

# Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	Embedded Systems	3
1.1.1	Hardware Platform	4
1.1.2	Embedded Software Applications	7
1.1.3	System Software	10
1.2	Problem Definition	11
1.2.1	Shortcomings of Static Solutions	14
1.3	Metrics and Cost Factors	15
1.3.1	Memory Fragmentation	16
1.3.2	Memory Footprint	17
1.3.3	Memory Access Count	18
1.3.4	Application Task-Level Performance	18
1.3.5	Overall Energy Consumption	19
1.4	Overview of the Proposed Approach	20
1.5	General Design Flow for Embedded Systems Conception	23
1.6	Chapters Overview	24
<b>2</b>	<b>Analysis and Characterization of Dynamic Multimedia Applications</b>	<b>27</b>
2.1	Characteristics of Multimedia Applications	27
2.1.1	Example: 3D Image Reconstruction System	28
2.1.2	Potential for Optimizations	32
2.2	Dynamic Data Handling	34
2.2.1	Dynamic Data Structure Optimization Opportunities	35
2.2.2	Dynamic Memory Manager	39
2.3	Proposed Optimization Method	41
2.3.1	Method Overview	42
2.3.2	Profiling and Metadata Collection	45
2.3.3	Intermediate Variable Removal	45

2.3.4	Dynamic Data Type Refinement . . . . .	46
2.3.5	Dynamic Memory Manager Optimizations . . . . .	48
2.3.6	Task-level Data Transfer and Storage Exploration . . . . .	49
2.4	Conclusions . . . . .	49
<b>3</b>	<b>Profiling and Analysis of Dynamic Applications . . . . .</b>	<b>51</b>
3.1	Software Metadata Structure . . . . .	52
3.1.1	Definition and Categorization of Metadata . . . . .	53
3.2	Metadata Mining . . . . .	57
3.2.1	Raw Data Extraction Through Profiling . . . . .	58
3.2.2	Analysis Techniques for Metadata Inference . . . . .	63
3.3	Case Study: Integrated Example on DDR Scheduling . . . . .	66
3.3.1	Goal and Procedure . . . . .	68
3.3.2	Description of the Case Study Application . . . . .	69
3.3.3	Profiling and Analysis . . . . .	70
3.3.4	Dynamic Data Type Refinement—DDTR . . . . .	71
3.3.5	Dynamic Memory Management Refinement—DMMR . . . . .	74
3.3.6	Dynamic Memory Block Transfer Optimization . . . . .	86
3.4	Comparison to Related Work . . . . .	91
3.5	Conclusions . . . . .	91
<b>4</b>	<b>Dynamic Data Types Optimization in Multimedia and Communication Applications . . . . .</b>	<b>93</b>
4.1	Related Work . . . . .	97
4.2	Analysis and Characterization of Multimedia and Wireless Network Applications . . . . .	98
4.2.1	Application Specific Access Behavior . . . . .	99
4.2.2	Representative Sizes and Types of Basic Allocated Elements . . . . .	99
4.3	Example: 3D Image Reconstruction System . . . . .	100
4.4	Transformations of Dynamic Data Types . . . . .	104
4.4.1	Adding a Linked Structure . . . . .	105
4.4.2	Implicit Versus Explicit Keys . . . . .	106
4.4.3	Exploiting Indirection . . . . .	107
4.4.4	Marking . . . . .	107
4.4.5	Key Splitting . . . . .	108
4.4.6	Partitioning . . . . .	108
4.5	Example: DDT Transformations in Tetris Game . . . . .	109
4.5.1	Tetris Game . . . . .	109
4.5.2	The Pixels Buffer . . . . .	110
4.5.3	The Initial Pixels Buffer: A Sparse Array . . . . .	110
4.5.4	Implem2: Explicit Keys . . . . .	110
4.5.5	Implem3: Explicit Keys and Indirection . . . . .	112
4.5.6	Comparing the Different Implementations . . . . .	113
4.5.7	Implem4: Key Splitting . . . . .	115

4.6	Exploration and Optimization Methodology of DDTs Implementations . . . . .	116
4.6.1	Profiling Library of Dynamic Data Allocation. . . . .	118
4.6.2	Library of DDTs Implementations for Multimedia and Communication Applications . . . . .	119
4.6.3	Multi-objective Exploration of DDT Implementations . . .	125
4.7	Application of the Exploration and Optimization Methodology to Multimedia and Communication Applications . . . . .	129
4.7.1	Exploration and Refinement of DDT Implementations in a 3D Image Reconstruction Application . . . . .	129
4.7.2	Exploration and Refinement of DDT Implementations in a Network Scheduling Application. . . . .	131
4.8	Conclusions . . . . .	133
<b>5</b>	<b>Intermediate Variable Removal from Dynamic Applications. . . . .</b>	<b>135</b>
5.1	Related Work . . . . .	137
5.2	Problem Formalization . . . . .	139
5.2.1	Sequences . . . . .	139
5.2.2	Intermediate Sequence Removal . . . . .	141
5.2.3	Abstraction Level . . . . .	143
5.3	Method. . . . .	144
5.3.1	Rewrite Rules . . . . .	146
5.3.2	Delimited Continuations. . . . .	151
5.3.3	Demonstration. . . . .	159
5.3.4	Data-Flow Constraints . . . . .	163
5.4	Experimental Results . . . . .	163
5.5	Conclusions . . . . .	166
<b>6</b>	<b>Dynamic Memory Management Optimization for Multimedia Applications . . . . .</b>	<b>167</b>
6.1	Related Work . . . . .	168
6.2	Relevant Design Space for Dynamic Memory Management in Dynamic Multimedia and Wireless Network Applications . . .	170
6.2.1	Dynamic Memory Management Design Space for Reduced Memory Footprint. . . . .	170
6.2.2	Interdependencies Between the Orthogonal Trees . . . . .	173
6.2.3	Construction of Global Dynamic Memory Managers . . .	175
6.3	Order for Reduced Dynamic Memory Footprint in Dynamic Multimedia and Wireless Network Applications. . . . .	176
6.3.1	Factors of Influence for Dynamic Memory Footprint Exploration. . . . .	176
6.3.2	Analysis of de/allocation Characteristics of Dynamic Embedded Multimedia and Wireless Network Applications . . . . .	177

6.3.3	Order of the Trees for Reduced Memory Footprint in Dynamic Multimedia and Wireless Network Applications . . . . .	178
6.4	Overview of the Global Flow in the Dynamic Memory Management Methodology . . . . .	181
6.5	Case Studies and Experimental Results . . . . .	183
6.5.1	Method Applied to a Network Scheduling Application . . . . .	183
6.5.2	Methodology Applied to a 3D Image Reconstruction System . . . . .	187
6.5.3	Methodology Applied to a 3D Video Rendering System . . . . .	189
6.6	Conclusions . . . . .	192
<b>7</b>	<b>Systematic Placement of Dynamic Objects Across Heterogeneous Memory Hierarchies . . . . .</b>	<b>193</b>
7.1	Methodology for Placement of Dynamic Data . . . . .	195
7.1.1	Instrumentation and Profiling . . . . .	198
7.1.2	Analysis . . . . .	198
7.1.3	Group Creation . . . . .	199
7.1.4	Definition of Pool Algorithms . . . . .	200
7.1.5	Mapping into Memory Resources . . . . .	200
7.1.6	Simulation and Evaluation . . . . .	202
7.1.7	Final Deployment . . . . .	204
7.1.8	Suitability and Current Limitations . . . . .	204
7.2	Detailed Approach for Group Creation . . . . .	205
7.2.1	Goals . . . . .	205
7.2.2	Liveness and Exploitation Ratio . . . . .	206
7.2.3	The Algorithm . . . . .	208
7.2.4	Algorithm Parameters . . . . .	209
7.3	Experimental Results . . . . .	210
7.3.1	Description of Memory Organizations . . . . .	211
7.3.2	Case Study 1: Wireless Sensors Network . . . . .	213
7.3.3	Case Study 2: Network Routing . . . . .	218
7.3.4	Case Study 3: Synthetic Benchmark . . . . .	223
7.4	Comparison to Related Work . . . . .	225
7.4.1	Static Data . . . . .	225
7.4.2	Software-Controlled Memories . . . . .	226
7.4.3	Dynamic Memory Management . . . . .	226
7.4.4	Placement . . . . .	227
7.5	Conclusions . . . . .	229

Contents	xiii
<b>Appendix A: Description of Profiling Format . . . . .</b>	<b>231</b>
<b>References. . . . .</b>	<b>235</b>

Dynamic Memory Management for Embedded Systems

Atienza Alonso, D.; Mamagkakis, S.; Poucet, C.;

Peón-Quirós, M.; Bartzas, A.; Catthoor, F.; Soudris, D.

2015, XIII, 243 p. 86 illus., 53 illus. in color., Hardcover

ISBN: 978-3-319-10571-0