Contents

PREFACE xi

LIST OF FIGURES xv

LIST OF TABLES xxi

CHAPTER 1. INTRODUCTION TO REAL-TIME SCHEDULING 1
Emmanuel GROLLEAU

1.1. Real-time systems 1
1.2. Material architectures 5
1.2.1. CPUs 5
1.2.2. Communication networks 7
1.2.3. Sensors and actuators 9
1.3. Operating systems 9
1.3.1. Generalities. 10
1.3.2. Real-time operating systems 10
1.3.3. Primitives provided by the kernel 12
1.4. Scheduling 14
1.4.1. Online and offline scheduling 14
1.4.2. Task characterization 16

1.4.3. Criticality 19
1.4.4. Metrics related to scheduling 20
1.4.5. Practical factors 22
1.4.6. Multi-core scheduling 27
1.5. Real-time application modeling and analysis 30
1.5.1. Modeling 30
1.5.2. Analysis 31
1.6. System architecture and schedulability 34

CHAPTER 2. UNIPROCESSOR ARCHITECTURE SOLUTIONS 39
Laurent GEORGE and Jean-François HERMANT

2.1. Introduction 40
2.2. Characterization of a scheduling problem 42
2.2.1. Task model 42
2.2.2. Temporal constraint models 45
2.2.3. Scheduling model 46
2.2.4. Concepts and notations 50
2.3. Scheduling algorithms/optimality 52
2.3.1. FP fixed-job priority algorithms 52
2.3.2. JFP algorithms 55
2.3.3. Dynamic priority algorithms 57
2.4. Busy periods and worst-case scenarios 58
2.4.1. Busy periods 58
2.4.2. Worst-case scenarios 60
2.5. Feasibility conditions 66
2.5.1. FP feasibility conditions 66
2.5.2. JFP feasibility conditions 70
2.6. Sensitivity analysis 75
2.6.1. Sensitivity of WCETs 78
2.6.2. Sensitivity of periods 88

2.6.3. Sensitivity of deadlines 90
2.7. Conclusion 95
2.8. Bibliography. 97

CHAPTER 3. MULTIPROCESSOR ARCHITECTURE SOLUTIONS 105
Joël GOOSSENS and Pascal RICHARD

3.1. Introduction 105
3.1.1. Application modeling 106
3.1.2. Platform modeling 108
3.2. Scheduler classification 108
3.2.1. Online and offline schedulers 108
3.2.2. Task preemption and migration 109
3.2.3. Priorities of tasks 111
3.2.4. Classification. 111
3.3. Properties of schedulers 111
3.3.1. Qualitative properties 112
3.3.2. Quantitative properties 117
3.4. Partitioned scheduling 121
3.4.1. Partitioning algorithms 121
3.4.2. Evaluation of partitioning algorithms 126
3.5. Global scheduling 131
3.5.1. Proportionate fair algorithms 132
3.5.2. Generalization of uniprocessor scheduling algorithms 142
3.6. Conclusion 143
3.7. Bibliography. 143

CHAPTER 4. SYNCHRONIZATIONS: SHARED RESOURCE ACCESS PROTOCOLS. 149
Serge MIDONNET and Frédéric FAUBERTEAU

4.1. Introduction 150
4.2. Terminology and notations 150

4.2.1. Diagrams 152
4.2.2. Synchronization protocols 153
4.3. Synchronization problems 160
4.3.1. Unbounded priority inversion 160
4.3.2. Deadlock 166
4.3.3. Chained blocking 172
4.4. Calculating the blocking factor 177
4.4.1. The case of uniprocessor architectures 177
4.4.2. The case of multiprocessor architectures . . . 180
4.5. Conclusion 187
4.6. Bibliography. 188

CHAPTER 5. ESTIMATION OF EXECUTION TIME AND DELAYS. 193
Claire MAIZA, Pascal RAYMOND and Christine ROCHANGE

5.1. Worst-case execution time analysis: an example. 195
5.1.1. Embedded system architecture analysis . . . 197
5.1.2. Execution path analysis 206
5.2. Going further 211
5.2.1. Multi-task: the cost of preemption 211
5.2.2. Multi-core and other complex architectures 215
5.2.3. Influence of critical embedded systems design methods 218
5.2.4. Tools. 224
5.3. Conclusion 225
5.4. Bibliography. 225

CHAPTER 6. OPTIMIZATION OF ENERGY CONSUMPTION 231
Cécile BELLEUDY

6.1. Introduction 232
6.2. State of the art 235

6.2.1. General comments 235
6.2.2. Modeling the consumption of an operating system 237
6.2.3. Consumption management strategies within multicore systems 238
6.3. Modeling consumption. 242
6.3.1. Characterization platform: hardware and software 242
6.3.2. Power consumption modeling 243
6.3.3. Context switch. 244
6.3.4. Inter-process communication. 247
6.4. Low consumption scheduling 249
6.4.1. Simulation environment 250
6.4.2. Low power consumption scheduling policy. 251
6.5. Experimental results. 255
6.5.1. Application test: H.264 decoder 255
6.5.2. Analysis of the simulation results 258
6.6. Conclusion 262
6.7. Bibliography. 262

LIST OF AUTHORS. 269

INDEX 271

SUMMARY OF VOLUME 2 275