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Microprocessor Design

A Practical Guide from Design Planning to Manufacturing

Grant McFarland

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Preface

Reading This Book

Microprocessor design isn't hard, but sometimes it seems that way. As processors have grown in complexity and processor design teams have grown in size, individual design engineers have become more specialized, focusing on only one part of the design process. Each step in the design flow has its own jargon; today it is not at all hard to be working on a processor design team and still not have a clear understanding of aspects of design that don't involve you personally. Likewise, most textbooks focus on one particular aspect of processor design, often leaving out information about what steps came before or what will happen afterward. The intent of this book is to provide an overall picture of the microprocessor design flow, from the initial planning of a processor through all the steps required to ship to customers.

Covering the entire design flow in a single book means that only the most important aspects of each step are covered. This book provides the key concepts of processor design and the vocabulary to enable the reader to learn more about each step. Students may use this book to gain a broad knowledge of design and to decide which area they are most interested in pursuing further. Engineers already working in design will find out how their specialty fits into the overall flow. Nonengineers who interact with design teams, such as managers, marketers, or customers, will learn the jargon and concepts being used by the engineers with whom they work.

The flow of the book follows the life of a microprocessor design. The first two chapters cover the concepts required before a design really begins. Chapter 1 discusses transistors and how their evolution drives processor design. Chapter 2 describes some of the other components with which the processor will communicate. Chapter 3 begins the processor design flow with planning, and the following chapters take the design through each of the needed steps to go all the way from an idea to shipping a finished product.

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Chapter list

Chapter 1—The Evolution of the Microprocessor: Describes the development of the microprocessor and how transistor scaling has driven its evolution.

Chapter 2—Computer Components: Discusses computer components besides the microprocessor and the buses through which they interact with the processor.

Chapter 3—Design Planning: Explains the overall steps required to design a processor and some of the planning required to get started.

Chapter 4—Computer Architecture: Examines trade-offs in choosing an instruction set and how both instructions and data are encoded.

Chapter 5—Microarchitecture: Explains the operation of the different functional areas of a processor and how they determine performance.

Chapter 6—Logic Design: Discusses converting a microarchitectural design into the logic equations required to simulate processor behavior.

Chapter 7—Circuit Design: Shows logic design equations being converted into a transistor implementation.

Chapter 8—Layout: Demonstrates circuit designs being converted to layout drawings of the different layers of material required for fabrication.

Chapter 9—Semiconductor Manufacturing: Shows how integrated circuits are manufactured from layout.

Chapter 10—Microprocessor Packaging: Discusses how completed die are packaged for use and the trade-offs of different types of packages.

Chapter 11—Silicon Debug and Test: Explains how designs are checked for flaws and completed die are tested before shipping to customers.

The many specialized terms and acronyms of processor design are explained as they are introduced in the text, but for reference there is also a glossary at the end of the book. After reading this, microprocessor design won't seem that hard after all.

The Future of Processor Design

The rapid changes in the semiconductor industry make predicting the future of processor design difficult at best, but there are two critical questions designers must address in the coming years.

- How can design make best use of ever-increasing numbers of transistors?
- How can processors be designed to be more power efficient?

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The first of these questions has remained the biggest question facing processor designers since the beginning of the industry. By the end of 2006, that is, when this book gets published, the highest transistor count processors on the market should include more than 1 billion devices. If the current rate of increase continues, a 10-billion device processor is likely before 2015 and a 100-billion device processor by 2025. What will these processors be like? The most recent answer for how to make use of more transistors is to put multiple processor cores onto a single die. Does this mean that a 10-billion transistor processor will merely be a combination of ten 1-billion transistor processors? This is certainly possible, but a 100-billion transistor processor will almost certainly not be a hundred core processor. At least today, most software problems cannot be divided into this many separate pieces. Perhaps new methods will be found, but it is likely that the number of cores in future processors will be limited more by software than by hardware.

If most software applications will only be able to make use of a very small number of cores, will each single core contain tens of billions of transistors? Design tools and methods of today are not up to creating the design for such a processor. We may be moving from a time when processors designs are no longer determined by the limits of fabrication, but instead by the limits of the design process itself. Perhaps the processor will absorb the functionality of other computer components, as has happened in the past. A microprocessor with several general-purpose cores as well as a graphics processor, memory controller, and even main memory itself, all built into a single die, could make use of a very large number of transistors indeed. Maybe this type of true "system-on-a-chip" will be the future. In the past, it has always been feared that the end of fabrication improvements was just a few years away. It is physically impossible for the shrinking of transistors to continue at its current pace forever, but every prediction so far of the end of scaling has been wrong. Today, the problems of new hardware and software design methodologies threaten to slow processor improvements before manufacturing limits.

The second critical question of power efficiency has received serious attention from the industry only recently. Early "low-power" processors were simply desktop designs operated at lower voltages and frequencies in order to save power. Only recently has the rapidly growing popularity of portable computing products led to the creation of a number of processor designs intended from conception as low power. Power efficiency has become even more important as high-performance desktops and server processors have reached the limits of cost-effective power delivery and cooling. Suddenly, 100-W server processors and 1-W embedded processors have started to be designed for low power.

The industry has used a number of circuit designs and some fabrication techniques to reduce power, but we have barely scratched the surface of

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designing power-efficient architectures or microarchitectures. How should things like design validation, test, and packaging change to support power reduction? How should the design of the transistors themselves be altered? These questions are made more complex by a growing need to focus not just on maximum power, but also on average power across a variety of applications. Performance per watt is rapidly becoming more important than simple performance, and our design methods have only just begun to take this into account.

It is not for this book to say what the answers to these questions will be. Instead, time will tell, but a future edition of this book will likely have some of the answers as well as a whole list of new questions. In the meantime, the methods described in this book are the foundation of these future designs. With an understanding of the overall design flow, the reader is ready to ask questions about today's methods, and asking questions is the first step toward finding answers.

Grant McFarland
February, 2006

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