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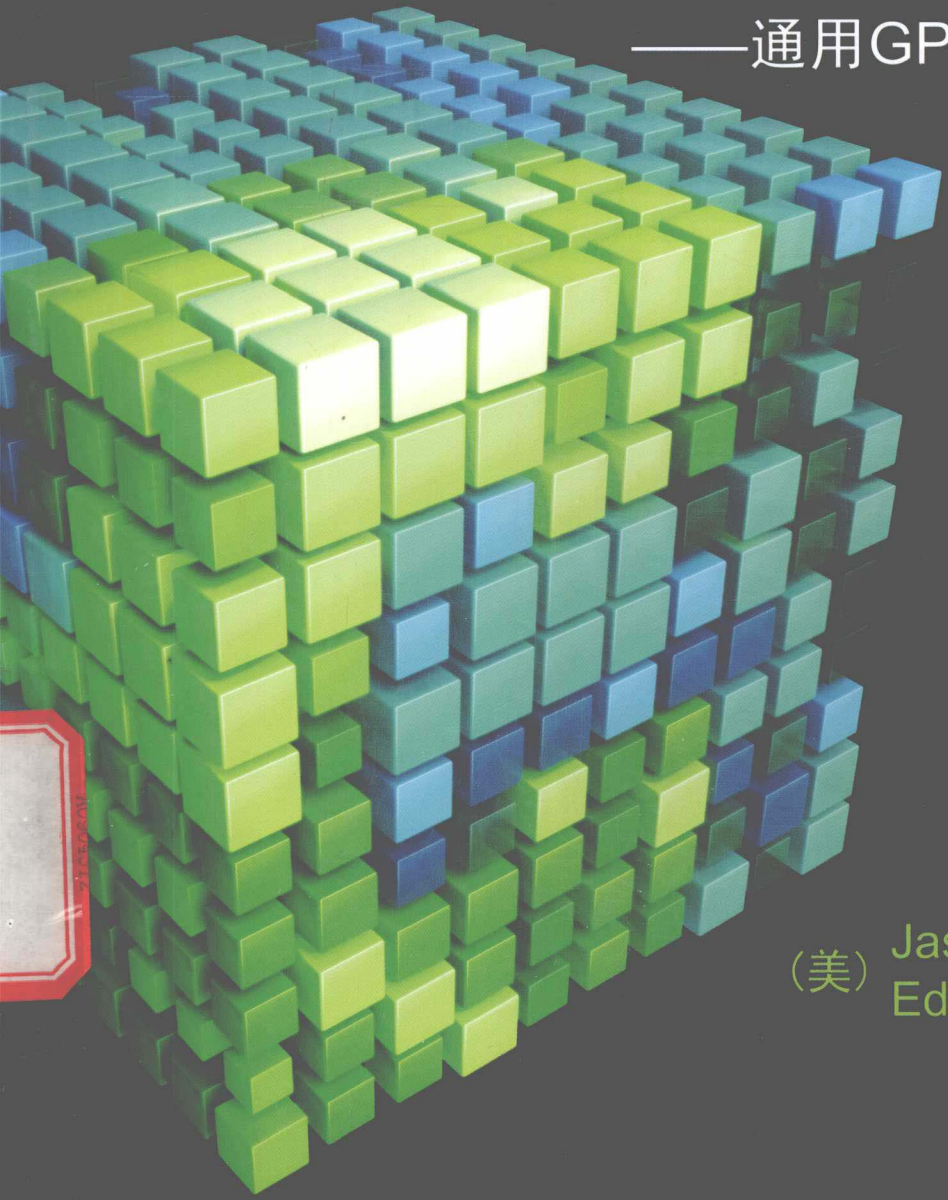
CUDA 范例精解

——通用GPU编程(影印版)

CUDA by Example:
An Introduction to
General-Purpose
GPU Programming



(美) Jason Sanders
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北 京

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Foreword

Recent activities of major chip manufacturers such as NVIDIA make it more evident than ever that future designs of microprocessors and large HPC systems will be hybrid/heterogeneous in nature. These heterogeneous systems will rely on the integration of two major types of components in varying proportions:

- **Multi- and many-core CPU technology**: The number of cores will continue to escalate because of the desire to pack more and more components on a chip while avoiding the power wall, the instruction-level parallelism wall, and the memory wall.
- **Special-purpose hardware and massively parallel accelerators**: For example, GPUs from NVIDIA have outpaced standard CPUs in floating-point performance in recent years. Furthermore, they have arguably become as easy, if not easier, to program than multicore CPUs.

The relative balance between these component types in future designs is not clear and will likely vary over time. There seems to be no doubt that future generations of computer systems, ranging from laptops to supercomputers, will consist of a composition of heterogeneous components. Indeed, the *petaflop* (10^{15} floating-point operations per second) performance barrier was breached by such a system.

And yet the problems and the challenges for developers in the new computational landscape of hybrid processors remain daunting. Critical parts of the software infrastructure are already having a very difficult time keeping up with the pace of change. In some cases, performance cannot scale with the number of cores because an increasingly large portion of time is spent on data movement rather than arithmetic. In other cases, software tuned for performance is delivered years after the hardware arrives and so is obsolete on delivery. And in some cases, as on some recent GPUs, software will not run at all because programming environments have changed too much.

CUDA by Example addresses the heart of the software development challenge by leveraging one of the most innovative and powerful solutions to the problem of programming the massively parallel accelerators in recent years.

This book introduces you to programming in CUDA C by providing examples and insight into the process of constructing and effectively using NVIDIA GPUs. It presents introductory concepts of parallel computing from simple examples to debugging (both logical and performance), as well as covers advanced topics and issues related to using and building many applications. Throughout the book, programming examples reinforce the concepts that have been presented.

The book is required reading for anyone working with accelerator-based computing systems. It explores parallel computing in depth and provides an approach to many problems that may be encountered. It is especially useful for application developers, numerical library writers, and students and teachers of parallel computing.

I have enjoyed and learned from this book, and I feel confident that you will as well.

Jack Dongarra
University Distinguished Professor, University of Tennessee Distinguished Research Staff Member, Oak Ridge National Laboratory

Preface

This book shows how, by harnessing the power of your computer's graphics process unit (GPU), you can write high-performance software for a wide range of applications. Although originally designed to render computer graphics on a monitor (and still used for this purpose), GPUs are increasingly being called upon for equally demanding programs in science, engineering, and finance, among other domains. We refer collectively to GPU programs that address problems in nongraphics domains as *general-purpose*. Happily, although you need to have some experience working in C or C++ to benefit from this book, you need not have any knowledge of computer graphics. None whatsoever! GPU programming simply offers you an opportunity to build—and to build mightily—on your existing programming skills.

To program NVIDIA GPUs to perform general-purpose computing tasks, you will want to know what CUDA is. NVIDIA GPUs are built on what's known as the *CUDA Architecture*. You can think of the CUDA Architecture as the scheme by which NVIDIA has built GPUs that can perform *both* traditional graphics-rendering tasks *and* general-purpose tasks. To program CUDA GPUs, we will be using a language known as *CUDA C*. As you will see very early in this book, CUDA C is essentially C with a handful of extensions to allow programming of massively parallel machines like NVIDIA GPUs.

We've geared *CUDA by Example* toward experienced C or C++ programmers who have enough familiarity with C such that they are comfortable reading and writing code in C. This book builds on your experience with C and intends to serve as an example-driven, "quick-start" guide to using NVIDIA's CUDA C programming language. By no means do you need to have done large-scale software architecture, to have written a C compiler or an operating system kernel, or to know all the ins and outs of the ANSI C standards. However, we do not spend time reviewing C syntax or common C library routines such as `malloc()` or `memcpy()`, so we will assume that you are already reasonably familiar with these topics.

You will encounter some techniques that can be considered general parallel programming paradigms, although this book does not aim to teach general parallel programming techniques. Also, while we will look at nearly every part of the CUDA API, this book does not serve as an extensive API reference nor will it go into gory detail about every tool that you can use to help develop your CUDA C software. Consequently, we highly recommend that this book be used in conjunction with NVIDIA's freely available documentation, in particular the *NVIDIA CUDA Programming Guide* and the *NVIDIA CUDA Best Practices Guide*. But don't stress out about collecting all these documents because we'll walk you through everything you need to do.

Without further ado, the world of programming NVIDIA GPUs with CUDA C awaits!

Acknowledgments

It's been said that it takes a village to write a technical book, and *CUDA by Example* is no exception to this adage. The authors owe debts of gratitude to many people, some of whom we would like to thank here.

Ian Buck, NVIDIA's senior director of GPU computing software, has been immeasurably helpful in every stage of the development of this book, from championing the idea to managing many of the details. We also owe Tim Murray, our always-smiling reviewer, much of the credit for this book possessing even a modicum of technical accuracy and readability. Many thanks also go to our designer, Darwin Tat, who created fantastic cover art and figures on an extremely tight schedule. Finally, we are much obliged to John Park, who helped guide this project through the delicate legal process required of published work.

Without help from Addison-Wesley's staff, this book would still be nothing more than a twinkle in the eyes of the authors. Peter Gordon, Kim Boedigheimer, and Julie Nahil have all shown unbounded patience and professionalism and have genuinely made the publication of this book a painless process. Additionally, Molly Sharp's production work and Kim Wimpsett's copyediting have utterly transformed this text from a pile of documents riddled with errors to the volume you're reading today.

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To our families and friends, who gave us endless support.
To our readers, who will bring us the future.
And to the teachers who taught our readers to read.

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