Preface

My association with hardware description (design) languages for digital systems dates back to 1981 when, as a graduate student at Stanford University, Professor Willem vanCleemput taught us EE481: Computer-aided design (CAD) of digital systems. Prior to that, Professsor R. M. K. Sinha at IIT Kanpur had thoroughly enthused us by teaching computer architecture design, utilizing AHPL, the APL-based hardware programming language, proposed by Professsors Hill and Peterson in their book on a hardware programming language (AHPL). My own Ph.D. dissertation on an Ada-based distributed hardware design language and simulation environment with Professsor W. vanCleemput, my investigations at Fairchild Advanced Research & Development Laboratory (Palo Alto) on a behavior-level fault simulator in ADLIB-SABLE, my research at Bell Labs Research with Dr Erik Debenedictis, Dr. Meng-Lin Yu, and Dr. P. A. Subrahmanyam, my collaborations with my Ph.D. advisees—Peter Walker at Brown University and Jerry Schumacher at Arizona State University—and my interactions with Professsor Norbert Giambiasi of the University of Marseilles in France, have imparted to me a deep appreciation and understanding of the fundamentals of HDLs. This, I wish to share with my readers.

My motivation for writing the book is three-fold. First, it is an expression of my gratitude and it is my humble effort to reciprocate the kind teachings of all of my teachers and the extraordinary books that had educated me in the art of thinking from first principles. Second, in the course of my research with my Ph.D. advisees and while teaching CSE 517: Hardware Design Languages (HDL), to computer science and electrical engineering graduate students at Arizona State University and the technical staff from Motorola Inc., Intel Corp., VTI, etc., in the Phoenix valley in Fall 1996–7, I realized that for many of the key HDL concepts, the reasonings and fundamental principles were either scattered in journal or conference papers or were simply unavailable. Following a week-long take-home exam, many of the students had remarked to me that, despite reading most of the available books on VHDL and a thorough search of the literature utilizing DIALOG, INSPEC, UNCOVER, and WWW, they could not obtain the relevant material. Professsor Giambiasi had remarked to me that, while teaching VHDL in France, his students found many of the language constructs as unnatural, deviant from the underlying hardware design principles, and difficult. Third, throughout my education, my teachers in high school and my professors at Indian Institute of Technology, Kanpur, and at Stanford University had always stressed the importance and long-term value of understanding the basics. When one understands the underlying principles and can relate them to one's own basic understanding, learning becomes fun and enjoyable. It becomes a captivating and intoxicating exercise in creativity. One acquires a fine, subtle, sense of the whys underlying the whats and one can "see" where the future is headed. The existing knowledge no longer appears to be shrouded in mystery but is seen as natural. The need for memorization followed by regurgitation disappears. Most important of all, the understanding and the knowledge become firmly integrated with one's own thought processes. I have made every effort and it is my earnest hope that, when the reader has reached the end of this book, the evolution of the HDLs, the complexity of the language constructs, and the seemingly unending possibilities of complex interactions between the different language constructs, will evoke a single thought, "Yes, it is what it should be." At the same time, the reader will "see" where the HDLs must be headed in the future.

The field of HDL is rich and fascinating for it represents an unique interaction of a number of disciplines from electrical engineering and computer science—namely, language design, hardware design and computer architecture, compilers, language environments, simulation, distributed algorithms, parallel processing, and yes, philosophy. An effort to understand the basics, starting from the first principles, promises a number of additional advantages. First, it reveals the reason for each specific language construct, leading to a better appreciation of how to use it to realize the maximum benefit. As a result, one evolves into a superior decision maker and develops superb digital designs. Second, one develops a deeper understanding of the whats and whys of the underlying limitations. As circuits become faster and more complex in the future, one is better equipped to address the problems and may even initiate changes to update the HDLs. Third, knowledge of the fundamentals provides a continuity of understanding through the hundreds of publications in the literature on HDLs. Fourth, fundamentals are very convenient since they are usually few in number and they reflect a highly condensed and crystallized form of knowledge. The fundamentals are like a tiny seed that holds the many details of the huge banyan tree of the future. Fifth, virtually all of the HDLs to-date including Verilog HDL and VHDL execute only on uniprocessors, implying excruciatingly long simulation times for large hardware systems. The two key reasons include the lack of an intricate and correct weaving of concurrency into the HDLs and the absence of a successful asynchronous, distributed event driven simulation algorithm that detects and discards inconsistent events while being free of deadlocks. This book addresses both limitations, starting from the first principles. Last, should a new HDL come around in the future, one that is based on new principles superseding today's time-based and event driven simulation principles, to one conversant in the basics it offers little resistance to understanding and mastering it.

My own experience with CSE517 at Arizona State University has been particularly revealing. At the onset, I had stated to the class that I would start from first principles and proceed from one HDL to the subsequent one, starting with the first HDL and working our way towards the state-of-the-art in hardware design language—VHDL. In the process, we will examine each evolutionary development, reasoning about it from the fundamentals and analyzing its purpose and utility from the underlying principles of hardware design and the primary intent of HDLs. A number of students, however, were driven by their desire to quickly learn VHDL to either complete their assignments at work or to secure jobs in the semiconductor industry. Their impatience persisted through the first half of the semester until we started to critically analyze the VHDL constructs. Suddenly, as it were, the entire class stumbled upon the realization that the basic principles of HDL design form a continuous thread through all HDLs starting with the first one and that the elements of VHDL fall straight out from these basic principles. They could literally see through the past 30 years of HDL efforts and, if asked, they could even undertake the design of the principal elements of VHDL from scratch.

This book presents HDLs as a science, not a mysterious elite art. It starts with clear and unambiguous logical principles that are grounded in physics, reality, and the first principles. The book argues and reasons about these principles and from it develops practical mechanisms for describing hardware, constructing simulators, synthesizing executable hardware descriptions, and executing them on a computer. Not only will these basic principles provide the key to understanding the secrets of all HDLs ever invented, they will continue to remain in effect even if the current HDLs are replaced with new ones in the future. The book has been written for practicing electronic CAD engineers, researchers in simulation and verification of electronic CAD, graduate and doctoral students in computer design, and undergraduates specializing in electronic hardware design.

The book starts from the very basics and assumes only that the reader is familiar with the rudiments of digital design and is willing to reason, think, and introspect. My conviction in this Socratic style of education is based on my sincere belief that all knowledge is inherent in the human mind and it needs to be brought forth by the right stimulus. The book has been so structured that anyone with a minimal background can reason from the fundamentals and discover the principles for oneself. For one adept in HDL usage, knowledge of the enormous possibilities and fundamental limitations will foster greater creativity in achieving higher quality hardware designs.

Chapter 1 introduces HDLs, traces the origins of the early HDLs, why they were invented, and what is the fundamental definition of an HDL. Chapter 2 follows the evolutionary development of the early HDLs, revealing every major improvement achieved by the successive HDLs. It also analyzes the fundamental differences between HDLs and programming languages to show how the HDL effort was able to maintain its unique identity as distinct from the general-purpose programming languages. The analysis presented in Chapter 2 leads directly into the issue of behavior-level HDLs. Chapter 3 presents the fundamentals of any behavior-level HDL, arguing from a combination of first principles, physics, and the underlying philosophy of this universe. It is probably the most basic and revealing of all the chapters in the book and, upon completion, it is my hope that the reader will have acquired a vision that will allow him or her to comprehend the past 30 years of HDL effort in a nutshell. Chapter 4 examines the first behavior-level HDL very carefully and critically, and aims to strengthen the principles of Chapter 3 through an example. Chapter 5 analyzes the Verilog hardware description language proposed by Cadence, Inc. in the light of the fundamentals. Chapter 6 presents an exercise towards a simple and effective HDL design. Chapter 7 analyzes the massive VHDL effort in the light of the fundamentals established in Chapter 3. It analyzes both its achievements and weaknesses, reasons the causes for the limitations, and presents mechanisms to address the limitations. Chapter 8 illustrates the development of hardware descriptions from first principles through a series of case studies—three real-world complex digital systems. A thorough understanding of these representative example systems will provide adequate knowledge to the reader to undertake the writing of accurate hardware descriptions of just about any complex digital system. Chapter 9 presents the principles underlying the concurrent simulation of the HDLs in general and VHDL in particular, and explains why this effort is unique in the discipline of Computer Science and

Engineering. Chapter 10 addresses the issue of transport delay that is gaining increasing importance in the current era of higher VLSI densities, higher clock speeds, and newer bus design techniques. This chapter is unique in that it shows how two apparently diverse branches of knowledge—languages and grammars from computer science and the classical transmission line theory in electrical engineering—must come together to solve a problem. Finally, Chapter 11 summarizes the book and presents some parting thoughts on where HDLs are headed in the future and relevant philosophical reflections.

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