

# Learning-Oriented Reliability Improvement of Computing Systems From Transistor to Application Level

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**Abstract**—Due to technology scaling in modern computing platforms, the safety and reliability issues have increased tremendously, which often accelerate aging, lead to permanent faults, and cause unreliable execution of applications. Failure in some computing systems like avionics may cause catastrophic consequences. Therefore, managing reliability under all circumstances of stress and environmental changes is crucial in all abstraction layers, from application to transistor levels. Machine learning techniques are recently being employed for dynamic reliability estimation and optimization. They can adapt to varying workloads and system conditions. This paper presents reliability improvement approaches from multiple perspectives—from transistor-level to application-level—and discusses their effectiveness and limitations as well as open challenges.

**Index Terms**—Aging, Cross-layer reliability, Device and circuit reliability, Dynamic reliability estimation, Error mitigation, Machine learning for systems, Task scheduling, Timing reliability.

## I. INTRODUCTION

**T**ECHNOLOGY advancement has enabled computing systems to become an integral part of human life. However, the ongoing technology scaling is introducing an ever-increasing number of reliability challenges, especially when it comes to advanced technology nodes [1], [2]. This endangers the correct operation of hardware and software of computing processors. A failure of such systems (applications or hardware) may lead to catastrophic consequences. To design a reliable system, mitigation and countermeasures against error and aging need to be applied across multiple abstraction layers of the computing system, from transistors to all the way up to the application design, since various levels may be involved in the error and aging process [3]. Several design- and run-time approaches should be exploited, which can adapt to varying system conditions, execution requirements, and workloads variations during run-time. Machine learning (ML) techniques are recently employed for dynamic reliability improvement [4]. They can effectively adapt to such variations and determine effective system configuration under dynamic and environmental changes. Although ML techniques are very promising for improving reliability, they introduce several challenges in each and across layers that need to be carefully considered.

This paper discusses various aspects of learning-based reliability monitoring and improvement in computing systems.



Fig. 1. Learning-based reliability management.

Fig. 1 shows a workflow for learning-based reliability management in which actions refer to optimization knobs used by the learning controller, states are the inputs based on the observation, and the agent aims to optimize the reward function, i.e., reliability improved in different abstraction layers, by using the resiliency models like mean time to failure (MTTF). In this paper, we first discuss how ML techniques can be used to estimate and mitigate aging from the transistor level to the standard-cell and circuit levels (Section II). Section III describes how ML can help to alleviate challenges of reliability modeling and improvement at the architectural level. Then, Section IV presents a survey of learning-based approaches that could improve reliability at the application layer through operating system (OS) techniques. We then analyze the reliability on a fault-tolerant system and discuss the timing costs in correcting register-level errors in Section V. Finally, we discuss the open challenges and limitations in Section VI and present summary in Section VII.

## II. ESTIMATING DEVICE AND CIRCUIT RELIABILITY USING CLASSICAL AND EMERGING MACHINE LEARNING

Reliability is one of colossal concerns for circuit designers. Transistor self-heating (SHE) is increasingly challenging because transistor scaling is reaching atomic levels in which quantum confinement becomes substantially prominent. With more confined 3D structures (e.g., TSMC Nanosheet FETs and Intel Ribbon FETs), heat arising in the transistor's channel cannot be easily dissipated and is hence “trapped” inside the transistor's channel. Such heat trapped inside the transistor

# Computing Systems Reliability

**A. Costes**



## **Computing Systems Reliability:**

**Computing System Reliability** Min Xie, Kim-Leng Poh, Yuan-Shun Dai, 2013-04-09 Computing systems are of growing importance because of their wide use in many areas including those in safety critical systems This book describes the basic models and approaches to the reliability analysis of such systems An extensive review is provided and models are categorized into different types Some Markov models are extended to the analysis of some specific computing systems such as combined software and hardware imperfect debugging processes failure correlation multi state systems heterogeneous subsystems etc One of the aims of the presentation is that based on the sound analysis and simplicity of the approaches the use of Markov models can be better implemented in the computing system reliability

**Computing System Reliability** Min Xie, Kim-Leng Poh, Yuan-Shun Dai, 2014-01-15 Reliable Computer Systems Santosh K. Shrivastava, 2012-12-06 A research project to investigate the design and construction of reliable computing systems was initiated by B Randell at the University of Newcastle upon Tyne in 1972 In over ten years of research on system reliability a substantial number of papers have been produced by the members of this project These papers have appeared in a variety of journals and conference proceedings and it is hoped that this book will prove to be a convenient reference volume for research workers active in this important area In selecting papers published by past and present members of this project I have used the following criteria a paper is selected if it is concerned with fault tolerance and is not a review paper and was published before 1983 I have used these criteria with only one or two exceptions in order to present a collection of papers with a common theme and at the same time to limit the size of the book to a reasonable length The papers have been grouped into seven chapters The first chapter introduces fundamental concepts of fault tolerance and ends with the earliest Newcastle paper on reliability The project perhaps became well known after the invention of recovery blocks a simple yet effective means of incorporating fault tolerance in software The second chapter contains papers on recovery blocks starting with the paper which first introduced the concept

**Computer System Reliability** B.S. Dhillon, 2016-04-19 Computer systems have become an important element of the world economy with billions of dollars spent each year on development manufacture operation and maintenance Combining coverage of computer system reliability safety usability and other related topics into a single volume Computer System Reliability Safety and Usability eliminates th

Reliability of Computer Systems and Networks Martin L. Shooman, 2003-03-25 With computers becoming embedded as controllers in everything from network servers to the routing of subway schedules to NASA missions there is a critical need to ensure that systems continue to function even when a component fails In this book bestselling author Martin Shooman draws on his expertise in reliability engineering and software engineering to provide a complete and authoritative look at fault tolerant computing He clearly explains all fundamentals including how to use redundant elements in system design to ensure the reliability of computer systems and networks Market Systems and Networking Engineers Computer Programmers IT Professionals

**Reliability in Computer**

**System Design** Balbir S. Dhillon, 1987 This volume covers wide areas of interest such as life cycle costing microcomputers common cause failures and space computers Every effort is made to present difficult material with the aid of an example along with its solution The material covered is summarized at the end of each chapter The information is written in a format that allows readers to learn and better understand the philosophy of reliability in computer system design At the same time it tests their comprehension through listed exercises *Cross-Layer Reliability of Computing Systems* Giorgio Di

Natale, Dimitris Gizopoulos, Stefano Di Carlo, Alberto Bosio, Ramon Canal, 2020-08-27 Reliability has always been a major concern in designing computing systems However the increasing complexity of such systems has led to a situation where efforts for assuring reliability have become extremely costly both for the design of solutions for the mitigation of possible faults and for the reliability assessment of such techniques *Achieving Safety and Reliability with Computer Systems* B.K. Daniels, 2012-12-06 The safe operation of computer systems in both their software and hardware continues to be a key issue in many real time applications when people environment investment or goodwill can be at risk Such applications include the monitoring and control of high energy processes of nuclear and chemical plants of factory automation of transportation systems or funds transfer and of communication and information systems This book represents the proceedings of the 1987 Safety and Reliability Society Symposium held in Altrincham UK 11 12 November 1987 It is thus part of the series of proceedings for Society Events which in previous years have not addressed the topic of the Safety and Reliability of Computer Systems The book is also part of another series of reports and is closely related to the Elsevier Book Safety and Reliability of Programmable Electronic Systems which I edited in 1986 and the series of workshops known as SAFECOMP held in 1979 1982 1983 1985 1986 which are referenced in some of the papers The structure of the book represents the structure of the Symposium itself The session titles and the papers as selected represent the current practice in many industries The trend is towards more industrial usage of Formal Methods and tools to support these methods whilst continuing to make best use of Software Engineering Safety and Reliability Assessment and accumulated experience

Computing Systems Reliability A. Costes, 1979

**Computing Systems Reliability** Tom Anderson, 1979

**Performance related reliability measures for computing systems** M. D. Beaudry, 1976 *Performance, Reliability, and Availability Evaluation of Computational Systems, Volume 2* Paulo Romero Martins Maciel, 2023-04-06 This textbook intends to be a comprehensive and substantially self contained two volume book covering performance reliability and availability evaluation subjects The volumes focus on computing systems although the methods may also be applied to other systems The first volume covers Chapter 1 to Chapter 14 whose subtitle is Performance Modeling and Background The second volume encompasses Chapter 15 to Chapter 25 and has the subtitle Reliability and Availability Modeling Measuring and Workload and Lifetime Data Analysis This text is helpful for computer performance professionals for supporting planning design configuring and tuning the performance reliability and availability of computing systems Such professionals may use

these volumes to get acquainted with specific subjects by looking at the particular chapters Many examples in the textbook on computing systems will help them understand the concepts covered in each chapter The text may also be helpful for the instructor who teaches performance reliability and availability evaluation subjects Many possible threads could be configured according to the interest of the audience and the duration of the course Chapter 1 presents a good number of possible courses programs that could be organized using this text Volume II is composed of the last two parts Part III examines reliability and availability modeling by covering a set of fundamental notions definitions redundancy procedures and modeling methods such as Reliability Block Diagrams RBD and Fault Trees FT with the respective evaluation methods adopts Markov chains Stochastic Petri nets and even hierarchical and heterogeneous modeling to represent more complex systems Part IV discusses performance measurements and reliability data analysis It first depicts some basic measuring mechanisms applied in computer systems then discusses workload generation After we examine failure monitoring and fault injection and finally we discuss a set of techniques for reliability and maintainability data analysis

### **Reliability in Computing Systems**

Allen Klinger,1972 **Software Design for Resilient Computer Systems** Igor Schagaev,Eugene Zouev,Kaegi

Thomas,2019-07-09 This book addresses the question of how system software should be designed to account for faults and which fault tolerance features it should provide for highest reliability With this second edition of Software Design for Resilient Computer Systems the book is thoroughly updated to contain the newest advice regarding software resilience With additional chapters on computer system performance and system resilience as well as online resources the new edition is ideal for researchers and industry professionals The authors first show how the system software interacts with the hardware to tolerate faults They analyze and further develop the theory of fault tolerance to understand the different ways to increase the reliability of a system with special attention on the role of system software in this process They further develop the general algorithm of fault tolerance GAFT with its three main processes hardware checking preparation for recovery and the recovery procedure For each of the three processes they analyze the requirements and properties theoretically and give possible implementation scenarios and system software support required Based on the theoretical results the authors derive an Oberon based programming language with direct support of the three processes of GAFT In the last part of this book they introduce a simulator using it as a proof of concept implementation of a novel fault tolerant processor architecture ERRIC and its newly developed runtime system feature wise and performance wise Due to the wide reaching nature of the content this book applies to a host of industries and research areas including military aviation intensive health care industrial control and space exploration

### Performance Considerations for the Reliability Analysis of Computing Systems Marie Danielle

Beaudry,1978 *Workload, Performance, and Reliability of Digital Computing Systems* Xavier Castillo,1981 In this paper a new modeling methodology to characterize failure processes in Time Sharing systems due to hardware transients and software errors is summarized The basic assumption made is that the instantaneous failure rate of a system resource can be

approximated by a deterministic function of time plus a zero mean stationary Gaussian process both depending on the usage of the resource considered The probability density function of the time to failure obtained under this assumption has a decreasing hazard function partially explaining why other decreasing hazard function densities such as the Weibull fit experimental data so well Furthermore by considering the Kernel of the Operating System as a system resource this methodology sets the basis for independent methods of evaluating the contribution of software to system unreliability and gives some non obvious hints about how system reliability could be improved A real system has been characterized according to this methodology and an extremely good fit between predicted and observed behavior has been found Also the predicted system behavior according to this methodology is compared with the predictions of other models such as the exponential Weibull and periodic failure rate Author *Reliable Computing Systems* R. F. Stone,1989 Abstract The use of programmed digital computers in situations requiring extreme reliability is increasing rapidly With more reliance being placed on such systems in life critical applications the need to develop control systems which are error free and remain so for the duration of their service has never been greater This reports surveys previous work in the area of computer systems reliability It provides an introduction to the area and covers most of the topics considered relevant such as reliability modelling The report concentrates on the acquisition of reliability via software fault tolerance In particular the key area of error recovery is considered

**Computer System Reliability** Roy Longbottom,1980 **Performance and Reliability Analysis of Computer Systems** Robin A. Sahner,Kishor Trivedi,Antonio Puliafito,2012-12-06 Performance and Reliability Analysis of Computer Systems An Example Based Approach Using the SHARPE Software Package provides a variety of probabilistic discrete state models used to assess the reliability and performance of computer and communication systems The models included are combinatorial reliability models reliability block diagrams fault trees and reliability graphs directed acyclic task precedence graphs Markov and semi Markov models including Markov reward models product form queueing networks and generalized stochastic Petri nets A practical approach to system modeling is followed all of the examples described are solved and analyzed using the SHARPE tool In structuring the book the authors have been careful to provide the reader with a methodological approach to analytical modeling techniques These techniques are not seen as alternatives but rather as an integral part of a single process of assessment which by hierarchically combining results from different kinds of models makes it possible to use state space methods for those parts of a system that require them and non state space methods for the more well behaved parts of the system The SHARPE Symbolic Hierarchical Automated Reliability and Performance Evaluator package is the toolchest that allows the authors to specify stochastic models easily and solve them quickly adopting model hierarchies and very efficient solution techniques All the models described in the book are specified and solved using the SHARPE language its syntax is described and the source code of almost all the examples discussed is provided Audience Suitable for use in advanced level courses covering reliability and performance of computer and communications systems

and by researchers and practicing engineers whose work involves modeling of system performance and reliability  
Computer Systems Reliability T. Anderson, Tom Anderson, Brian Randell, 1979-07-31

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