices rely on the ability to control and manipulate binary data stored in the phase information of quantum wave functions that describe the electronic states of individual atoms or the polarization states of photons While existing quantum technologies are in their infancy we

shall see that it is not too early to consider scalability and reliability In fact such considerations are a critical link in the development chain of viable device technologies capable oforchestrating reliable control of tens of millions quantum bits in a large scale system The goal of this lecture is to provide architectural abstractions common to potential technologies and explore the systemslevel challenges in achieving scalable fault tolerant quantum computation The central premise of the lecture is directed at quantum computation QC architectural issues We stress the fact that the basic tenet of large scale quantum computing is reliability through system balance the need to protect and control the quantum information just long enough for the algorithm to complete execution To architectQCsystems onemust understand what it takes to design and model a balanced fault tolerant quantum architecture just as the concept of balance drives conventional architectural design For example the register file depth in classical computers is matched to the number of functional units the memory bandwidth to the cache miss rate or the interconnect bandwidth matched to the compute power of each element of a multiprocessor We provide an engineering oriented introduction to quantum computation and provide an architectural case study based upon experimental data and future projection for ion trap technology We apply the concept of balance to the design of a quantum computer creating an architecture model that balances both quantum and classical resources in terms of exploitable parallelism in quantum applications From this framework we also discuss the many open issues remaining in designing systems to perform quantum computation Quantum computers can in theory solve certain problems far faster than a classical computer running any known classical algorithm While existing technologies for building quantum computers are in their infancy it is not too early to consider their scalability and reliability in the context of the design of large scale quantum computers To architect such systems one must understand what it takes to design and model a balanced fault tolerant quantum computer architecture The goal of this lecture is to provide architectural abstractions for the design of a quantum computer and to explore the systems level challenges in achieving scalable fault tolerant quantum computation In this lecture we provide an engineering oriented introduction to quantum computation with an overview of the theory behind key quantum algorithms Next we look at architectural case studies based upon experimental data and future projections for quantum computation implemented using trapped ions While we focus here on architectures targeted for realization using trapped ions the techniques for quantum computer architecture design quantum fault tolerance and compilation described in this lecture are applicable to many other physical technologies that may be viable candidates for building a large scale quantum computing system We also discuss general issues involved with programming a quantum computer as well as a discussion of work on quantum architectures based on quantum teleportation Finally we consider some of the open issues remaining in the design of quantum computers Table of Contents Introduction Basic Elements for Quantum Computation Key Quantum Algorithms

Building Reliable and Scalable Quantum Architectures Simulation of Quantum Computation Architectural Elements Case Study The Quantum Logic Array Architecture Programming the Quantum Architecture Using the QLA for Quantum Simulation The Transverse Ising Model Teleportation Based Quantum Architectures Concluding Remarks *Synthesis Lectures on Quantum Computing Vol. 16* Misczak,2012 This book is concerned with the models of quantum computation Information processing based on the rules of quantum mechanics provides us with new opportunities for developing more efficient algorithms and protocols However to harness the power offered by quantum information processing it is essential to control the behavior of quantum mechanical objects in a precise manner As this seems to be conceptually difficult at the level of quantum states and unitary gates high level quantum programming languages have been proposed for this purpose The aim of this book is to provide an introduction to abstract models of computation used in quantum information theory Starting from the abstract models of Turing machine and finite automata we introduce the models of Boolean circuits and Random Access Machine and use them to present quantum programming techniques and quantum programming languages

Quantum Computer Science Marco Lanzagorta,Jeffrey Uhlmann,2022-05-31 In this text we present a technical overview of the emerging field of quantum computation along with new research results by the authors What distinguishes our presentation from that of others is our focus on the relationship between quantum computation and computer science Specifically our emphasis is on the computational model of quantum computingrather than on the engineering issues associated with its physical implementation We adopt this approach for the same reason that a book on computer programming doesn t cover the theory and physical realization of semiconductors Another distinguishing feature of this text is our detailed discussion of the circuit complexity of quantum algorithms To the extent possible we have presented the material in a form that is accessible to the computer scientist but in many cases we retain the conventional physics notation so that the reader will also be able to consult the relevant quantum computing literature Although we expect the reader to have a solid understanding of linear algebra we do not assume a background in physics This text is based on lectures given as short courses and invited presentations around the world and it has been used as the primary text for a graduatecourse at George Mason University In all these cases our challenge has been the same how to present to a generalaudience a concise introduction to the algorithmic structure and applications of quantum computing on an extremely short period of time The feedback from these courses and presentations has greatly aided in making our exposition of challenging concepts more accessible to a general audience Table of Contents Introduction The Algorithmic Structure of Quantum Computing Advantages and Limitations of Quantum Computing Amplitude Amplification Case Study Computational Geometry The Quantum Fourier Transform Case Study The Hidden Subgroup Circuit Complexity Analysis of Quantum Algorithms Conclusions Bibliography   Quantum Computing for Computer Architects Tzvetan S. Metodi,Arvin I. Faruque,Frederic T. Chong,2011 Quantum computation may seem to be a topic for science fiction but small quantum computers have existed for

several years and larger machines are on the drawing table These efforts have been fueled by a tantalizing property while conventional computers employ a binary representation that allows computational power to scale linearly with resources at best quantum computations employ quantum phenomena that can interact to allow computational power that is exponential in the number of quantum bits in the system Quantum devices rely on the ability to control and manipulate binary data stored in the phase information of quantum wave functions that describe the electronic states of individual atoms or the polarization states of photons While existing quantum technologies are in their infancy we shall see that it is not too early to consider scalability and reliability In fact such considerations are a critical link in the development chain of viable device technologies capable of orchestrating reliable control of tens of millions quantum bits in a large scale system The goal of this lecture is to provide architectural abstractions common to potential technologies and explore the systems level challenges in achieving scalable fault tolerant quantum computation **Methodologies for Quantum Circuit and Algorithm Design at Low and High Levels** ,2022 Although the concept of quantum computing has existed for decades the technology needed to successfully implement a quantum computing system has not yet reached the level of sophistication reliability and scalability necessary for commercial viability until very recently Any viable computing system requires both hardware and software to work together harmoniously in order to perform useful computations While the achievements of IBM and other companies represent a large step forward for quantum hardware many gaps remain to be filled with respect to the corresponding software Specifically there is currently no clear path towards a complete process for translating quantum algorithms into physical operations that are directly executable on quantum hardware Such a process is analogous to a compiler that translates programs written in a high level language into executable machine instructions on a conventional digital computer and it is necessary if quantum computers are to be harnessed to perform practically useful computations Existing work has addressed individual components of this process but so far no unified method for translating the whole of a quantum algorithm into executable operations has been described I make substantial progress towards filling this gap by describing a set of high level and low level quantum circuit design techniques which when taken together reduce the need of a circuit designer to be concerned with low level details On the high level side I describe an approach or strategy to designing quantum oracles for Grover s algorithm that allows it to be applied to several types of problems **Silicon Enhancement Mode Structures for Quantum Computing** ,2010 **A Practical Guide to Quantum Computing** Elías F. Combarro,Samuel González-Castillo,2025-07-30 Learn about quantum information processing with Qiskit through hands on projects A foundational resource for STEM professionals researchers and university students interested in quantum computers and algorithms Key Features Understand the theoretical foundations of quantum computing Learn how to use the Qiskit framework and how to run quantum algorithms with it Discover top quantum algorithms like Grover s search and Shor s factoring methods Purchase of the print or Kindle book includes a free PDF eBook Book Description This book is an

introduction from scratch to quantum computing and the most important and foundational quantum algorithms ranging from humble protocols such as Deutsch s algorithm to ones with far reaching potential such as Shor s factoring algorithm offering clear explanations and a hands on approach with runnable code on simulators and real hardware The book is self contained and does not assume any previous experience in quantum computing Starting with a single qubit it scales to algorithms using superposition and entanglement At every step examples of applications are provided including how to create quantum money that is impossible to forge quantum cryptography that cannot be broken and algorithms for searching and factoring that are much faster than those that regular non quantum computers can use Code for each of these algorithms is provided and explained in detail using Qiskit 2 1 After reading this book you will understand how quantum algorithms work how to write your own quantum programs and how to run them on quantum simulators and actual quantum computers You will also be prepared to take the jump into quantum algorithms for optimization and artificial intelligence like those presented in our previous book A Practical Guide to Quantum Machine Learning and Quantum Optimization What you will learn Understand what makes a quantum computer unique Mathematically represent the state of multi qubit systems Describe the effects of measurements in quantum computers Know how quantum superposition entanglement and interference work Implement and run any quantum algorithm in Qiskit Understand how Shor s and Grover s algorithms work Gain familiarity with quantum fault tolerance and quantum advantage Who this book is for This book would be ideal for university level students in Computer Science Mathematics Physics or other STEM fields taking introductory level courses on quantum computing It also suits professionals researchers and self learners with a STEM background Potential readers of our previous book A Practical Guide to Quantum Machine Learning and Quantum Optimization will benefit from first building foundational quantum computing skills with this book   Application of Quantum Walks on Graph Structures to Quantum Computing Neil Brian Lovett,2011   **Quantum Computing and Quantum Algorithms** Daniel Serban,2020 The field of quantum computing and quantum algorithms is studied from the ground up Qubits and their quantum mechanical properties are discussed followed by how they are transformed by quantum gates From there quantum algorithms are explored as well as the use of high level quantum programming languages to implement them One quantum algorithm is selected to be implemented in the Qiskit quantum programming language The validity and success of the resulting computation is proven with matrix multiplication of the qubits and quantum gates involved   High-level Quantum Programming with Quantum Walks Héctor J. García,2007   *Quantum Computers, Algorithms and Chaos* G. Casati,D.L.. Shepelyansky,P. Zoller,2006-12-19 During the last ten years Quantum Information Processing and Communication QIPC has established itself as one of the new hot topic fields in physics with the potential to revolutionize many areas of science and technology QIPC replaces the laws of classical physics applied to computation and communication with the more fundamental laws of quantum mechanics This becomes increasingly important due to technological progress going down to smaller and smaller scales where quantum effects start to be

dominant In addition to its fundamental nature QIPC promises to advance computing power beyond the capabilities of any classical computer to guarantee secure communication and establish direct links to emerging quantum technologies such as for example quantum based sensors and clocks One of the outstanding feature of QIPC is its interdisciplinary character it brings together researchers from physics mathematics and computer science In particular within physics we have seen the emergence of a new QIPC community which ranges from theoretical to experimental physics and crosses boundaries of traditionally separated disciplines such as atomic physics quantum optics statistical mechanics and solid state physics all working on different and complementary aspects of QIPC This publication covers the following topics Introduction to quantum computing Quantum logic information and entanglement Quantum algorithms Error correcting codes for quantum computations Quantum measurements and control Quantum communication Quantum optics and cold atoms for quantum information Quantum computing with solid state devices Theory and experiments for superconducting qubits Interactions in many body systems quantum chaos disorder and random matrices Decoherence effects for quantum computing and Flature prospects of quantum information processing

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