Preface

The increasing diversity, density, and complexity of electronic devices is enabling the so-called digital revolution with the evident pervasive presence of electronics in everybody’s lives. The benefits of this ubiquitous presence are impressive and widespread: from the constant improvement of productivity in the workplace to the societal impact of a constantly connected and sharing community.

Whatever is the considered scenario, all this incredible progress has been relying on the assumption that the devices can be depended on in their application and for their purposes. The foundations for this assumption are based on a constant work behind the scenes of the technical and scientific community aimed at enhancing the dependability of the devices.

Dependability is a broad term that summarizes several aspects of a system, which typically include availability, reliability, maintainability, safety, and security. All these aspects define whether and how the system will behave according to several requirements which can have different levels of priority based on the specific application. In particular, availability measures the amount of time a system is readily operating, reliability measures the continuity of the correct service, maintainability shows the ability of the system of being repaired and/or modified, safety targets the avoidance of catastrophic consequences in the case of lack of service, and finally security targets the resilience of a systems to threats caused by malicious third parties.

There is an impressive amount of examples from technical literature and from the news about the dreadful consequences of the lack of dependability of an electronic system. Lack of dependability may have several negative consequences spreading from the loss of reputation of a manufacturer to the catastrophic loss of lives. Consider for example the automotive scenario, several cases of massive recalls were caused by issues in the electronic system: famously in one of such cases it was speculated that unintended acceleration causing loss of lives was to be ascribed to faults occurring in the drive-by-wire control modules.

Apart from the loss of lives, the economic impact of unreliable hardware must also be taken into account. Depending on the particular product and application domain, the costs associated to lack of dependability can be extremely high:
consider again the example, in the automotive domain, the costs caused by a massive recall of failing hardware, or in consumer electronics, the economic impact in loss of reputation for the manufacturer. Also, there are specific applications where the costs associated with replacing a failing hardware are just prohibitive: consider as an example the space industry where the replacement of failing hardware is all but impossible unless having to sustain huge costs.

A key step to obtaining dependable systems is at manufacturing. Manufacturing dependable digital electronic devices is a process that takes into account several aspects of the life and use of the designed device. At the manufacturing level, designers must take into account the new challenges introduced by the latest technology trends while at a system level the designer must include suitable approaches to counteract the potential occurrence of events that could lead to a non-dependable behavior.

Dependability and manufacturability are very related: from a temporal point of view, manufacturability deals with the cost-effectiveness of chips during production while dependability deals with the correctness of their operation later in the field. Manufacturability and dependability share common challenges and threats, have common objectives, and utilize common solutions regardless of the employment of chips in systems at the low end of performance and power (low-cost embedded systems or consumer electronics) or the high end of the performance (data centers, cloud computing facilities, or extremely powerful supercomputers).

It should be noted that aspects of manufacturability are very specific to the industrial process such as the cost of manufacturing and its accurate relation to yield. These aspects are not easily available to the academic community and therefore are not the focus of this book; instead, the book content is devoted to the actual physical threats and the mitigation techniques used in general and in particular application domains.

This book stems from the view of MEDIAN, a large network of researchers from academia and industry funded by COST\(^1\) collaborating in the areas of manufacturability and dependability of multicore architectures and their deployment in different computing application domains. In particular, the focus is on multicore architectures.

The shift from increasing core clock frequencies to exploiting parallelism and multicore chip architectures has been the main design drive across all application domains in the electronics and computing industry. The introduction of multicore chips enabled a constant increase in delivered performance otherwise impossible to achieve in single-core designs. Multiple microprocessor cores from different instruction set architectures stay at the epicenter of such chips and are surrounded by memory cores of different technologies, sizes, and functionalities, as well as by

\(^1\)COST is the longest-running European framework supporting transnational cooperation among researchers, engineers, and scholars across Europe and is supported by the EU Framework Programme Horizon 2020.
peripheral controllers, special function cores, analog and mixed-signal cores, reconfigurable cores, etc.

The functionality as well as the complexity of multicore chips is unprecedented. This is the aggregate result of several technologies that emerged and matured together the last few decades: (a) manufacturing process now approaching the 10 nm regime and soon expected to go beyond, (b) sophisticated electronic design automation tools assisting and refining every step of the design process, and (c) new processor architectures across the entire spectrum of performance and power consumption.

The book is structured in three parts.

Part I (Chapter “Manufacturing Threats” to Chapter “Application Scenarios”) describes the reliability threats of the latest nanoscale technologies and their modeling at different levels of abstraction of complex multicore systems, and shows the impact of these threats in several safety-critical scenarios.

Part II (Chapter “Manufacturing Solutions” to Chapter “Application-Specific Solutions”) illustrates the possible mitigation strategies that can be applied to increase the dependability of complex systems. Also in this part, a specific chapter is dedicated to specific application scenarios, showing the relationship between the mitigation solutions and the characteristic of the environment in which the system will operate.

Part III (Chapter “Variation-Mitigation for Reliable, Dependable and Energy-Efficient Future System Design” to Chapter “Roadmap for On-Board Processing and Data Handling Systems in Space”) collects the contributions of experts working in companies and public bodies (ARM, ESA, AMD, STMicroelectronics) providing their view about which are the most important and future trends in the field of design of dependable systems.

A detailed breakdown of contents of the chapters is the following.

Chapter “Manufacturing Threats” gives an overview of the reliability threats of the latest nanoscale generations of CMOS technology designs. First, a discussion on the process variability sources, and on the effect on circuit design and achievable performance is presented. After, the different wear-out physical effects such as Bias Temperature Instability (BTI), Hot Carrier Injection (HCI), Random Telegraph Noise (RTN), and Time-Dependent Dielectric Breakdown (TDDB) are analyzed. Finally, the chapter describes the physical phenomena provoking runtime variability effects such as voltage fluctuation and soft errors.

Chapter “Dependability Threats” provides an overview of fault/error models adopted in methodologies for dependability assessment, analysis, and mitigation, and presents an advanced reliability estimation technique for reliability estimation. Faults are categorized based on their applicability in the various abstraction layers. In particular, specific fault models have been included to take into account modern design trends such as FPGAs and NoCs. Furthermore, the chapter also gives special attention to modeling of aging and wear-out effects that arise during the operational life of the devices, causing either transient, intermittent, or permanent failures. The reliability estimation method is extended with the aim to provide a comprehensive system-level model able to consider multi-component architectures. The chapter
ends with an overview of the relevant dependability metrics used in methodologies and techniques targeting dependability problems.

Chapter “Application Scenarios” shows several examples of how the faults occurring in modern technologies impact the system design in domains, such as automotive, railroad and transportation, air and space, and medical, where safety-critical and reliable operations are mandatory requirements. It addresses current practices deployed in these different domains and highlights the risks involved when the effects of the ever scaling technologies and related design techniques on system reliability are not properly taken into consideration. The chapter also discusses the growing interest problem of hardware security, which is a common challenge in all the domains.

Chapter “Manufacturing Solutions” starts the second part of the book, where the design solution to the dependability threats discussed in the first part is presented. This chapter focuses on the threat described in Chapter “Manufacturing Threats” and presents the current available solution to mitigate faults. The presented solutions are applied at different design levels, depending on the specific threat to face and on the targeted dependability level. The chapter shows how to face some threat already during the process manufacturing, in which the used materials and the lithographic process are modified to limit the effects of process variability. Also, techniques based on layout design methodology are introduced. On a higher design level, several circuit level and RTL design level technologies are illustrated to different dependability threats (soft errors, voltage droop).

Chapter “Dependability Solutions” presents an overview of existing dependability solutions for processors and multicore processing systems. First, the existing techniques to protect processor cores both at the hardware and software level are discussed. Then the protection of the different memories that are present in a multicore is reviewed in the second section. Finally, the protection of the interconnections and an overview of specific Network on Chip dependability solutions are covered in the last section.

Chapter “Application-Specific Solutions” examines in detail some mitigation solutions applied in specific critical scenarios. It starts from the consideration presented in Chapter “Application Scenarios” considering a broader variety of application domains and their relation to dependability. The chapter shows how the specific design choices are strictly dependent on the application domain and how the selected solution can be different from each other.

Chapter “Variation-Mitigation for Reliable, Dependable and Energy-Efficient Future System Design” is the first chapter of the third part of the book. The chapter provides the view from two ARM researchers about the major issues related to microprocessor dependability design. The chapter focuses on the issues related to process, voltage, and temperature (PVT) variations and the related mitigation strategies. An overview of the various sources of variation and the traditional approaches for variation-mitigation is presented. Afterward, several promising techniques for variation-mitigation are discussed. In particular, in situ aging monitors, error-resilient techniques, and adaptive clocking techniques are examined. Furthermore, the chapter provides a detailed analysis of the Razor approach,
showing the silicon measurement results from multiple industrial and academic demonstration systems that employ Razor.

Chapter “Design for Test and Test Equipment Roadmap” reports the experience of and the view of two researchers at AMD, another big player deeply involved in the design of next-generation multicore processors. The chapter topic is the resilience proportionality design, an interesting methodology to provide efficient and reliable systems. The chapter observes that chip design companies have to make difficult decisions about the exact dependability level that each product in their portfolio should provide and have few hints on which are the specific request and needs of customers and market segments. Therefore, the tradeoff between design cost, deployment cost, and the dependability level is a critical issue to address. The chapter proposes a resilience proportionality approach able to adapt a design to the dependability needs of a wide range of applications and hardware configurations.

Chapter “Resilience Proportionality—A Paradigm for Efficient and Reliable System Design” presents STMicroelectronics view and a roadmap for Design for test and test equipments. The current and future issues of VLSI test are examinated, highlighting how the exasperated operating conditions (very high temperature, severe mission profiles) and the limited confidence of the various adopted fault models (stuck-at, transition, and bridging) enlarge a progressive gap between the effective adherence of fault models to the actual defects present in IC. The chapter offers some perspective analysis on how these challenges can be faced and hopefully resolved. New synergies between DfT, test equipment, and test methods shall be proposed to highlight cause–effect relations. Special attention shall also be given to the sustainability of the costs of the proposed solution.

Chapter “Roadmap for On-Board Processing and Data Handling Systems in Space” gives the view of two European Space Agency (ESA) scientists about the evolution of on-board processing and data handling systems in the space environment. First, the chapter surveys the state of the art in this field and presents the description of a generic On-Board Computers and Data Systems Architecture. Afterward, the chapter continues identifying the historical path in the design of space system, starting from the old space microprocessors going to the current generation systems (multicore, FPGA, etc.), concluding with the expected future trends.

Dependable and manufacturable computing is a broad and intense research area concentrating major research effort worldwide from the circuit, architecture, and software communities. We believe that the snapshot of the area we deliver with this book reveals the tough challenges, the current directions, as well as the research opportunities in the near future. The forthcoming manufacturing technologies and the requirements of specific application domains will determine the advances in the field and the level of investment the industry will put on it.
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