Spectral Interpretation and Applications of Decision Diagrams

BOGDAN J. FALKOWSKI[a],* and RADOMIR S. STANKOVIĆ[b]

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Different Decision Diagrams (DDs) for representation of discrete functions are discussed. DDs can be derived by applying some reduction rules to Decision Trees (DTs) which in turn are graphical representations of some function expressions for discrete functions. Various DTs and their generalizations based on lesser known AND-EXOR rather than AND-OR expressions are surveyed. Finally, the concept of spectral interpretation of DDs and some of their applications and ways of calculation are also presented.

Keywords: Logic design, decision diagrams, spectral techniques, AND-EXOR expressions, bit-level decision diagrams, word-level decision diagrams

1. INTRODUCTION

Manipulations and calculations with discrete functions are fundamental tasks in Computer Science and Engineering. Many problems in digital system design and testing can be expressed as a sequence of operations on discrete functions. The performance of CAD systems used in solving various problems in this area strongly depends on the efficiency of representation of discrete functions.

Decision diagrams (DDs) [1, 5] have proved very convenient data structure for discrete function representations, permitting manipulations and calculations with large discrete functions efficiently in terms of time and space. In many applications, as for example those involving large matrices, conventional algorithms are significantly improved by using DDs [11]. In logic design, such applications relate to the basic problems of the design, verification and testing of logical networks [13, 72, 79]. Therefore, DDs based packages are to become, or have already been, a standard part of many CAD tools in logic design.

This paper surveys basic concepts in theory and applications of DDs representations. Presentation is based on the following principle which, at the same time, determined the organization of the paper.

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Spectral Interpretation Of Decision Diagrams

Radomir Stankovic,Jaakko T Astola

Spectral Interpretation Of Decision Diagrams:

   Spectral Interpretation of Decision Diagrams Radomir Stankovic,Jaakko T. Astola,2003-06-16 Decision diagrams DDs are data structures for efficient time space representations of large discrete functions In addition to their wide application in engineering practice DDs are now a standard part of many CAD systems for logic design and a basis for severe signal processing algorithms Spectral Interpretation of Decision Diagrams derives from attempts to classify and uniformly interpret DDs through spectral interpretation methods relating them to different Fourier series like functional expressions for discrete functions and a group theoretic approach to DD optimization The book examines DDs found in literature and engineering practice and provides insights into relationships between DDs and different polynomial or spectral expressions for representation of discrete functions In addition it offers guidelines and criteria for selection of the most suitable representation in terms of space and time complexity The work complements theory with numerous illustrative examples from practice Moreover the importance of DD representations to the verification and testing of arithmetic circuits is addressed as well as problems related to various signal processing tasks   **Spectral Interpretation of Decision Diagrams** Radomir Stankovic,Jaakko T Astola,2014-01-15 Decision diagrams DDs are data structures for efficient time space representations of large discrete functions In addition to their wide application in engineering practice DDs are now a standard part of many CAD systems for logic design and a basis for severe signal processing algorithms Spectral Interpretation of Decision Diagrams derives from attempts to classify and uniformly interpret DDs through spectral interpretation methods relating them to different Fourier series like functional expressions for discrete functions and a group theoretic approach to DD optimization The book examines DDs found in literature and engineering practice and provides insights into relationships between DDs and different polynomial or spectral expressions for representation of discrete functions In addition it offers guidelines and criteria for selection of the most suitable representation in terms of space and time complexity The work complements theory with numerous illustrative examples from practice Moreover the importance of DD representations to the verification and testing of arithmetic circuits is addressed as well as problems related to various signal processing tasks   **Decision Diagram Techniques for Micro- and Nanoelectronic Design Handbook** Svetlana N. Yanushkevich,D. Michael Miller,Vlad P. Shmerko,Radomir S. Stankovic,2018-10-03 Decision diagram DD techniques are very popular in the electronic design automation EDA of integrated circuits and for good reason They can accurately simulate logic design can show where to make reductions in complexity and can be easily modified to model different scenarios Presenting DD techniques from an applied perspective Decision Diagram Techniques for Micro and Nanoelectronic Design Handbook provides a comprehensive up to date collection of DD techniques Experts with more than forty years of combined experience in both industrial and academic settings demonstrate how to apply the techniques to full advantage with more than 400 examples and illustrations Beginning with the fundamental theory data structures and logic underlying DD

techniques they explore a breadth of topics from arithmetic and word level representations to spectral techniques and event driven analysis The book also includes abundant references to more detailed information and additional applications Decision Diagram Techniques for Micro and Nanoelectronic Design Handbook collects the theory methods and practical knowledge necessary to design more advanced circuits and places it at your fingertips in a single concise reference *Fourier Analysis on Finite Groups with Applications in Signal Processing and System Design* Radomir S. Stankovic,Claudio Moraga,Jaakko Astola,2005-08-08 Discover applications of Fourier analysis on finite non Abeliangroups The majority of publications in spectral techniques considerFourier transform on Abelian groups However non Abelian groupsprovide notable advantages in efficient implementations of spectralmethods Fourier Analysis on Finite Groups with Applications in SignalProcessing and System Design examines aspects of Fourieranalysis on finite non Abelian groups and discusses differentmethods used to determine compact representations for discretefunctions providing for their efficient realizations and relatedapplications Switching functions are included as an example ofdiscrete functions in engineering practice Additionally consideration is given to the polynomial expressions and decisiondiagrams defined in terms of Fourier transform on finitenon Abelian groups A solid foundation of this complex topic is provided bybeginning with a review of signals and their mathematical modelsand Fourier analysis Next the book examines recent achievementsand discoveries in Matrix interpretation of the fast Fourier transform Optimization of decision diagrams Functional expressions on quaternion groups Gibbs derivatives on finite groups Linear systems on finite non Abelian groups Hilbert transform on finite groups Among the highlights is an in depth coverage of applications ofabstract harmonic analysis on finite non Abelian groups in compactrepresentations of discrete functions and related tasks in signalprocessing and system design including logic design All chaptersare self contained each with a list of references to facilitatethe development of specialized courses or self study With nearly 100 illustrative figures and fifty tables this isan excellent textbook for graduate level students and researchersin signal processing logic design and system theory as well asthe more general topics of computer science and appliedmathematics *Fundamentals of Switching Theory and Logic Design* Jaakko Astola,Radomir S. Stankovic,2006-03-07 Fundamentals of Switching Theory and Logic Design discusses the basics of switching theory and logic design from a slightly alternative point of view and also presents links between switching theory and related areas of signal processing and system theory Switching theory is a branch of applied mathematic providing mathematical foundations for logic design which can be considered as a part of digital system design concerning realizations of systems whose inputs and outputs are described by logic functions *Representations of Multiple-Valued Logic Functions* Radomir S. Stankovic,Jaakko Astola,Claudio Moraga,2022-06-01 Compared to binary switching functions the multiple valued functions MV offer more compact representations of the information content of signals modeled by logic functions and therefore their use fits very well in the general settings of data compression attempts and approaches The first task in dealing with such signals is to provide mathematical methods for their representation in a

way that will make their application in practice feasible Representation of Multiple Valued Logic Functions is aimed at providing an accessible introduction to these mathematical techniques that are necessary for application of related implementation methods and tools This book presents in a uniform way different representations of multiple valued logic functions including functional expressions spectral representations on finite Abelian groups and their graphical counterparts various related decision diagrams Three valued or ternary functions are traditionally used as the first extension from the binary case They have a good feature that the ratio between the number of bits and the number of different values that can be encoded with the specified number of bits is favourable for ternary functions Four valued functions also called quaternary functions are particularly attractive since in practical realization within today prevalent binary circuits environment they may be easy coded by binary values and realized with two stable state circuits At the same time there is much more considerable advent in design of four valued logic circuits than for other p valued functions Therefore this book is written using a hands on approach such that after introducing the general and necessarily abstract background theory the presentation is based on a large number of examples for ternary and quaternary functions that should provide an intuitive understanding of various representation methods and the interconnections among them Table of Contents Multiple Valued Logic Functions Functional Expressions for Multiple Valued Functions Spectral Representations of Multiple Valued Functions Decision Diagrams for Multiple Valued Functions Fast Calculation Algorithms   **Introduction to Logic Design** Svetlana N. Yanushkevich,Vlad P. Shmerko,2008-01-25 With an abundance of insightful examples problems and computer experiments Introduction to Logic Design provides a balanced easy to read treatment of the fundamental theory of logic functions and applications to the design of digital devices and systems Requiring no prior knowledge of electrical circuits or electronics it supplies the   **Systems, Controls, Embedded Systems, Energy, and Machines** Richard C. Dorf,2017-12-19 In two editions spanning more than a decade The Electrical Engineering Handbook stands as the definitive reference to the multidisciplinary field of electrical engineering Our knowledge continues to grow and so does the Handbook For the third edition it has expanded into a set of six books carefully focused on a specialized area or field of study Each book represents a concise yet definitive collection of key concepts models and equations in its respective domain thoughtfully gathered for convenient access Systems Controls Embedded Systems Energy and Machines explores in detail the fields of energy devices machines and systems as well as control systems It provides all of the fundamental concepts needed for thorough in depth understanding of each area and devotes special attention to the emerging area of embedded systems Each article includes defining terms references and sources of further information Encompassing the work of the world s foremost experts in their respective specialties Systems Controls Embedded Systems Energy and Machines features the latest developments the broadest scope of coverage and new material on human computer interaction   Advances in Signal Transforms Jaakko Astola,2007 Digital signal transforms are of a fundamental value in digital signal and image processing Their role is manifold Transforms selected appropriately enable

substantial compressing signals and images for storage and transmission No signal recovery image reconstruction and restoration task can be efficiently solved without using digital signal transforms Transforms are successfully used for logic design and digital data encryption Fast transforms are the main tools for acceleration of computations in digital signal and image processing The volume collects in one book most recent developments in the theory and practice of the design and usage of transforms in digital signal and image processing It emerged from the series of reports published by Tampere International Centre for Signal Processing Tampere University of Technology For the volume all contributions are appropriately updated to represent the state of the art in the field and to cover the most recent developments in different aspects of the theory and applications of transforms The book consists of two parts that represent two major directions in the field development of new transforms and development of transform based signal and image processing algorithms The first part contains four chapters devoted to recent advances in transforms for image compression and switching and logic design and to new fast transforms for digital holography and tomography In the second part advanced transform based signal and image algorithms are considered signal and image local adaptive restoration methods and two complementing families of signal and image re sampling algorithms fast transform based discrete sinc interpolation and spline theory based ones Publisher *Dyadic Walsh Analysis from 1924 Onwards Walsh-Gibbs-Butzer Dyadic Differentiation in Science Volume 2 Extensions and Generalizations* Radomir Stankovic,Paul Leo Butzer,Ferenc Schipp,William R. Wade,Weiyi Su,Yasushi Endow,Sandor Fridli,Boris I. Golubov,Franz Pichler,2015-12-29 The second volume of the two volumes book is dedicated to various extensions and generalizations of Dyadic Walsh analysis and related applications Considered are dyadic derivatives on Vilenkin groups and various other Abelian and finite non Abelian groups Since some important results were developed in former Soviet Union and China we provide overviews of former work in these countries Further we present translations of three papers that were initially published in Chinese The presentation continues with chapters written by experts in the area presenting discussions of applications of these results in specific tasks in the area of signal processing and system theory Efficient computing of related differential operators on contemporary hardware including graphics processing units is also considered which makes the methods and techniques of dyadic analysis and generalizations computationally feasible The volume 2 of the book ends with a chapter presenting open problems pointed out by several experts in the area **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 nanodimensions and guides you in the design and analysis of nanoICs using CAD The authors present data structures developed toward applications rather than a purely theoretical treatment Requiring only basic logic and circuits background Logic Design of NanoICs draws connections between traditional approaches to design and modern design in nanodimensions The book begins with an introduction to the directions and basic methodology of logic design at

the nanoscale then proceeds to nanotechnologies and CAD graphical representation of switching functions and networks word level and linear word level data structures 3 D topologies based on hypercubes multilevel circuit design and fault tolerant computation in hypercube like structures The authors propose design solutions and techniques going beyond the underlying technology to provide more applied knowledge This design oriented reference is written for engineers interested in developing the next generation of integrated circuitry illustrating the discussion with approximately 250 figures and tables 100 equations 250 practical examples and 100 problems Each chapter concludes with a summary references and a suggested reading section   **Computer Arithmetics for Nanoelectronics** Vlad P. Shmerko,Svetlana N. Yanushkevich,Sergey Edward Lyshevski,2018-10-03 Emphasizes the Basic Principles of Computational Arithmetic and Computational Structure Design Taking an interdisciplinary approach to the nanoscale generation of computer devices and systems Computer Arithmetics for Nanoelectronics develops a consensus between computational properties provided by data structures and phenomenological properties of nano and molecular technology Covers All Stages of the Design Cycle from Task Formulation to Molecular Based Implementation The book introduces the theoretical base and properties of various data structures along with techniques for their manipulation optimization and implementation It also assigns the computational properties of logic design data structures to 3D structures furnishes information theoretical measures and design aspects and discusses the testability problem The last chapter presents a nanoscale prospect for natural computing based on assorted computing paradigms from nature Balanced Coverage of State of the Art Concepts Techniques and Practices Up to date comprehensive and pragmatic in its approach this text provides a unified overview of the relationship between the fundamentals of digital system design computer architectures and micro and nanoelectronics   Claudio Moraga: A Passion for Multi-Valued Logic and Soft Computing Rudolf Seising,Héctor Allende-Cid,2016-10-20 The book is an authoritative collection of contributions by leading experts on the topics of fuzzy logic multi valued logic and neural network Originally written as an homage to Claudio Moraga seen by his colleagues as an example of concentration discipline and passion for science the book also represents a timely reference guide for advance students and researchers in the field of soft computing and multiple valued logic   Computer Aided Systems Theory – EUROCAST 2005 Roberto Moreno-Díaz,Franz Pichler,Alexis Quesada Arencibia,2005-09-22 This book constitutes the thoroughly refereed post proceedings of the 10th International Conference on Computer Aided Systems Theory EUROCAST 2005 held in Las Palmas de Gran Canaria Spain in February 2005 The 83 revised full papers presented were carefully reviewed and selected for inclusion in the book The papers are organized in topical sections on formal approaches in modelling intelligent information systems information applications components cryptography and spectral analysis computer vision biocomputing intelligent vehicular systems robotic soccer robotics and control   **Modeling Digital Switching Circuits with Linear Algebra** Mitchell A. Thornton,2022-05-31 Modeling Digital Switching Circuits with Linear Algebra describes an approach for modeling digital information and circuitry that is an

alternative to Boolean algebra While the Boolean algebraic model has been wildly successful and is responsible for many advances in modern information technology the approach described in this book offers new insight and different ways of solving problems Modeling the bit as a vector instead of a scalar value in the set 0 1 allows digital circuits to be characterized with transfer functions in the form of a linear transformation matrix The use of transfer functions is ubiquitous in many areas of engineering and their rich background in linear systems theory and signal processing is easily applied to digital switching circuits with this model The common tasks of circuit simulation and justification are specific examples of the application of the linear algebraic model and are described in detail The advantages offered by the new model as compared to traditional methods are emphasized throughout the book Furthermore the new approach is easily generalized to other types of information processing circuits such as those based upon multiple valued or quantum logic thus providing a unifying mathematical framework common to each of these areas Modeling Digital Switching Circuits with Linear Algebra provides a blend of theoretical concepts and practical issues involved in implementing the method for circuit design tasks Data structures are described and are shown to not require any more resources for representing the underlying matrices and vectors than those currently used in modern electronic design automation EDA tools based on the Boolean model Algorithms are described that perform simulation justification and other common EDA tasks in an efficient manner that are competitive with conventional design tools The linear algebraic model can be used to implement common EDA tasks directly upon a structural netlist thus avoiding the intermediate step of transforming a circuit description into a representation of a set of switching functions as is commonly the case when conventional Boolean techniques are used Implementation results are provided that empirically demonstrate the practicality of the linear algebraic model   Representations of Discrete Functions Tsutomu Sasao,Masahira Fujita,2012-12-06 Representations of Discrete Functions is an edited volume containing 13 chapter contributions from leading researchers with a focus on the latest research results The first three chapters are introductions and contain many illustrations to clarify concepts presented in the text It is recommended that these chapters are read first The book then deals with the following topics binary decision diagrams BDDs multi terminal binary decision diagrams MTBDDs edge valued binary decision diagrams EVBDDs functional decision diagrams FDDs Kronecker decision diagrams KDDs binary moment diagrams BMDs spectral transform decision diagrams STDDs ternary decision diagrams TDDs spectral transformation of logic functions other transformations oflogic functions EXOR based two level expressions FPRM minimization with TDDs and MTBDDs complexity theories on FDDs multi level logic synthesis and complexity of three level logic networks Representations of Discrete Functions is designed for CAD researchers and engineers and will also be of interest to computer scientists who are interested in combinatorial problems Exercises prepared by the editors help make this book useful as a graduate level textbook   *Proceedings of the ASP-DAC ... Asia and South Pacific Design Automation Conference* ,1998   **International Journal of Applied Mathematics and Computer Science** ,2006   **Spectral Logic**

and Its Applications for the Design of Digital Devices Mark G. Karpovsky,Radomir S. Stankovic,Jaakko T. Astola,2008-04-15 Spectral techniques facilitate the design and testing of today s increasingly complex digital devices There is heightened interest in spectral techniques for the design of digital devices dictated by ever increasing demands on technology that often cannot be met by classical approaches Spectral methods provide a uniform and consistent theoretic environment for recent achievements in this area which appear divergent in many other approaches Spectral Logic and Its Applications for the Design of Digital Devices gives readers a foundation for further exploration of abstract harmonic analysis over finite groups in the analysis design and testing of digital devices After an introduction this book provides the essential mathematical background for discussing spectral methods It then delves into spectral logic and its applications covering Walsh Haar arithmetic transform Reed Muller transform for binary valued functions and Vilenkin Chrestenson transform generalized Haar and other related transforms for multiple valued functions Polynomial expressions and decision diagram representations for switching and multiple value functions Spectral analysis of Boolean functions Spectral synthesis and optimization of combinational and sequential devices Spectral methods in analysis and synthesis of reliable devices Spectral techniques for testing computer hardware This is the authoritative reference for computer science and engineering professionals and researchers with an interest in spectral methods of representing discrete functions and related applications in the design and testing of digital devices It is also an excellent text for graduate students in courses covering spectral logic and its applications   ISMVL 2004 International Symposium on Multiple Valued Logic (34, 2004, Toronto),IEEE Computer Society,2004

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