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Saleem Mohammed Ridha Taha

Reversible Logic Synthesis Methodologies with Application to Quantum Computing

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Preface

Traditional technologies are increasingly beginning to suffer from the increasing miniaturization and the exponential growth of the number of transistors in integrated circuits. The high rate of power consumption and the emergence of quantum effects for highly dense integrated circuits are the biggest problems in system design today and will be in the future. Reversible logic provides an alternative to face the upcoming challenges. One of the main benefits that reversible logic brings about is theoretically zero power dissipation. In order to reduce power consumption, physical processes have to be logically reversible. Every future technology will have to use reversible logic circuits in order to reduce power consumption. In the area of quantum computation and low-power design, very promising results have already been obtained today. Nevertheless, research on reversible logic is still at the beginning stage.

This book provides several novel contributions to reversible logic synthesis. Twelve reversible logic synthesis methodologies are presented for the first time in a single literature. Evaluations for the comparative advantages and disadvantages of these methodologies are also provided. Reversible sequential logic circuits are discussed, with new designs of reversible sequential elements.

The tendency of current technologies is towards the nanoscale. Therefore, there is a need to incorporate the physical quantum mechanical effects that are unavoidable in the nanoscales. Representations and operations in quantum computing that use theorems of reversible computing and reversible structures to compute functionalities using quantum logic are introduced. Applications of wavelet and multiwavelet transformations to quantum computing structures are discussed. New techniques to implement the Daubechies wavelets and multiwavelets using quantum circuits are proposed.

Finally, highlights of novel contributions that are presented in this book and the future directions of research are provided.

In this context, the contributions to this book provide a good starting point. It is hoped that this book will help to spur further research in the field of reversible and quantum computations. In fact researchers in academia or industry and graduate students, who work in this field, will be interested in this book. Books that are concerned with reversible synthesis of logic functions are rare. Therefore, there is a need to publish books in this field. The first book [1] presented for the first time comprehensive and systematic methods of reversible logic synthesis. It is hoped that this book will be more valuable, because 12 methods of reversible logic synthesis are introduced here, while only five are in Ref. [1]. Also, for the first time the sequential reversible logic circuitries are discussed in a book.

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, with some new proposals.

Baghdad
January 2015

Saleem Mohammed Ridha Taha

Reference

1. A.N. Al-Rabadi, *Reversible Logic Synthesis: From Fundamentals to Quantum Computing* (Springer-Verlag, 2004)

Contents

Abbreviations

1-RPL	1-Reduced Post Literal
3D	Three-Dimensional
3DTDRL	Three-Dimensional Ternary Davio Reversible Lattice
BDD	Binary Decision Diagram
CCW	Counter Clock Wise
CIN	Common Indices Nodes
CNOT	Controlled NOT
CRA	Conventional Reconstructability Analysis
D	Davio expansion
DD	Decision Diagram
DMWT	Discrete Multiwavelet Transform
DT	Decision Tree
ESOP	EXOR Sum-Of-Product
EXOR	Exclusive-OR
GBFM	Generalized Basis Functions Matrix
GF	Galois Field
GGS	Gate–Garbage–Sum
IDMWT	Inverse DMWT
K-map	Karnough map
MRA	Modified Reconstructability Analysis
NCTSF	NOT, CNOT, Toffoli, Swap, Fredkin reversible gates
nD	Negative Davio
pD	Positive Davio
PUS	Positive Unate Symmetric
Qubit	Quantum bit
RDD	Reversible Decision Diagram
RDDT	Reversible Davio Decision Tree
RDT	Reversible Decision Tree
RGBFM	Reversible GBFM
RMRA	Reversible MRA
RPGA	Reversible Programmable Gate Array

RSGBFM	Reversible Shannon GBFM
RSPP	Rational SPP
S	Shannon expansion
S/D	Shannon/Davio
SBDD	Shared BDD
SPP	Size Power-consumption Product
T.M.	Transform Matrix
ULM	Universal Logic Modules

Symbols

$D_{2^n}^{(4)}$	Daubechies fourth-order wavelet kernel of dimension 2^n
Q_{2^n}	Downshift Permutation matrix
Π_4	Qubit Swap gate
Π_{2^n}	Perfect Shuffle Permutation matrices
$\|\cdot\rangle$	Vector representing a quantum state
$\otimes$	Tensor product
$\oplus$	Modulo 2 addition
$\dagger$	Adjoint
$\equiv$	Equivalence
$\wedge$	Logical AND operator
$\vee$	Logical OR operator
$\cap$	Intersection operation

Chapter 1
Introduction

In this chapter, some of the background of the body of research upon which this book builds is outlined (Sect. 1.1), description (Sect. 1.2) and motivation (Sect. 1.3) of the topic of this book are explained, the major contributions of this book are summarized (Sect. 1.4), a brief overview of the contents of the later chapters is given (Sect. 1.5), and the overall message of the book is highlighted (Sect. 1.6).

1.1 Background

Interest in reversible logic started when Landauer in 1961 [1] proved that traditional binary irreversible gates lead to power dissipation in a circuit regardless of implementation. Each bit of information that is lost, generates KT ln(2) Joules of heat energy, where K is Boltzmann's constant ($\approx 1.380658 \times 10^{-23}$ J/K) and T the absolute temperature (Kelvins) at which computation is performed. For room temperature T the amount of dissipating heat is small (i.e. 2.9×10^{-21} J), but not negligible [2–4]. Bennett in 1973 showed that for power not to be dissipated in an arbitrary circuit, it is necessary that this circuit be built from reversible gates. The importance of Bennett's theorem lies in the technological necessity that every future technology will have to use reversible gates in order to reduce power loss [5, 6].

Reversible circuits are those circuits that do not lose information and reversible computation in a system can be performed only when the system comprises of reversible gates. These circuits can generate unique output vector from each input vector, and vice versa, that is, there is a one-to-one mapping (a permutation) between input and output vectors [7, 8].

Hardware development truly took off in 1948, when the transistor was developed. Computer hardware has grown in power at an amazing pace ever since, so much so that the growth was codified by Gordan Moore in 1965 in what has come to be known as Moore's law. This law states that since the invention of the transistor the number of transistors per chip roughly doubled every 18–24 months, which means an increase in the computing power of computers [9]. This increase in computing power is due primarily to the continuing miniaturization of the elements of which computers are made, resulting in more and more elementary gates per unit

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