Using Multiple-Valued Logic Decision Diagrams to Model System Threat Probabilities

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Abstract—System security continues to be of increasing importance. To effectively address both natural and intentional threats to large systems, the threats must be cataloged and analyzed. Extremely large and complex system can have an accordingly large number of threat scenarios. Simply listing the threats and devising countermeasures for each is ineffective and not efficient. We describe a threat cataloging methodology whereby a large number of threats can be efficiently cataloged and analyzed for common features. This allows countermeasures to be formulated that address a large number of threats that share common features. The methodology utilizes Multiple-Valued Logic for describing the state of a large system and a multiple-valued decision diagram (MDD) for the threat catalog and analysis.

Large System Security, Threat cataloging, MDD

I. INTRODUCTION

In recent years, more emphasis has been placed on design for security, security assessment, disaster recovery, disaster tolerance, in addition to the ongoing efforts in the established areas in fault tolerance. All of these areas require the identification and analysis of faults or threats. Most fault models and analysis methods assume that a fault causes a system to either function or fail and are thus modeled with binary conditions.

Recent events have demonstrated our vulnerability to disasters, both natural and man-made. This motivates the need to incorporate disaster tolerance into large system designs. Disaster tolerance is a superset of the more established approaches commonly referred to as fault tolerance. Models for disaster tolerance differ from those for fault tolerance since they assume that failures can occur due to single or massive numbers of individual faults occurring simultaneously or in a rapidly cascading manner. Traditional fault tolerance models single points of failure. Therefore, a disaster-tolerant system can withstand a catastrophic failure and still function with some degree of normality [8, 15].

Threats on a system can include both accidental and intentional effects. Examples of accidental events include random component failures, natural disasters, and fires. Examples of intentional effects include sabotage and cyber threats. A variety of tree structures have been developed to represent possible system threats. These tree structures are commonly called fault trees or attack trees. Fault trees were originally developed to identify the effects of component failures on a system [16] while attack trees traditionally focused on the effects of cyber security breaches [14]. There have been recent variants of these trees, and sometimes these trees have been used interchangeably [2, 5, 6, 7, 11]. However, these trees all have one thing in common: they are binary-valued trees, connected with AND and OR operators. This limits the effectiveness of how they can represent possible system-wide attacks. Modeling different operational modes other than just the binary case of failure or normal operation are critical in analyzing large systems in the presence of threats. As an example, in the 2003 blackout of the US power grid, many complex interactions caused a blackout to occur in a large portion of the northeastern US; however, it would be incorrect to state that the entire US power grid failed. In order to effectively catalog system threats, it is necessary to determine the probabilities of these threats based on various system stimuli, including input conditions and their probabilities.

As part of our preliminary research on large-scale system threat assessment, we developed threat tree models [12]. Threat trees are a superset of fault and attack trees since they are based on multiple-valued (MV) or radix-p valued algebras over a finite and discrete set of values [10]. When the radix $p=2$, the threat tree reduces to a fault or attack tree depending on the nature of the disruptive events. Generally, threat trees have $p>2$: these additional logic states allow for more complicated interactions to be modeled. In particular, these additional states can represent partial failures or degraded performance in a system, which are critical in analyzing large systems in the presence of threats.

The structure of this paper is the following: First, background information on decision diagram models is provided. Next, an approach is presented using decision diagram models to determine system threat probabilities. Finally, a system example is used to illustrate these concepts.

II. DECISION DIAGRAMS

Fig. 1 shows an example of a simple binary fault tree where the circular nodes represent the event of a single component failure and the logic operators (AND/OR gates) show how the events combine to result in a subsystem failure. Referring to

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Bernd Steinbach

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1997 27th International Symposium on Multiple-Valued Logic ,1997   **Advances in Applied Logics** Jair Minoro Abe,2023-10-30 This book contains contributions from several international authors to topics of current interest such as AI intelligent systems and logic applications in different branches of knowledge Foundational aspects of the various techniques are also covered notably non classical formalisms The tome is intended for researchers undergraduate and graduate students and lay readers The book is dedicated to researcher Seiki Akama on his sixtieth birthday Akama is one of the critical scientists who dedicated himself to understanding the use of alternative logic in the various issues of AI ranging from its foundations to concrete applications and philosophical reflections   **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   **ISMVL 2004** International Symposium on Multiple Valued Logic (34, 2004, Toronto),IEEE Computer Society,2004   *Technologies for Constructing Intelligent Systems 1* Bernadette Bouchon-Meunier,Julio Gutierrez-Rios,Luis Magdalena,Ronald R. Yager,2013-03-20 Intelligent systems enhance the capacities made available by the internet and other computer based technologies This book deals with the theory behind the

solutions to difficult problems in the construction of intelligent systems Particular attention is paid to situations in which the available information and data may be imprecise uncertain incomplete or of linguistic nature Various methodologies for these cases are discussed among which are probabilistic possibilistic fuzzy logical evidential and network based frameworks One purpose of the book is to consider how these methods can be used cooperatively Topics included in the book include fundamental issues in uncertainty the rapidly emerging discipline of information aggregation neural networks bayesian networks and other network methods as well as logic based systems **Handbook of Philosophical Logic** Dov M. Gabbay,Franz Guenthner,2013-03-09 It is with great pleasure that we are presenting to the community the second edition of this extraordinary handbook It has been over 15 years since the publication of the first edition and there have been great changes in the landscape of philosophical logic since then The first edition has proved invaluable to generations of students and researchers in formal philosophy and language as weIl as to consumers of logic in many applied areas The main logic artiele in the Encyelopaedia Britannica 1999 has described the first edition as the best starting point for exploring any of the topics in logic We are confident that the second edition will prove to be just as good The first edition was the second handbook published for the logic commu nity It followed the North Holland one volume Handbook 0 Mathematical Logic published in 1977 edited by the late Jon Barwise The four volume Handbook 0 Philosophical Logic published 1983 1989 came at a fortunate at the evolution of logic This was the time when logic temporal junction was gaining ground in computer science and artificial intelligence cireles These areas were under increasing commercial pressure to provide devices which help andjor replace the human in his daily activity This pressure required the use of logic in the modelling of human activity and organisa tion on the one hand and to provide the theoretical basis for the computer program constructs on the other **Relational and Algebraic Methods in Computer Science** Wolfram Kahl,Timothy G. Griffin,2012-09-12 This book constitutes the thoroughly refereed post conference proceedings of the 13th International Conference on Relational and Algebraic Methods in Computer Science RAMiCS 13 held in Cambridge UK in September 2012 The 23 revised full papers presented were carefully selected from 39 submissions in the general area of relational and algebraic methods in computer science adding special focus on formal methods for software engineering logics of programs and links with neighboring disciplines The papers are structured in specific fields on applications to software specification and correctness mechanized reasoning in relational algebras algebraic program derivation theoretical foundations relations and algorithms and properties of specialized relations **Binary Decision Diagrams and Extensions for System Reliability Analysis** Liudong Xing,Suprasad V. Amari,2015-06-05 Recent advances in science and technology have made modern computing and engineering systems more powerful and sophisticated than ever The increasing complexity and scale imply that system reliability problems not only continue to be a challenge but also require more efficient models and solutions This is the first book systematically covering the state of the art binary decision diagrams and their extended models which can provide

efficient and exact solutions to reliability analysis of large and complex systems The book provides both basic concepts and detailed algorithms for modelling and evaluating reliability of a wide range of complex systems such as multi state systems phased mission systems fault tolerant systems with imperfect fault coverage systems with common cause failures systems with disjoint failures and systems with functional dependent failures These types of systems abound in safety critical or mission critical applications such as aerospace circuits power systems medical systems telecommunication systems transmission systems traffic light systems data storage systems and etc The book provides both small scale illustrative examples and large scale benchmark examples to demonstrate broad applications and advantages of different decision diagrams based methods for complex system reliability analysis Other measures including component importance and failure frequency are also covered A rich set of references is cited in the book providing helpful resources for readers to pursue further research and study of the topics The target audience of the book is reliability and safety engineers or researchers The book can serve as a textbook on system reliability analysis It can also serve as a tutorial and reference book on decision diagrams multi state systems phased mission systems and imperfect fault coverage models **1998 28th International Symposium on Multiple-Valued Logic** ,1998 *Index of Conference Proceedings* British Library. Document Supply Centre,2001 Mathematical Reviews ,2005 **Proceedings of the First NASA/DoD Workshop on Evolvable Hardware** Adrian Stoica,Didier Keymeulen,Jason Lohn,1999 Looks at applying evolution inspired formalisms to hardware design in order to produce self reconfigurable electronic hardware by evolutionary and genetic reconfiguration mechanisms The 35 papers cover the evolution of FPGAs digital functions analog and mixed signal circuits cellular automata and brain inspired architectures reconfiguration architectures and dynamic reconfiguration advanced reconfigurable devices applications to the design and adaptation of space sub systems and genetic algorithms applications Titles but not texts are included for the nine invited talks Authors but not subjects are indexed Annotation copyrighted by Book News Inc Portland OR **Annual Symposium on Theoretical Aspects of Computer Science** ,2003 *Proceedings of the ... Midwest Symposium on Circuits and Systems* ,2003 **Directory of Published Proceedings** ,2002 *Logic, Artificial Intelligence, and Robotics* Jair Minoro Abe,João Inácio da Silva Filho,2001 Boolean Problems Bernd Steinbach,2002 **International Symposium on Multiple-Valued Logic** ,1984 **IEEE Computer Society Annual Symposium on VLSI** ,2005 **Fuzzy Systems Conference (FUZZ), 2000** IEEE Neural Networks Council,2000-05

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