Contents

Prepublication Reviews i

List of Figures xi

List of Tables xv

List of Definitions xvii

Preface xix

Acknowledgments xxi

Contributing Authors xxiii

Trademarks xxix

1
Introduction and Motivation 1
Kurt Keutzer

1. What is a Design Discontinuity? 3
   - 1.1 A History of Design Discontinuities in EDA 3
   - 1.2 General Characteristics of Design Discontinuities 6
2. The Current Environment for Design 7
   - 2.1 The Push to a New Methodology from Semiconductors 7
   - 2.2 The Application Pull for Programmable Platforms 12
3. What is the Next Design Discontinuity? 12
   - 3.1 System Level Design 12
   - 3.2 Design through Intellectual Property (IP) Block Assembly 13
4. Programmable Platforms: The Next Design Discontinuity 15
5. Contemporary Evidence 15
6. Makimoto's Wave 17
7. Could We Be Wrong? 18
   - 7.1 Could ASIPs be the Wrong Choice? 18
   - 7.2 When Will We Ever Know for Sure? 21
8. Gaps in Existing Methodologies 21
9. A Methodology for ASIP Design 23
   - 9.1 Element 1: Judiciously Using Benchmarking 23
   - 9.2 Element 2: Inclusively Identify the Architectural Space 24
   - 9.3 Element 3: Efficiently Describe and Evaluate the ASIPs 24
   - 9.4 Element 4: Comprehensively Explore the Design Space 25

9.5 Element 5: Successfully Deploy the ASIP 25
10. What is Missing in This Book 25
10.1 A Comprehensive Survey of Related Work 25
10.2 The Impact of Silicon Issues on ASIP Architecture Selection 26
10.3 Teams – The Human Element 26
10.4 From ASIPs to Programmable Platforms 27
11. Summary 27
12. Overview of the Remainder of the Book 27

Part I The MESCAL Methodology for Building ASIPs

2
Judiciously Using Benchmarking 33
Mel Tsai, Niraj Shah, Chidamber Kulkarni, Christian Sauer, Matthias Gries, Kurt Keutzer
1. Introduction 34
2. A Benchmarking Methodology 36
2.1 Comparable 36
2.2 Representative 36
2.3 Indicative 36
2.4 Precise Specification Method 37
3. A Benchmarking Methodology for NPUs 38
3.1 Functional Specification 38
3.2 Environment Specification 38
3.3 Measurement Specification 44
4. An Example Benchmark Specification 44
4.1 Functional Specification 45
4.2 Environment Specification 46
4.3 Performance Measurement 47
5. The NPU Benchmark Suite 47
5.1 Granularity 47
5.2 Choosing the Benchmarks 48
5.3 Benchmarking Results for Intel IXP 50
6. Related Work on Benchmarking 52
7. Conclusion 56

3
Inclusively Identifying the Architectural Space 57
Niraj Shah, Christian Sauer, Matthias Gries, Yujia Jin, Matthew Moskewicz, Kurt Keutzer
1. The ASIP Landscape 58
1.1 ISA Based ASIPs 58
1.2 Programmable Hardware Based ASIPs 62
2. A Closer Look into Sub-Spaces 63
2.1 Memory Design Space 63
2.2 Peripheral Design Space 68
3. Network Processing Design Space 73
3.1 Parallel Processing 74
3.2 Special Purpose Hardware 76

3.3 Memory Architectures 78
3.4 On-chip Communication Mechanisms 78
3.5 Peripherals 79
4. Conclusion 82

4
Efficiently Describing and Evaluating the ASIPs 85
Scott Weber, Yujia Jin, Matthias Gries, Christian Sauer, Matthew Moskewicz
1. Best Practice in ASIP Design 86
1.1 Architecture Description Languages (ADLs) 86
1.2 Hardware Description Languages (HDLs) 87
2. Recipe for Developing ASIPs 87
2.1 Design Principles 87
2.2 Tipi's Implementation of the Design Principles 88
3. The Tipi Design Flow 89
3.1 Multi-view Operation-Level Design 90
3.2 Generating Bit-True Cycle-Accurate Simulators 99
4. Tipi Case Study 109
4.1 Design Entry 109
4.2 Simulator Generation 112
4.3 Discussion 113
5. Designing Memory Systems with Tipi 114
5.1 Memory Design Space Element Library 115
5.2 Simulator Generation Flow 116
5.3 Memory Domain 117
5.4 Multi-PE Domain 119
5.5 Memory Domain Translation 120
5.6 Related Memory Design Frameworks 126
6. Designing Interconnects in Tipi 127
7. Designing Co-processors and Peripherals in Tipi 128
8. Conclusion 129

5
Comprehensively Exploring the Design Space 131
Matthias Gries and Yujia Jin
1. Introduction 132
1.1 Separation of Concerns for Automated DSE 132
1.2 Evaluating Designs 133
1.3 Complexity of the Exploration Process 134
2. Optimization Strategy 135
3. Objective/Cost Functions and Metrics 138
3.1 Primary Objectives 139
3.2 Secondary Objectives 139
3.3 Combined Metrics 141
4. Methods for Evaluating a Single Design Point 142
4.1 Simulation-Based Evaluation 143
4.2 Combining Simulation and Analytical Methods 145
4.3 Purely Analytical Approaches 146
5. Methods for Exploring the Design Space 148

5.1 Strategies for Covering the Design Space 148
5.2 Pruning the Design Space 152
6. Support for DSE in Tipi 155
6.1 Micro-Architecture Design 155
6.2 Memory Subspace 156
7. Conclusion 176

6
Successfully Deploying the ASIP 179
Niraj Shah, William Plishker, Kaushik Ravindran, Matthias Gries, Scott Weber, Andrew Mihal, Chidamber Kulkarni, Matthew Moskewicz, Christian Sauer, Kurt Keutzer
1. Deployment Requirements on Design Tool Flow 180
1.1 Support for Successfully Deploying Architectures in Tipi 181
1.2 Improving the Programmer's View 185
2. Deployment Case Study: Network Processing 191
2.1 NP-Click: A Programming Model for the IXP1200 192
2.2 Automated Task Allocation 215
3. Conclusion 224

Part II MESCAL Methodology Applied by Commercial Tools

7
Designing and Modeling MPSoC Processors and Communication Architectures 229
Heinrich Meyr, Oliver Schliebusch, Andreas Wieferink, David Kammler, Ernst Martin Witte, Olaf Lüthje, Manuel Hohenauer, Gunnar Braun, Anupam Chattopadhyay
1. Benchmarking the Application Requirements 230
2. The Architectural Design Space 235
3. ASIP Design Based on ADLs 236
3.1 Traditional ASIP Design Methodology 236
3.2 The ADL Approach 237
4. The LISA Processor Design Platform 238
4.1 The LISA Language 240
4.2 Architecture Exploration 241
4.3 Automatic Architecture Implementation 243
4.4 Application Development Software Tools 245
4.5 System Integration 250
5. ASIP Verification 251
5.1 Automatic Generation of Test Vectors from LISA 254
5.2 Genesys 255
6. ASIP Design Case Studies 257
6.1 ICORE: Deriving Optimized Instructions 257
6.2 ASMD & LISA 68HC11: Improving Existing Architectures 263
6.3 ST200: Modeling a High-end VLIW Architecture 267
7. Modeling Interconnects of an MPSoC 271
7.1 Need for Early System Simulation 271
7.2 Abstraction Levels: From Timed to Cycle Accurate 272
7.3 Co-Simulation and System Simulation 273
7.4 The SystemC Library 274
8. The NoC Exploration Platform GRACE++ 274

8.1 Overview 275
8.2 NoC Exploration Methodology 276
8.3 Unified Modeling of On-Chip Communication 277
8.4 Network Engine Algorithms 279
9. Summary 279

8
Commercial Configurable Processors and the MESCAL Approach 281
Grant Martin and Steve Leibson
1. The Tensilica Approach to ASIPs 282
2. Element 1: Judiciously Using Benchmarking 285
2.1 Standard Industry Benchmarks 285
2.2 Application-Specific Benchmarking 294
3. Element 2: Inclusively Identifying the Architectural Space 295
4. Element 3: Efficiently Describing and Evaluating the ASIPs 296
5. Element 4: Comprehensively Exploring the Design Space 297
5.1 XPRES^{TM} Techniques for Performance Optimization 300
6. Element 5: Successfully Deploying the ASIP 301
6.1 Towards MPSoC Deployment 302
6.2 Flow-Through Processing 308
7. Conclusion: Further MPSoC Progress 310

Acronyms 313

References 319

Index 343