

# A Constructive Approach for Threshold Logic Circuit Synthesis

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**Abstract** – In this paper, a novel method to synthesize circuits based on threshold logic gates (TLG) is proposed. Synthesis considering TLGs is quite relevant, since threshold logic has been revisited as a promising alternative to conventional CMOS integrated circuits due to its suitability to emerging technologies, such as tunneling diodes, memristors and spintronics devices. A constructive process is applied to generate optimized TLG networks taking into account multiple goals and design costs, including gate count, logic depth and number of interconnections. Experiments carried out over MCNC benchmark circuits have shown an average gate count reduction of circa 32%, reaching up to 54% in some cases, in comparison to related approaches.

**Keywords** – Digital circuits, logic synthesis, threshold logic, functional composition, threshold networks, TLG.

## I. INTRODUCTION

The limits of MOS transistor scaling have motivated investigations about new alternative devices, such as spintronics, resonant tunneling devices (RTD), quantum cellular automata (QCA), single electron transistor (SET) and memristors [1]-[3]. In this new scenario, it has been verified that threshold logic gates (TLG) are more suitable to implement digital integrated circuits (ICs) based on these new technologies, differently from the standard AND/OR based CMOS circuit design [4][5].

However, specific CAD tools must be available for developing TLG based ICs. In this sense, one critical task is to obtain efficient network built using TLGs to implement a specific Boolean function. In [5], Zhang *et al.* proposed a recursive partition of a logic function that is not threshold and merge nodes respecting fan-in restrictions. Unfortunately, the quality of results is very sensitive to the initial Boolean network. On the other hand, the method presented by Subirats *et al.*, in [6], is based on the truth table description of the function. The algorithm compute an ordering of variables using information of on-set and off-set, performing Shannon decomposition up to find threshold logic functions (TLF). However, this approach provides as output a two-level threshold network, without fan-in restriction, being more suitable for neural networks than for IC design. In [7], Gowda *et al.* used a factorized tree to generate a network of threshold gates. The method recursively breaks the given initial expression tree into sub-expressions, identifying sub-tree that are TLFs and assigning the input weights. It is appropriate for IC synthesis using several TLGs, but represents a very time consuming process and presents a strong dependence to the initial expression structure, including the ordering of the initial tree.

In this paper, an algorithm is proposed to synthesize threshold networks aiming to (1) minimize threshold networks taking into account other costs besides threshold gate count, like logic depth and number of interconnections, (2) generate more than one effective solution, considering a design cost order, and (3) eliminate the structural bias dependence in order to improve the quality of results. It is based on a constructive synthesis [8]-[10], which associates simpler sub-solutions with known costs in order to build more complex networks, allowing the optimization of different cost functions other than just the TLG count. The algorithm uses a novel AND/OR association between threshold networks to reduce the total number of TLGs in the circuit.

The rest of this paper is organized as follows. In Section II, some fundamentals are briefly presented for a better understanding of our approach. Section III describes the algorithm proposed to synthesize threshold logic networks. Section IV provides the experimental results, whereas the conclusions are outlined in Section V.

## II. PRELIMINARIES

First of all, basic concepts of threshold logic are briefly reviewed for a better understanding of the proposed method.

### A. Threshold Logic Gate

Differently from the traditional logic gate design, the threshold logic gate (TLG) implements Boolean function considering weight values for inputs (function variables) and a gate threshold value to be attained. If the sum of weights of activate ('1') inputs is equal to or higher than the given threshold value, then the output logic level of the TLG is high ('1'). Otherwise, the gate output is at low level ('0'). Such operating principle can be expressed as follows:

$$f = \begin{cases} 1 & \text{if } \sum_{i=1}^n w_i x_i \geq T \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

where  $x_i$  and  $w_i$  represent the logic value and weight of each input, respectively, and  $T$  is the threshold value [11].

### B. Threshold Logic Function

Threshold logic function (TLF), also called linearly separable function, is a Boolean function that can be implemented into a single TLG. TLF can be completely represented in a compact vector format such as  $[w_1, w_2, \dots, w_n; T]$ . For instance, the function  $f = x_1 x_2 + x_3 x_3$  can be represented as  $f = [2, 1, 1; 3]$ .

# Threshold Logic A Synthesis Approach

**Ashok Kumar Palaniswamy**



## **Threshold Logic A Synthesis Approach:**

**Threshold Logic** Michael L. Dertouzos, 1965      *Synthesis and Testing of Threshold Logic Circuits* Ashok Kumar Palaniswamy, 2014 Threshold logic gates gaining more importance in recent years due to the significant development in the switching devices This renewed the interest in synthesis and testing of circuits with threshold logic gates Two important synthesis considerations of threshold logic circuits are addressed namely threshold logic function identification and reducing the total number of threshold logic gates required to represent the given boolean circuit description A fast method to identify the given Boolean function as a threshold logic function with weight assignment is introduced It characterizes the threshold logic function based on the modified chows parameters which results in drastic reduction in time and complexity Experiment results shown that the proposed method is at least 10 times faster for each input and around 20 times faster for 7 and 8 input when comparing with the algorithmic based methods Similarly it is 100 times faster for 8 input when comparing with a summable method Existing threshold logic synthesis methods decompose the larger input functions into smaller input functions and perform synthesis for them This results in increase in the number of threshold logic gates required to represent the given circuit description The proposed implicit synthesis methods increase the size of the functions that can be handled by the synthesis algorithm thus the number of threshold logic gates required to implement very large input function decreases Experiment results shown that the reduction in the TLG count is 24% in the best case and 18% on average An automatic test pattern generation approach for transition faults on a circuit consisting of current mode threshold logic gates is introduced The generated pattern for each fault excites the maximum propagation delay at the gate the fault site This is a high quality ATPG Since current mode threshold logic gate circuits are pipelined and the combinational depth at each pipeline stage is practically one It is experimentally shown that the fault coverage for all benchmark circuits is approximately 97% It is also shown that the proposed method is time efficient      Switching and Finite Automata Theory Zvi Kohavi, Niraj K. Jha, 2010 Understand the structure behavior and limitations of logic machines with this thoroughly updated third edition Many new topics are included such as CMOS gates logic synthesis logic design for emerging nanotechnologies digital system testing and asynchronous circuit design to bring students up to speed with modern developments The intuitive examples and minimal formalism of the previous edition are retained giving students a text that is logical and easy to follow yet rigorous Kohavi and Jha begin with the basics and then cover combinational logic design and testing before moving on to more advanced topics in finite state machine design and testing Theory is made easier to understand with 200 illustrative examples and students can test their understanding with over 350 end of chapter review questions      **Introduction to the Methodology of Switching Circuits** George J. Klir, 1972      **Design, Automation, and Test in Europe** Rudy Lauwereins, Jan Madsen, 2008-01-08 In 2007 The Design Automation and Test in Europe DATE conference celebrated its tenth anniversary As a tribute to the chip and system level design and design technology community this book presents a

compilation of the three most influential papers of each year This provides an excellent historical overview of the evolution of a domain that contributed substantially to the growth and competitiveness of the circuit electronics and systems industry

**Artificial Neural Networks - ICANN 2006** Stefanos Kollias, Andreas Stafylopatis, Wlodzislaw Duch, Erkki Oja, 2006-09-01 The two volume set LNCS 4131 and LNCS 4132 constitutes the refereed proceedings of the 16th International Conference on Artificial Neural Networks ICANN 2006 The set presents 208 revised full papers carefully reviewed and selected from 475 submissions This first volume presents 103 papers organized in topical sections on feature selection and dimension reduction for regression learning algorithms advances in neural network learning methods ensemble learning hybrid architectures and more

**Spectral Techniques in Digital Logic** Stanley Leonard Hurst, D. M. Miller, D. Michael Miller, Jon C. Muzio, 1985

Applied Automata Theory Julius T. Tou, 2013-10-22 Applied Automata Theory provides an engineering style of presentation of some of the applied work in the field of automata theory Topics covered range from algebraic foundations and recursive functions to regular expressions threshold logic and switching circuits Coding problems and stochastic processes are also discussed along with content addressable memories probabilistic reliability and Turing machines Much emphasis is placed on engineering applications Comprised of nine chapters this book first deals with the algebraic foundations of automata theory focusing on concepts such as semigroups groups and homomorphisms and partially ordered sets and lattices as well as congruences and other relations The reader is then introduced to regular expressions stochastic automata and discrete systems theory and switching networks as models of discrete stochastic processes Subsequent chapters explore applications of automata theory in coding content addressable and distributed logic memories recursive functions and switching circuit theory and synthesis of a cellular computer The book concludes with an assessment of the fundamentals of threshold logic This monograph is intended for graduates or advanced undergraduates taking a course in information science or a course on discrete systems in modern engineering curriculum

**Basic Switching Circuit Theory** Moshe Krieger, 1967

Switching Circuits; Theory and Logic Design H. C. Tornig, 1972

*U.S. Government Research & Development Reports*, 1967

*Modeling and Simulation* ISA, 1987-12

Nanoelectronic Circuit Design Niraj K. Jha, Deming Chen, 2010-12-21 This book is about large scale electronic circuits design driven by nanotechnology where nanotechnology is broadly defined as building circuits using nanoscale devices that are either implemented with nanomaterials e.g. nanotubes or nanowires or following an unconventional method e.g. FinFET or III V compound based devices These nanoscale devices have significant potential to revolutionize the fabrication and integration of electronic systems and scale beyond the perceived scaling limitations of traditional CMOS While innovations in nanotechnology originate at the individual device level realizing the true impact of electronic systems demands that these device level capabilities be translated into system level benefits This is the first book to focus on nanoscale circuits and their design issues bridging the existing gap between nanodevice research and nanosystem design

**Cumulative Computer**

**Abstracts** Geoffrey Knight,1968     *Electronic Design* ,1967     *The Challenges of Systems Biology* Gustavo Stolovitzky,Pascal Kahlem,Andrea Califano,2009-05-18 At a microscopic level organisms are ruled by interacting systems of biomolecules Historically scientists painstakingly elucidated chains of molecular events using experiments that reveal individual interactions although they recognized that members of different pathways frequently interact In recent years researchers have built richer interconnected networks to mathematically summarize their knowledge of these interactions This systems biology enterprise largely stimulated by high throughput tools like microarrays that measure mRNA levels as an indicator of gene expression is a vital and increasingly important activity in both basic biology and in medicine A nagging concern however is how accurately these networks represent the biology For complex systems like biological networks there are practical limits on how well even massive amounts of data can uniquely define the underlying structure and yield useful predictions of measurable events Indeed although its advocates call this process reverse engineering the topology and the detailed molecular interactions of the inferred networks will likely never be known with precision This volume captures the ongoing process to assess the ability of scientists and their computer servants to infer networks from experimental data by comparing their predictions to gold standard networks whose structure is thought to be known NOTE Annals volumes are available for sale as individual books or as a journal For information on institutional journal subscriptions please visit [www.blackwellpublishing.com](http://www.blackwellpublishing.com) nyas ACADEMY MEMBERS Please contact the New York Academy of Sciences directly to place your order [www.nyas.org](http://www.nyas.org) Members of the New York Academy of Science receive full text access to the Annals online and discounts on print volumes Please visit [www.nyas.org](http://www.nyas.org) membership main.asp for more information about becoming a member

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