

Contents

Preface	xiii
Acknowledgements	xix
Dedication	xxi
CHAPTER 1 Introduction	1
1.1 Heterogeneous Parallel Computing	2
1.2 Architecture of a Modern GPU	8
1.3 Why More Speed or Parallelism?.....	10
1.4 Speeding Up Real Applications.....	12
1.5 Parallel Programming Languages and Models.....	14
1.6 Overarching Goals	16
1.7 Organization of the Book	17
References	21
CHAPTER 2 History of GPU Computing	23
2.1 Evolution of Graphics Pipelines	23
The Era of Fixed-Function Graphics Pipelines.....	24
Evolution of Programmable Real-Time Graphics.....	28
Unified Graphics and Computing Processors	31
2.2 GPGPU: An Intermediate Step.....	33
2.3 GPU Computing.....	34
Scalable GPUs.....	35
Recent Developments	36
Future Trends	37
References and Further Reading	37
CHAPTER 3 Introduction to Data Parallelism and CUDA C	41
3.1 Data Parallelism	42
3.2 CUDA Program Structure.....	43
3.3 A Vector Addition Kernel	45
3.4 Device Global Memory and Data Transfer.....	48
3.5 Kernel Functions and Threading	53
3.6 Summary	58
Function Declarations	59
Kernel Launch.....	59
Predefined Variables.....	59
Runtime API	60
3.7 Exercises.....	60
References	62

CHAPTER 4	Data-Parallel Execution Model	63
4.1	Cuda Thread Organization.....	64
4.2	Mapping Threads to Multidimensional Data.....	68
4.3	Matrix-Matrix Multiplication—A More Complex Kernel.....	74
4.4	Synchronization and Transparent Scalability.....	81
4.5	Assigning Resources to Blocks.....	83
4.6	Querying Device Properties.....	85
4.7	Thread Scheduling and Latency Tolerance.....	87
4.8	Summary.....	91
4.9	Exercises.....	91
CHAPTER 5	CUDA Memories	95
5.1	Importance of Memory Access Efficiency.....	96
5.2	CUDA Device Memory Types.....	97
5.3	A Strategy for Reducing Global Memory Traffic.....	105
5.4	A Tiled Matrix–Matrix Multiplication Kernel.....	109
5.5	Memory as a Limiting Factor to Parallelism.....	115
5.6	Summary.....	118
5.7	Exercises.....	119
CHAPTER 6	Performance Considerations	123
6.1	Warps and Thread Execution.....	124
6.2	Global Memory Bandwidth.....	132
6.3	Dynamic Partitioning of Execution Resources.....	141
6.4	Instruction Mix and Thread Granularity.....	143
6.5	Summary.....	145
6.6	Exercises.....	145
	References.....	149
CHAPTER 7	Floating-Point Considerations	151
7.1	Floating-Point Format.....	152
	Normalized Representation of M	152
	Excess Encoding of E	153
7.2	Representable Numbers.....	155
7.3	Special Bit Patterns and Precision in IEEE Format.....	160
7.4	Arithmetic Accuracy and Rounding.....	161
7.5	Algorithm Considerations.....	162
7.6	Numerical Stability.....	164
7.7	Summary.....	169
7.8	Exercises.....	170
	References.....	171

CHAPTER 8 Parallel Patterns: Convolution	173
8.1 Background	174
8.2 1D Parallel Convolution—A Basic Algorithm	179
8.3 Constant Memory and Caching	181
8.4 Tiled 1D Convolution with Halo Elements.....	185
8.5 A Simpler Tiled 1D Convolution—General Caching.....	192
8.6 Summary	193
8.7 Exercises.....	194
CHAPTER 9 Parallel Patterns: Prefix Sum	197
9.1 Background	198
9.2 A Simple Parallel Scan	200
9.3 Work Efficiency Considerations.....	204
9.4 A Work-Efficient Parallel Scan.....	205
9.5 Parallel Scan for Arbitrary-Length Inputs.....	210
9.6 Summary	214
9.7 Exercises.....	215
Reference	216
CHAPTER 10 Parallel Patterns: Sparse Matrix–Vector Multiplication	217
10.1 Background	218
10.2 Parallel SpMV Using CSR	222
10.3 Padding and Transposition.....	224
10.4 Using Hybrid to Control Padding.....	226
10.5 Sorting and Partitioning for Regularization	230
10.6 Summary	232
10.7 Exercises.....	233
References.....	234
CHAPTER 11 Application Case Study: Advanced MRI Reconstruction	235
11.1 Application Background	236
11.2 Iterative Reconstruction	239
11.3 Computing F^{HD}	241
Step 1: Determine the Kernel Parallelism Structure.....	243
Step 2: Getting Around the Memory Bandwidth Limitation	249
Step 3: Using Hardware Trigonometry Functions	255
Step 4: Experimental Performance Tuning	259
11.4 Final Evaluation	260
11.5 Exercises.....	262
References.....	264

CHAPTER 12	Application Case Study: Molecular Visualization and Analysis	265
12.1	Application Background	266
12.2	A Simple Kernel Implementation	268
12.3	Thread Granularity Adjustment	272
12.4	Memory Coalescing	274
12.5	Summary	277
12.6	Exercises	279
	References	279
CHAPTER 13	Parallel Programming and Computational Thinking	281
13.1	Goals of Parallel Computing	282
13.2	Problem Decomposition	283
13.3	Algorithm Selection	287
13.4	Computational Thinking	293
13.5	Summary	294
13.6	Exercises	294
	References	295
CHAPTER 14	An Introduction to OpenCL™	297
14.1	Background	297
14.2	Data Parallelism Model	299
14.3	Device Architecture	301
14.4	Kernel Functions	303
14.5	Device Management and Kernel Launch	304
14.6	Electrostatic Potential Map in OpenCL	307
14.7	Summary	311
14.8	Exercises	312
	References	313
CHAPTER 15	Parallel Programming with OpenACC	315
15.1	OpenACC Versus CUDA C	315
15.2	Execution Model	318
15.3	Memory Model	319
15.4	Basic OpenACC Programs	320
	Parallel Construct	320
	Loop Construct	322
	Kernels Construct	327
	Data Management	331
	Asynchronous Computation and Data Transfer	335
15.5	Future Directions of OpenACC	336
15.6	Exercises	337

CHAPTER 16 Thrust: A Productivity-Oriented Library for CUDA	339
16.1 Background	339
16.2 Motivation	342
16.3 Basic Thrust Features.....	343
Iterators and Memory Space	344
Interoperability	345
16.4 Generic Programming	347
16.5 Benefits of Abstraction	349
16.6 Programmer Productivity	349
Robustness.....	350
Real-World Performance	350
16.7 Best Practices	352
Fusion.....	353
Structure of Arrays.....	354
Implicit Ranges	356
16.8 Exercises.....	357
References.....	358
CHAPTER 17 CUDA FORTRAN	359
17.1 CUDA FORTRAN and CUDA C Differences.....	360
17.2 A First CUDA FORTRAN Program	361
17.3 Multidimensional Array in CUDA FORTRAN	363
17.4 Overloading Host/Device Routines With Generic Interfaces	364
17.5 Calling CUDA C Via <code>Iso_C_Binding</code>	367
17.6 Kernel Loop Directives and Reduction Operations	369
17.7 Dynamic Shared Memory	370
17.8 Asynchronous Data Transfers.....	371
17.9 Compilation and Profiling	377
17.10 Calling Thrust from CUDA FORTRAN.....	378
17.11 Exercises	382
CHAPTER 18 An Introduction to C++ AMP	383
18.1 Core C++ Amp Features.....	384
18.2 Details of the C++ AMP Execution Model	391
Explicit and Implicit Data Copies	391
Asynchronous Operation.....	393
Section Summary	395
18.3 Managing Accelerators	395
18.4 Tiled Execution.....	398
18.5 C++ AMP Graphics Features	401
18.6 Summary	405
18.7 Exercises.....	405

CHAPTER 19	Programming a Heterogeneous Computing Cluster	407
19.1	Background	408
19.2	A Running Example	408
19.3	MPI Basics	410
19.4	MPI Point-to-Point Communication Types	414
19.5	Overlapping Computation and Communication	421
19.6	MPI Collective Communication	431
19.7	Summary	431
19.8	Exercises	432
	Reference	433
CHAPTER 20	CUDA Dynamic Parallelism	435
20.1	Background	436
20.2	Dynamic Parallelism Overview	438
20.3	Important Details	439
	Launch Environment Configuration	439
	API Errors and Launch Failures	439
	Events	439
	Streams	440
	Synchronization Scope	441
20.4	Memory Visibility	442
	Global Memory	442
	Zero-Copy Memory	442
	Constant Memory	442
	Texture Memory	443
20.5	A Simple Example	444
20.6	Runtime Limitations	446
	Memory Footprint	446
	Nesting Depth	448
	Memory Allocation and Lifetime	448
	ECC Errors	449
	Streams	449
	Events	449
	Launch Pool	449
20.7	A More Complex Example	449
	Linear Bezier Curves	450
	Quadratic Bezier Curves	450
	Bezier Curve Calculation (Predynamic Parallelism)	450
	Bezier Curve Calculation (with Dynamic Parallelism)	453
20.8	Summary	456
	Reference	457

CHAPTER 21 Conclusion and Future Outlook	459
21.1 Goals Revisited	459
21.2 Memory Model Evolution	461
21.3 Kernel Execution Control Evolution	464
21.4 Core Performance	467
21.5 Programming Environment.....	467
21.6 Future Outlook	468
References.....	469
 Appendix A: Matrix Multiplication Host-Only Version Source Code	471
Appendix B: GPU Compute Capabilities	481
 Index.....	487