CONTENTS

Online Chapters and Appendices 13

VideoNotes 15

Preface 17

About the Author 27

PART 1 BACKGROUND 29

Chapter 1 Computer System Overview 29

1.1 Basic Elements 30
1.2 Evolution of the Microprocessor 32
1.3 Instruction Execution 32
1.4 Interrupts 35
1.5 The Memory Hierarchy 46
1.6 Cache Memory 49
1.7 Direct Memory Access 53
1.8 Multiprocessor and Multicore Organization 54
1.9 Key Terms, Review Questions, and Problems 58
1A Performance Characteristics of Two-Level Memories 61

Chapter 2 Operating System Overview 68

2.1 Operating System Objectives and Functions 69
2.2 The Evolution of Operating Systems 73
2.3 Major Achievements 83
2.4 Developments Leading to Modern Operating Systems 92
2.5 Fault Tolerance 95
2.6 OS Design Considerations for Multiprocessor and Multicore 98
2.7 Microsoft Windows Overview 101
2.8 Traditional UNIX Systems 108
2.9 Modern UNIX Systems 110
2.10 Linux 113
2.11 Android 118
2.12 Key Terms, Review Questions, and Problems 127

PART 2 PROCESSES 129

Chapter 3 Process Description and Control 129

3.1 What is a Process? 131
3.2 Process States 133
3.3 Process Description 148

3.4 Process Control 157
3.5 Execution of the Operating System 163
3.6 UNIX SVR4 Process Management 166
3.7 Summary 171
3.8 Key Terms, Review Questions, and Problems 171

Chapter 4 Threads 176

4.1 Processes and Threads 177
4.2 Types of Threads 183
4.3 Multicore and Multithreading 190
4.4 Windows Process and Thread Management 195
4.5 Solaris Thread and SMP Management 202
4.6 Linux Process and Thread Management 206
4.7 Android Process and Thread Management 211
4.8 Mac OS X Grand Central Dispatch 215
4.9 Summary 217
4.10 Key Terms, Review Questions, and Problems 218

Chapter 5 Concurrency: Mutual Exclusion and Synchronization 223

5.1 Mutual Exclusion: Software Approaches 226
5.2 Principles of Concurrency 232
5.3 Mutual Exclusion: Hardware Support 241
5.4 Semaphores 244
5.5 Monitors 257
5.6 Message Passing 263
5.7 Readers/Writers Problem 270
5.8 Summary 274
5.9 Key Terms, Review Questions, and Problems 275

Chapter 6 Concurrency: Deadlock and Starvation 289

6.1 Principles of Deadlock 290
6.2 Deadlock Prevention 299
6.3 Deadlock Avoidance 300
6.4 Deadlock Detection 306
6.5 An Integrated Deadlock Strategy 308
6.6 Dining Philosophers Problem 309
6.7 UNIX Concurrency Mechanisms 313
6.8 Linux Kernel Concurrency Mechanisms 315
6.9 Solaris Thread Synchronization Primitives 324
6.10 Windows Concurrency Mechanisms 326
6.11 Android Interprocess Communication 330
6.12 Summary 331
6.13 Key Terms, Review Questions, and Problems 332

PART 3 MEMORY 339

Chapter 7 **Memory Management 339**

7.1 Memory Management Requirements 340
7.2 Memory Partitioning 344
7.3 Paging 355
7.4 Segmentation 358
7.5 Summary 360
7.6 Key Terms, Review Questions, and Problems 360
7A Loading and Linking 363

Chapter 8 **Virtual Memory 370**

8.1 Hardware and Control Structures 371
8.2 Operating System Software 388
8.3 UNIX and Solaris Memory Management 407
8.4 Linux Memory Management 413
8.5 Windows Memory Management 417
8.6 Android Memory Management 419
8.7 Summary 420
8.8 Key Terms, Review Questions, and Problems 421

PART 4 SCHEDULING 425

Chapter 9 **Uniprocessor Scheduling 425**

9.1 Types of Processor Scheduling 426
9.2 Scheduling Algorithms 430
9.3 Traditional UNIX Scheduling 452
9.4 Summary 454
9.5 Key Terms, Review Questions, and Problems 455

Chapter 10 **Multiprocessor, Multicore, and Real-Time Scheduling 460**

10.1 Multiprocessor and Multicore Scheduling 461
10.2 Real-Time Scheduling 474
10.3 Linux Scheduling 489
10.4 UNIX SVR4 Scheduling 492
10.5 UNIX FreeBSD Scheduling 494
10.6 Windows Scheduling 498
10.7 Summary 500
10.8 Key Terms, Review Questions, and Problems 500

PART 5 INPUT/OUTPUT AND FILES 505

Chapter 11 **I/O Management and Disk Scheduling 505**

11.1 I/O Devices 506
11.2 Organization of the I/O Function 508
11.3 Operating System Design Issues 511

11.4 I/O Buffering 514
11.5 Disk Scheduling 517
11.6 RAID 524
11.7 Disk Cache 533
11.8 UNIX SVR4 I/O 537
11.9 Linux I/O 540
11.10 Windows I/O 544
11.11 Summary 546
11.12 Key Terms, Review Questions, and Problems 547

Chapter 12 File Management 550

12.1 Overview 551
12.2 File Organization and Access 557
12.3 B-Trees 561
12.4 File Directories 564
12.5 File Sharing 569
12.6 Record Blocking 570
12.7 Secondary Storage Management 572
12.8 UNIX File Management 580
12.9 Linux Virtual File System 585
12.10 Windows File System 589
12.11 Android File Management 594
12.12 Summary 595
12.13 Key Terms, Review Questions, and Problems 596

PART 6 EMBEDDED SYSTEMS 599

Chapter 13 Embedded Operating Systems 599

13.1 Embedded Systems 600
13.2 Characteristics of Embedded Operating Systems 605
13.3 Embedded Linux 609
13.4 TinyOS 615
13.5 Key Terms, Review Questions, and Problems 625

Chapter 14 Virtual Machines 627

14.1 Virtual Machine Concepts 628
14.2 Hypervisors 631
14.3 Container Virtualization 635
14.4 Processor Issues 642
14.5 Memory Management 644
14.6 I/O Management 645
14.7 VMware ESXi 647
14.8 Microsoft Hyper-V and Xen Variants 650
14.9 Java VM 651
14.10 Linux Vserver Virtual Machine Architecture 652
14.11 Summary 655
14.12 Key Terms, Review Questions, and Problems 655

Chapter 15 Operating System Security 657

15.1 Intruders and Malicious Software 658
15.2 Buffer Overflow 662
15.3 Access Control 670
15.4 UNIX Access Control 678
15.5 Operating Systems Hardening 681
15.6 Security Maintenance 685
15.7 Windows Security 686
15.8 Summary 691
15.9 Key Terms, Review Questions, and Problems 692

Chapter 16 Cloud and IoT Operating Systems 695

16.1 Cloud Computing 696
16.2 Cloud Operating Systems 704
16.3 The Internet of Things 720
16.4 IoT Operating Systems 724
16.5 Key Terms and Review Questions 731

APPENDICES

Appendix A Topics in Concurrency A-1

A.1 Race Conditions and Semaphores A-2
A.2 A Barbershop Problem A-9
A.3 Problems A-14

Appendix B Programming and Operating System Projects B-1

B.1 Semaphore Projects B-2
B.2 File Systems Project B-3
B.3 OS/161 B-3
B.4 Simulations B-4
B.5 Programming Projects B-4
B.6 Research Projects B-6
B.7 Reading/Report Assignments B-7
B.8 Writing Assignments B-7
B.9 Discussion Topics B-7
B.10 BACI B-7

References R-1

Credits CL-1

Index I-1