

Reversible Logic Circuit Synthesis

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ABSTRACT

Reversible, or information-lossless, circuits have applications in digital signal processing, communication, computer graphics and cryptography. They are also a fundamental requirement for quantum computation. We investigate the synthesis of reversible circuits that employ a minimum number of gates and contain no redundant input-output line-pairs (temporary storage channels). We propose new constructions for reversible circuits composed of NOT, Controlled-NOT, and TOFFOLI gates (the *CNT* gate library) based on permutation theory. A new algorithm is given to synthesize optimal reversible circuits using an arbitrary gate library, and we describe much faster heuristic algorithms. We also pursue applications of the proposed techniques to the synthesis of quantum circuits.

1. INTRODUCTION

In most computing tasks, the number of output bits is relatively small compared to the number of input bits. For example, in a decision problem, the output is only one bit (yes or no), and the input can be as large as desired. However, computational tasks in digital signal processing, communication, computer graphics and cryptography require that all of the information encoded in the input be preserved in the output. Some of these tasks are important enough to justify new microprocessor instructions to HP PA-RISC (MAX and MAX-2), Sun SPARC (VRS), PowerPC (Altivec), IA-32 and IA-64 (MMX) instruction sets [15, 9]. In particular, new bit-permutation instructions were shown to vastly improve performance of several standard algorithms, including matrix transposition and DES, as well as recent cryptographic algorithms Twofish and Serpent [9]. Bit-permutations are a special case of *reversible functions*, that is,

"This work was partially supported by the Undergraduate Summer Research Program at the University of Michigan and by the DARPA QuIST program. The views and conclusions contained herein are those of the authors and should not be interpreted as necessarily representing official policies of endorsements, either expressed or implied, of the Defense Advanced Research Projects Agency (DARPA), the Air Force Research Laboratory, or the U.S. Government.

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functions that permute the set of possible input values. For example, the butterfly operation $(a, b) \rightarrow (a + b, a - b)$ is reversible but isn't a bit permutation. It is a key element of Fast Fourier Transform algorithms and has been used in application-specific processors from Tensilica. One might expect to get further speed-ups by adding instructions to allow computation of an arbitrary reversible function; the problem of chaining such instructions together provides one motivation for studying reversible logic circuits, that is, logic circuits composed of gates computing reversible functions.

Reversible circuits are also interesting because the loss of bits of information implies energy loss [2]. Youssef and Knight [18] showed that some reversible circuits can be made asymptotically energy-lossless if their delay is allowed to be arbitrarily large. Currently, energy losses due to irreversibility are dwarfed by the overall power dissipation, but this may change if Moore's law holds until 2020 and power dissipation improves [11]. In particular, reversibility is important for nanotechnologies where switching devices with gain are difficult to build.

Finally, reversible circuits can be viewed as a special case of quantum circuits because quantum evolution must be reversible. Classical (non-quantum) reversible gates are subject to the same "circuit rules", whether they operate on classical bits or quantum states. In fact, popular universal gate libraries for quantum computation often contain, as their subsets, universal gate libraries for classical reversible computation. While the speed-ups which make quantum computing attractive are not available without purely quantum gates, logic synthesis for classical reversible circuits is a first step toward synthesis of quantum circuits. Moreover, algorithms for quantum communications and cryptography often do not have classical competitors because they act on quantum states, even if their action in a given computational basis corresponds to classical reversible functions on bit-strings. Another connection between classical and quantum computing comes from "pseudo-classical" circuits, as used, e.g., in Grover's search algorithm [4]. These circuits are close to classical reversible circuits [5] and their definition involves an arbitrary one-output (irreversible) Boolean function.

We now briefly review existing work on classical reversible circuits. Toffoli [16] gives constructions for an arbitrary reversible or irreversible function in terms of a certain gate library. However, his method makes use of a large (although linear in the input size) number of temporary storage channels, i.e. input-output wire-pairs other than those on which the function is computed. Sasao and Kinoshita show that any conservative function $f(x)$ is conservative if $\forall x, x$ and $f(x)$ contain the same number of 1s in their binary expansions) has an implementation with only 3 temporary storage channels using a certain fixed library of conservative gates, although no explicit construction was given [12]. Kerntopf uses exhaustive search methods to examine small scale synthesis problems

Reversible Logic Synthesis From Fundamen

Alejandro Salcido



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Reversible Logic Synthesis Anas N. Al-Rabadi, 2012-12-06 For the first time in book form this comprehensive and systematic monograph presents the methods for the reversible synthesis of logic functions and circuits This methodology offers designers the capability to solve major problems in system design now and in the future such as the high rate of power consumption and the emergence of quantum effects for highly dense ICs The challenge addressed here is to design reliable systems that consume as little power as possible and in which the signals are processed and transmitted at very high speeds with very high signal integrity Researchers in academia or industry and graduate students who work in logic synthesis computer design computer aided design tools and low power VLSI circuit design will find this book a valuable resource

Reversible Logic Synthesis Methodologies with Application to Quantum Computing Saleem Mohammed Ridha Taha, 2015-09-24 This book opens the door to a new interesting and ambitious world of reversible and quantum computing research It presents the state of the art required to travel around that world safely Top world universities companies and government institutions are in a race of developing new methodologies algorithms and circuits on reversible logic quantum logic reversible and quantum computing and nano technologies In this book twelve reversible logic synthesis methodologies are presented for the first time in a single literature with some new proposals Also the sequential reversible logic circuitries are discussed for the first time in a book Reversible logic plays an important role in quantum computing Any progress in the domain of reversible logic can be directly applied to quantum logic One of the goals of this book is to show the application of reversible logic in quantum computing A new implementation of wavelet and multiwavelet transforms using quantum computing is performed for this purpose Researchers in academia or industry and graduate students who work in logic synthesis quantum computing nano technology and low power VLSI circuit design will be interested in this book

Classical Cellular Automata. Homogeneous Structures V. Z. Aladjev, 2010-09 Book on cellular automata CA considers such questions as nonconstructible configurations extremal possibilities of CA complexity of finite configurations and global transition functions modeling in CA decomposition of global transition functions appendices of CA etc

Multiple-Valued Logic D. Michael Miller, Mitchell A. Thornton, 2022-05-31 Multiple Valued Logic Concepts and Representations begins with a survey of the use of multiple valued logic in several modern application areas including electronic design automation algorithms and circuit design The mathematical basis and concepts of various algebras and systems of multiple valued logic are provided including comparisons among various systems and examples of their application The book also provides an examination of alternative representations of multiple valued logic suitable for implementation as data structures in automated computer applications Decision diagram structures for multiple valued applications are described in detail with particular emphasis on the recently developed quantum multiple valued decision diagram Table of Contents Multiple Valued Logic Applications MVL Concepts and Algebra Functional Representations

Reversible and Quantum Circuits Quantum Multiple Valued Decision Diagrams Summary Bibliography Cellular Automata
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models in the fields of Quantum Computing Materials Science Cryptography and Coding and Robotics and Image Processing
are presented **Introduction to Reversible Computing** Kalyan S. Perumalla, 2013-09-10 Few books comprehensively
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offers an expanded view of the field that includes the traditional energy motivated hardware viewpoint as well as the
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the book can serve as a one stop reference to other topics in the field Logic Design of NanoICS Svetlana N.
Yanushkevich, Vlad P. Shmerko, Sergey Edward Lyshevski, 2017-12-19 Today s engineers will confront the challenge of a new
computing paradigm relying on micro and nanoscale devices Logic Design of NanoICs builds a foundation for logic in
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Lock-in Thermography Otwin Breitenstein, Wilhelm Warta, Martin Langenkamp, 2013-03-09 Although the first publication on lock in thermography appeared in 1988 concerning electronic device testing this technique only became popular in the 1990s in connection with the nondestructive testing of materials NDT especially photothermal and thermoelastic investigations In the early 1990s our group at the Max Planck Institute of Microstructure Physics in Halle had the task to image small leakage currents in silicon solar cells We soon realized that neither conventional steady state thermography nor the only available lock in thermography system of that time was sensitive enough to image the tiny temperature differences caused by these leakage currents Therefore we developed the Dynamic Precision Contact Thermography technique DPCT which was the first lock in thermography system having a detection limit below 100 J LK However this system turned out to be too impracticable for general use since it worked in a mechanical contacting mode and its measurement time was necessarily many hours With the availability of highly sensitive focal plane array thermocameras at the end of the 1990s the way was opened to construct highly sensitive IR based lock in thermography systems This was done independently by groups working in NDT and by us working in electronic device testing whereby the different demands in the different fields lead to partly different approaches in the realization For photothermal investigations a low lock in frequency is usually used in order to see sub surface details and for thermoelastic investigations the thermocamera cannot usually be synchronized to the temperature modulation *Advanced Intelligent Computing Theories and Applications. With Aspects of Theoretical and Methodological Issues* De-Shuang Huang, Donald C. Wunsch, Daniel S. Levine, Kang-Hyun Jo, 2008-09-08 The International Conference on Intelligent Computing ICIC was formed to provide an annual forum dedicated to the emerging and challenging topics in artificial intelligence machine learning bioinformatics and computational biology etc It aims to bring together researchers and practitioners from both academia and industry to share ideas problems and solutions related to the multifaceted aspects of intelligent computing ICIC 2008 held in Shanghai China September 15 18 2008 constituted the 4th International Conference on Intelligent Computing It built upon the success of ICIC 2007 ICIC 2006 and ICIC 2005 held in Qingdao Kunming and Hefei China 2007 2006 and 2005 respectively This year the conference concentrated mainly on the theories and methodologies as well as the emerging applications of intelligent computing Its aim was to unify the picture of contemporary intelligent computing techniques as an integral concept that highlights the trends in

advanced computational intelligence and bridges theoretical research with applications Therefore the theme for this conference was Emerging Intelligent Computing Technology and Applications Papers focusing on this theme were solicited addressing theories methodologies and applications in science and technology

Quantum Computing Fundamentals

William (Chuck) Easttom II, 2021-06-17 ONE VOLUME INTRODUCTION TO QUANTUM COMPUTING Clearly explains core concepts terminology and techniques Covers the foundational physics math and information theory you need Provides hands on practice with quantum programming The perfect beginner's guide for anyone interested in a quantum computing career Dr Chuck Easttom brings together complete coverage of basic quantum computing concepts terminology and issues along with key skills to get you started Drawing on 30 years as a computer science instructor consultant and researcher Easttom demystifies the field's underlying technical concepts and math shows how quantum computing systems are designed and built explains their implications for cyber security and previews advances in quantum resistant cryptography Writing clearly and simply he introduces two of today's leading quantum programming languages Microsoft Q and QASM and guides you through sample projects Throughout tests projects and review questions help you deepen and apply your knowledge Whether you're a student professional or manager this guide will prepare you for the quantum computing revolution and expand your career options too Master the linear algebra and other mathematical skills you'll need Explore key physics ideas such as quantum states and uncertainty Review data structures algorithms and computing complexity Work with probability and set theory in quantum computing Familiarize yourself with basic quantum theory and formulae Understand quantum entanglement and quantum key distribution Discover how quantum computers are architected and built Explore several leading quantum algorithms Compare quantum and conventional asymmetric algorithms See how quantum computing might break traditional cryptography Discover several approaches to quantum resistant cryptography Start coding with Q Microsoft's quantum programming language Simulate quantum gates and algorithms with QASM

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