005.2
D15
1996

Distributed Real-Time Systems

Monitoring, Visualization, Debugging, and Analysis

JEFFREY J. P. TSAI

YAODONG BI

STEVE J. H. YANG

ROSS A. W. SMITH

GIFT OF
THE ASIA FOUNDATION
NOT FOR RE-SALE

ĐẠI HỌC QUỐC GIA HÀ NỘI
TRUNG TÂM THÔNG TIN THƯ VIỆN
A-DO/3930

A Wiley-Interscience Publication
JOHN WILEY & SONS, INC.
New York • Chichester • Brisbane • Toronto • Singapore

Contents

List of Tables xi
List of Figures xiii
Preface xv

I BASIC CONCEPTS 1

1 Distributed Real-Time Systems 3
1.1 Real-Time Systems 4
1.2 Periodic Processes and Aperiodic Processes 5
1.3 Distributed Systems 6
1.4 Architectural Issues 6
1.4.1 Distributed Processing Algorithms 9
1.5 Communication and Synchronization Primitives 10
1.6 Processor Interconnection 11
1.7 Network Topologies 11
1.7.1 Buses 12
1.7.2 Stars 13
1.7.3 Rings 14
1.7.4 Meshes 15
1.7.5 Trees 15
1.8 Switching Techniques 15
1.9 Distributed Real-Time Systems 17
1.10 Characteristics of DRTSs 18
1.11 Review of Architectures of DRTSs 19
1.12 A Model of Real-Time Distributed Systems 22
1.13 Summary 27

2 Monitoring Systems 29
2.1 Monitoring Real-Time Systems 29
2.2 Monitoring at Different Levels of Detail 32
2.2.1 Process-Level Monitoring 32
2.2.2 Function-Level Monitoring 34
2.3 Spectrum of Monitoring Approaches 35
2.3.1 Software Monitoring 35

2.3.2 Hardware Monitoring 37
2.3.3 Hybrid Monitoring 40
2.4 Monitoring DRTSs 43
2.5 Summary 44

3 Software Monitoring Systems **49**
3.1 Introduction to Software Monitoring 49
3.2 Monitoring at the Program Level 52
3.2.1 Chodrow, Jahanian, and Donner's Monitor 53
3.2.2 Raju, Rajkumar, and Jahanian's Monitor 55
3.2.3 Joyce, Lomow, Slind, and Ungar's Monitor 56
3.2.4 Dodd and Ravishankar's HMON for HARTS 59
3.3 Monitoring at the System Level 62
3.3.1 Miller, Macrander, and Sechrest's Monitor 63
3.3.2 Tokuda, Kotera, and Mercer's Monitor 66
3.4 Perturbation Analysis 67
3.5 Summary 68

4 Hardware Monitoring **75**
4.1 Introduction to Hardware Monitoring 75
4.2 Monitoring Single-Processor Architectures 76
4.2.1 Architectures for Hardware Monitoring 76
4.2.2 Monitoring at Different Levels of Abstraction 82
4.3 Monitoring Multiprocessor Architectures 85
4.3.1 Architectures for Hardware Monitoring 85
4.3.2 Monitoring at Different Levels of Abstraction 92
4.4 Monitoring Distributed Systems 96
4.5 Summary 99

5 Hybrid Monitoring **103**
5.1 Introduction to Hybrid Monitoring 103
5.2 Monitoring Uniprocessor Architectures 105
5.3 Monitoring Multiprocessor Architectures 107
5.3.1 Memory-Mapped Monitoring 107
5.3.2 Coprocessor Monitoring 116
5.4 Monitoring Distributed Systems 122
5.4.1 Distributed Monitoring System Architectures 122
5.4.2 Global Time and Clock Synchronization 124
5.5 Summary 125

6 Debugging Distributed Real-Time Systems **127**
6.1 Static Analysis and Debugging Techniques 128
6.2 Dynamic Analysis and Debugging Techniques 131
6.3 Debugging Approaches with Monitoring Support 134
6.3.1 Deterministic Replay 136

6.3.2 Real-Time Debugging 137
6.3.3 Related Work 138
6.4 Problems Facing Monitoring Supported Debuggers 139
6.5 Summary 140

7 Specification Techniques 143
7.1 Real-Time Processes 143
7.2 Specification of Real-Time Processes 145
7.3 Timed Petri Nets 146
7.3.1 Petri Nets Enabling and Firing Modes 147
7.3.2 Time-Related Extensions 148
7.4 Temporal Logic 150
7.5 Timed State Transition Systems 153
7.6 Timed Process Algebra 155
7.7 Synchronous Programming Languages 157
7.8 Summary 158

II THEORY AND PRACTICE 161

8 A Noninterference Monitoring Approach 163
8.1 A Noninterference Hardware Approach 164
8.2 Overview of the Monitoring System 164
8.3 The Interface Module 167
8.4 The Development Module 169
8.5 Process-Level Monitoring 170
8.6 Function-Level Monitoring 175
8.7 Process-Level Data Processing 178
8.7.1 Postprocessing at the Process Level 178
8.7.2 Logical Views at the Process Level 181
8.8 Function-Level Data Processing 186
8.9 Summary 189

9 A Graph-Based Timing Analysis 191
9.1 Causes of Timing Errors 191
9.1.1 Three Basic Causes of Timing Errors 192
9.1.2 Four Immediate Causes of Timing Errors 192
9.2 Representations of Timing Behavior 194
9.3 Timing Analysis of Synchronization Causes 199
9.3.1 Analysis Procedure for Synchronization Causes 201
9.3.2 Distributed Termination 203
9.3.3 Deadlocks 205
9.3.4 Missed Operations and Starvation 207
9.3.5 Lost Messages and Communication Deadlocks 209
9.4 Computation and Scheduling Causes 209