BRIEF CONTENTS

Preface	xxxi
Chapter 1: History and Standards	1
Chapter 2: Fundamental Concepts	21
Chapter 3: System Programming Concepts	43
Chapter 4: File I/O: The Universal I/O Model	69
Chapter 5: File I/O: Further Details	89
Chapter 6: Processes	113
Chapter 7: Memory Allocation	139
Chapter 8: Users and Groups	153
Chapter 9: Process Credentials	167
Chapter 10: Time	185
Chapter 11: System Limits and Options	211
Chapter 12: System and Process Information	223
Chapter 13: File I/O Buffering	233
Chapter 14: File Systems	251
Chapter 15: File Attributes	279
Chapter 16: Extended Attributes	311
Chapter 17: Access Control Lists	319
Chapter 18: Directories and Links	339
Chapter 19: Monitoring File Events	375

Chapter 20: Signals: Fundamental Concepts	387
Chapter 21: Signals: Signal Handlers	421
Chapter 22: Signals: Advanced Features	447
Chapter 23: Timers and Sleeping	479
Chapter 24: Process Creation	513
Chapter 25: Process Termination	531
Chapter 26: Monitoring Child Processes	541
Chapter 27: Program Execution	563
Chapter 28: Process Creation and Program Execution in More Detail	591
Chapter 29: Threads: Introduction	617
Chapter 30: Threads: Thread Synchronization	631
Chapter 31: Threads: Thread Safety and Per-Thread Storage	655
Chapter 32: Threads: Thread Cancellation	671
Chapter 33: Threads: Further Details	681
Chapter 34: Process Groups, Sessions, and Job Control	699
Chapter 35: Process Priorities and Scheduling	733
Chapter 36: Process Resources	753
Chapter 37: Daemons	767
Chapter 38: Writing Secure Privileged Programs	783
Chapter 39: Capabilities	797
Chapter 40: Login Accounting	81 <i>7</i>
Chapter 41: Fundamentals of Shared Libraries	833
Chapter 42: Advanced Features of Shared Libraries	859
Chapter 43: Interprocess Communication Overview	877
Chapter 44: Pipes and FIFOs	889
Chapter 45: Introduction to System V IPC	921
Chapter 46: System V Message Queues	937

Chapter 47: System V Semaphores	965
Chapter 48: System V Shared Memory	997
Chapter 49: Memory Mappings)1 <i>7</i>
Chapter 50: Virtual Memory Operations	045
Chapter 51: Introduction to POSIX IPC) <i>57</i>
Chapter 52: POSIX Message Queues	063
Chapter 53: POSIX Semaphores	289
Chapter 54: POSIX Shared Memory	107
Chapter 55: File Locking	117
Chapter 56: Sockets: Introduction	149
Chapter 57: Sockets: UNIX Domain	165
Chapter 58: Sockets: Fundamentals of TCP/IP Networks	179
Chapter 59: Sockets: Internet Domains	197
Chapter 60: Sockets: Server Design	239
Chapter 61: Sockets: Advanced Topics	253
Chapter 62: Terminals 12	289
Chapter 63: Alternative I/O Models	325
Chapter 64: Pseudoterminals 13	3 <i>7</i> 5
Appendix A: Tracing System Calls	401
Appendix B: Parsing Command-Line Options	405
Appendix C: Casting the NULL Pointer	413
Appendix D: Kernel Configuration	41 <i>7</i>
Appendix E: Further Sources of Information	419
Appendix F: Solutions to Selected Exercises	425
Bibliography14	43 <i>7</i>
Index 14	447

CONTENTS IN DETAIL

PREF/	PREFACE xxx		
1	HISTORY	Y AND STANDARDS	1
1.1	A Brief His	story of UNIX and C	2
1.2		story of Linux	
	1.2.1	The GNU Project	
	1.2.2	The Linux Kernel	
1.3	Standardiz	zation	
	1.3.1	The C Programming Language	
	1.3.2	The First POSIX Standards	
	1.3.3	X/Open Company and The Open Group	13
	1.3.4	SUSv3 and POSIX.1-2001	
	1.3.5	SUSv4 and POSIX.1-2008	
	1.3.6 1.3. <i>7</i>	UNIX Standards Timeline	
	1.3.7	Implementation StandardsLinux, Standard Base	
1.4		Linux, Siandards, and the Linux Siandard base	
1.4	Summary		17
2	FUNDAN	MENTAL CONCEPTS	21
2.1	The Core C	Operating System: The Kernel	21
2.2			
2.3		Groups	
2.4		ectory Hierarchy, Directories, Links, and Files	
2.5		lodel	
2.6	•		
2.7			
2.8 2.9		Aappings	
2.9		Shared Librariesss Communication and Synchronization	
2.10		ss Communication and Synchronization	
2.12	•		
2.13		roups and Shell Job Control	
2.14		Controlling Terminals, and Controlling Processes	
2.15	Pseudoterm	ninals	39
2.16	Date and T	Time	40
2.17	Client-Serve	er Architecture	40
2.18	Realtime		41
2.19		File System	
2.20	Summary		42
3	SYSTEM	PROGRAMMING CONCEPTS	43
3.1	System Ca	ılls	13
3.2	,	nctions	
3.3		ard C Library; The GNU C Library (glibc)	
3.4		Errors from System Calls and Library Functions	
3.5		he Example Programs in This Book	
	3.5.1	Command-Line Options and Arguments	50
	3.5.2	Common Functions and Header Files	51

3.6	Portability Is	ssues	61
	3.6.1	Feature Test Macros	
	3.6.2		
	3.6.3	, ,,	
3.7	Summary	,	
3.8			
_			
4	FILE I/O:	THE UNIVERSAL I/O MODEL	69
4.1	Overview		69
4.2	Universality	of I/O	72
4.3	Opening a	File: <i>open()</i>	72
	4.3.1	The open() flags Argument	
	4.3.2	Errors from open()	77
	4.3.3	The <i>creat()</i> System Call	
4.4		m a File: $read()$	
4.5		a File: write()	
4.6		ile: close()	
4.7		he File Offset: <i>lseek()</i>	
4.8		Outside the Universal I/O Model: ioctl()	
4.9			
4.10	Exercises		87
_			
5	-	: FURTHER DETAILS	89
5.1		nd Race Conditions	
5.2		Operations: fcntl()	
5.3		Status Flags	
5.4		Between File Descriptors and Open Files	
5.5		File Descriptors	
5.6		a Specified Offset: <i>pread()</i> and <i>pwrite()</i>	
5.7		ner I/O: readv() and writev()	
5.8		a File: truncate() and ftruncate()	
5.9		g I/O	
5.10		ge_Files	
5.11		l Directory	
5.12		mporary Files	
5.13			
5.14	Exercises		110
6	PROCESS	SES	113
6.1		nd Programs	
6.2		and Parent Process ID	
6.3		yout of a Process	
6.4 6.5		nory Management	
6.6	Commanda	nd Stack Frames	121
o.o 6.7			
6.8		t Lista Nonlocal Goto: setjmp() and longjmp()	
6.9		a Noniocal Goto: setjmp() and tongjmp()	
6.9 6.10	Evereises		138

7	MEMORY ALLOCATION	139
<i>7</i> .1	Allocating Memory on the Heap	139
	7.1.1 Adjusting the Program Break: $brk()$ and $sbrk()$	
	7.1.2 Allocating Memory on the Heap: $malloc()$ and $free()$	
	7.1.3 Implementation of <i>malloc()</i> and <i>free()</i>	144
	7.1.4 Other Methods of Allocating Memory on the Heap	147
7.2	Allocating Memory on the Stack: alloca()	150
7.3	Summary	151
7.4	Exercises	152
8	USERS AND GROUPS	153
8.1	The Password File: /etc/passwd	1.53
8.2	The Shadow Password File: /etc/shadow	
8.3	The Group File: /etc/group	
8.4	Retrieving User and Group Information	
8.5	Password Encryption and User Authentication	
8.6	Summary	
8.7	Exercises	
9	PROCESS CREDENTIALS	167
9.1	Real User ID and Real Group ID	
9.1 9.2	Effective User ID and Effective Group ID.	107
9.2 9.3	Set-User-ID and Set-Group-ID Programs	
9.3 9.4	Saved Set-User-ID and Saved Set-Group-ID	
9.4 9.5	File-System User ID and File-System Group ID.	
9.6	Supplementary Group IDs	
7.0 9.7	Retrieving and Modifying Process Credentials	
/./	9.7.1 Retrieving and Modifying Real, Effective, and Saved Set IDs	
	9.7.2 Retrieving and Modifying File-System IDs	
	9.7.3 Retrieving and Modifying Supplementary Group IDs	
	9.7.4 Summary of Calls for Modifying Process Credentials	
	9.7.5 Example: Displaying Process Credentials	182
9.8	Summary	
9.9	Exercises	
10	TIME	185
-		
10.1	Calendar Time Time-Conversion Functions	
10.2	10.2.1 Converting <i>time_t</i> to Printable Form	
	10.2.2 Converting Between $time_t$ and Broken-Down Time	
	10.2.3 Converting Between Broken-Down Time and Printable Form	
10.3	Timezones	
10.3	Locales	
10.4	Updating the System Clock	
10.5	The Software Clock (Jiffies)	
10.7	Process Time	
10.8	Summary	
10.0	Fyerrise	210

11	SYSTEM LIMITS AND OPTIONS	211
11.1	System Limits	212
11.2	Retrieving System Limits (and Options) at Run Time	
11.3	Retrieving File-Related Limits (and Options) at Run Time	
11.4	Indeterminate Limits	
11.5	System Options	
11.6	Summary	
11.7	Exercises	
12	SYSTEM AND PROCESS INFORMATION	223
12.1	The /proc File System	
12.1	12.1.1 Obtaining Information About a Process: /proc/PID	
	12.1.2 System Information Under /proc	
12.2	System Identification: uname()	
12.2	Summary	
12.4	Exercises	
13	ELLE I/O DIJECEDINO	222
	FILE I/O BUFFERING	233
13.1	Kernel Buffering of File I/O: The Buffer Cache	233
13.2	Buffering in the stdio Library	
13.3	Controlling Kernel Buffering of File I/O	
13.4	Summary of I/O Buffering	
13.5	Advising the Kernel About I/O Patterns	
13.6	Bypassing the Buffer Cache: Direct I/O	246
13.7	Mixing Library Functions and System Calls for File I/O	
13.8	Summary	
13.9	Exercises	250
14	FILE SYSTEMS	251
14.1	Device Special Files (Devices)	252
14.2	Disks and Partitions	
14.3	File Systems	
14.4	I-nodes	
14.5	The Virtual File System (VFS)	259
14.6	Journaling File Systems	260
14.7	Single Directory Hierarchy and Mount Points	261
14.8	Mounting and Unmounting File Systems	262
	14.8.1 Mounting a File System: <i>mount()</i>	264
	14.8.2 Unmounting a File System: <i>umount()</i> and <i>umount2()</i>	269
14.9	Advanced Mount Features	271
	14.9.1 Mounting a File System at Multiple Mount Points	271
	14.9.2 Stacking Multiple Mounts on the Same Mount Point	
	14.9.3 Mount Flags That Are Per-Mount Options	
	14.9.4 Bind Mounts	
	14.9.5 Recursive Bind Mounts	
14.10		
14.11	Obtaining Information About a File System: statufs()	
14.12	,	
14.13	Exercise	278

15	FILE ATTRIBUTES	279
15.1	Retrieving File Information: stat()	279
15.2	File Timestamps	
	15.2.1 Changing File Timestamps with $utime()$ and $utimes()$	
	15.2.2 Changing File Timestamps with <i>utimensat()</i> and <i>futimens()</i>	
15.3	File Ownership	291
	15.3.1 Ownership of New Files	
	15.3.2 Changing File Ownership: chown(), fchown(), and lchown()	
15.4	File Permissions	
	15.4.1 Permissions on Regular Files	
	15.4.2 Permissions on Directories	
	15.4.3 Permission-Checking Algorithm	
	15.4.4 Checking File Accessibility: access()	
	15.4.5 Set-User-ID, Set-Group-ID, and Sticky Bits	
	15.4.6 The Process File Mode Creation Mask: umask()	
	15.4.7 Changing File Permissions: chmod() and fchmod()	
15.5	I-node Flags (ext2 Extended File Attributes)	
15.6	Summary	
15.7	Exercises	
16	EXTENDED ATTRIBUTES	311
16.1	Overview	
16.2	Extended Attribute Implementation Details	313
16.3	System Calls for Manipulating Extended Attributes	314
16.4	Summary	318
16.5	Exercise	318
17	ACCESS CONTROL LISTS	319
1 <i>7</i> .1	Overview	320
1 <i>7</i> .2	ACL Permission-Checking Algorithm	321
1 <i>7</i> .3	Long and Short Text Forms for ACLs	323
17.4	The ACL_MASK Entry and the ACL Group Class	324
1 <i>7</i> .5	The getfacl and setfacl Commands	325
17.6	Default ACLs and File Creation	327
1 <i>7.7</i>	ACL Implementation Limits	328
1 <i>7</i> .8	The ACL API	329
1 <i>7</i> .9	Summary	337
1 <i>7</i> .10	Exercise	337
18	DIRECTORIES AND LINKS	339
18.1	Directories and (Hard) Links	
18.2	Symbolic (Soft) Links	
18.3	Creating and Removing (Hard) Links: link() and unlink()	
18.4	Changing the Name of a File: rename()	
18.5	Working with Symbolic Links: symlink() and readlink()	
18.6	Creating and Removing Directories: mkdir() and rmdir()	
18.7	Removing a File or Directory: remove()	
18.8	Reading Directories: opendir() and readdir()	252
18.9	File Tree Walking: nftw()	358
18.10	File Tree Walking: $nftw()$	358 363
18.10 18.11	File Tree Walking: $nftw()$	358 363 365
18.10	File Tree Walking: $nftw()$	

	Parsing Pathname Strings: dirname() and basename()	
	Summary	
16.10	Exercises	3/3
19	MONITORING FILE EVENTS	375
19.1	Overview	
19.2	The inotify API	
19.3 19.4	inotify Events	
19.4	Reading inotify Events	
19.5	An Older System for Monitoring File Events: dnotify	
19.7	Summary	
19.8	Exercise	
20	SIGNALS: FUNDAMENTAL CONCEPTS	387
20.1	Concepts and Overview.	388
20.2	Signal Types and Default Actions	
20.3	Changing Signal Dispositions: signal()	
20.4	Introduction to Signal Handlers	
20.5	Sending Signals: kill()	401
20.6	Checking for the Existence of a Process	
20.7	Other Ways of Sending Signals: raise() and killpg()	
20.8	Displaying Signal Descriptions	
20.9 20.10	Signal Sets	
20.10	Pending Signals	
20.11	Signals Are Not Queued	
20.12	Changing Signal Dispositions: sigaction()	
20.14	Waiting for a Signal: pause()	
20.15	Summary	
20.16	Exercises	419
21	SIGNALS: SIGNAL HANDLERS	421
21.1	Designing Signal Handlers	422
	21.1.1 Signals Are Not Queued (Revisited)	
	21.1.2 Reentrant and Async-Signal-Safe Functions	
	21.1.3 Global Variables and the sig_atomic_t Data Type	
21.2	Other Methods of Terminating a Signal Handler	428
	21.2.1 Performing a Nonlocal Goto from a Signal Handler	
21.3	21.2.2 Terminating a Process Abnormally: abort()	
21.3	The SA SIGINFO Flag	
21.5	Interruption and Restarting of System Calls	
21.6	Summary	
21.7	Exercise	
22	SIGNALS: ADVANCED FEATURES	447
22.1	Core Dump Files	448
22.2	Special Cases for Delivery, Disposition, and Handling	
22.3	Interruptible and Uninterruptible Process Sleep States	
22.4	Hardware-Generated Signals	452
22.5	Synchronous and Asynchronous Signal Generation	452

22.6 22.7 22.8	Timing and Order of Signal Delivery	454
	22.8.1 Sending Realtime Signals	
	22.8.2 Handling Realtime Signals	
22.9	Waiting for a Signal Using a Mask: sigsuspend()	464
22.10		
22.11	Fetching Signals via a File Descriptor	
22.12	- 1	
22.13		
22.14	· · · · · · · · · · · · · · · · · · ·	
22.13	Exercises	4/ 6
23	TIMERS AND SLEEPING	479
23.1	Interval Timers	
23.2	Scheduling and Accuracy of Timers	485
23.3	Setting Timeouts on Blocking Operations	
23.4	Suspending Execution for a Fixed Interval (Sleeping)	
	23.4.1 Low-Resolution Sleeping: sleep()	
	23.4.2 High-Resolution Sleeping: nanosleep()	
23.5	POSIX Clocks	
	23.5.1 Retrieving the Value of a Clock: clock_gettime()	491
	23.5.2 Setting the Value of a Clock: clock_settime()	
	23.5.3 Obtaining the Clock ID of a Specific Process or Thread	
	23.5.4 Improved High-Resolution Sleeping: clock_nanosleep()	
23.6	POSIX Interval Timers	
	23.6.1 Creating a Timer: <i>timer_create()</i>	
	23.6.2 Arming and Disarming a Timer: timer_settime()	498
	23.6.3 Retrieving the Current Value of a Timer: timer_gettime()	499
	23.6.4 Deleting a Timer: timer_delete()	
	23.6.5 Notification via a Signal	
	23.6.7 Notification via a Thread	
23.7	Timers That Notify via File Descriptors: the timerfd API	
23.8	Summary	
23.9	Exercises	
20.7	<u> </u>	
24	PROCESS CREATION	513
24.1	Overview of fork(), exit(), wait(), and execve()	513
24.2	Creating a New Process: fork()	
	24.2.1 File Sharing Between Parent and Child	
	24.2.2 Memory Semantics of $fork()$	
24.3	The vfork() System Call	
24.4	Race Conditions After fork()	
24.5	Avoiding Race Conditions by Synchronizing with Signals	
24.6	Summary	
24.7	Exercises	530
25	PROCESS TERMINATION	531
25.1	Terminating a Process: _exit() and exit()	531
25.2	Details of Process Termination	
25.3	Exit Handlers	
25 /	Interactions Retween forb() stdio Ruffers and exit()	537

25.5 25.6	Summary Exercise	
26	MONITORING CHILD PROCESSES	541
26.1	Waiting on a Child Process	541
	26.1.1 The <i>wait()</i> System Call	541
	26.1.2 The <i>waitpid()</i> System Call	544
	26.1.3 The Wait Status Value	
	26.1.4 Process Termination from a Signal Handler	
	26.1.5 The waitid() System Call	
	26.1.6 The wait3() and wait4() System Calls	
26.2	Orphans and Zombies	
26.3	The SIGCHLD Signal	
	26.3.1 Establishing a Handler for SIGCHLD	
	26.3.2 Delivery of SIGCHLD for Stopped Children	
0 / /	26.3.3 Ignoring Dead Child Processes	
26.4	Summary	
26.5	Exercises	562
27	PROGRAM EXECUTION	563
27.1	Executing a New Program: execve()	
27.1	The exec() Library Functions	
27.2	27.2.1 The PATH Environment Variable	
	27.2.2 Specifying Program Arguments as a List	
	27.2.3 Passing the Caller's Environment to the New Program	
	27.2.4 Executing a File Referred to by a Descriptor: fexecue()	
27.3	Interpreter Scripts	
27.4	File Descriptors and exec()	
27.5	Signals and exec()	
27.6	Executing a Shell Command: system()	
27.7	Implementing system()	
27.8	Summary	
27.9	Exercises	
28	PROCESS CREATION AND PROGRAM EXECUTION IN MORE DETAIL	591
28.1	Process Accounting	591
28.2	The clone() System Call	
	28.2.1 The <i>clone() flags</i> Argument	
	28.2.2 Extensions to waitpid() for Cloned Children	609
28.3	Speed of Process Creation	610
28.4	Effect of exec() and fork() on Process Attributes	612
28.5	Summary	616
28.6	Exercise	616
29	THREADS: INTRODUCTION	617
29.1	Overview	
29.2	Background Details of the Pthreads API	
29.3	Thread Creation	622
29.4	Thread Termination	
29.5	Thread IDs	
29.6	Joining with a Terminated Thread	
29.7	Detaching a Thread	627
xviii	Contents in Detail	

29.8 29.9	Threads Vers	outes	629	
29.10				
29.11	Exercises		630	
30	THREADS:	THREAD SYNCHRONIZATION	631	
30.1	Protecting Ad	ccesses to Shared Variables: Mutexes		
	30.1.1	Statically Allocated Mutexes		
	30.1.2	Locking and Unlocking a Mutex		
	30.1.3	Performance of Mutexes		
	30.1.4 30.1.5	Mutex Deadlocks		
	30.1.5	Mutex Attributes		
	30.1. <i>7</i>	Mutex Types		
30.2		nanges of State: Condition Variables		
00.2	30.2.1	Statically Allocated Condition Variables		
	30.2.2	Signaling and Waiting on Condition Variables		
	30.2.3	Testing a Condition Variable's Predicate		
	30.2.4	Example Program: Joining Any Terminated Thread	648	
	30.2.5	Dynamically Allocated Condition Variables		
30.3	,			
30.4	Exercises		652	
31	THREADS:	THREAD SAFETY AND PER-THREAD STORAGE	655	
31.1	Thread Safet	y (and Reentrancy Revisited)	655	
31.2		tialization		
31.3	Thread-Specific Data			
	31.3.1	Thread-Specific Data from the Library Function's Perspective		
	31.3.2	Overview of the Thread-Specific Data API	660	
	31.3.3	Details of the Thread-Specific Data API		
	31.3.4	Employing the Thread-Specific Data API		
	31.3.5	Thread-Specific Data Implementation Limits		
31.4		Storage		
31.5	Summary			
31.6	Exercises		6/0	
32	THREADS:	THREAD CANCELLATION	671	
32.1	Canceling a	Thread	671	
32.2		State and Type	672	
32.3		Points		
32.4		nread Cancellation		
32.5		ndlers		
32.6		s Cancelability		
32.7	Summary		680	
33	THREADS:	FURTHER DETAILS	681	
33.1		.s	481	
33.1		Signals		
30.2	33.2.1	How the UNIX Signal Model Maps to Threads		
	33.2.2	Manipulating the Thread Signal Mask		
	33.2.3	Sending a Signal to a Thread		
	33.2.4	Dealing with Asynchronous Signals Sanely		

33.3 33.4	Thread Implementation Models	687
33.5	Linux Implementations of POSIX Threads	689
	33.5.3 Which Threading Implementation?	
33.6	Advanced Features of the Pthreads API	696
33.7	Summary	
33.8	Exercises	697
34	PROCESS GROUPS, SESSIONS, AND JOB CONTROL	
34.1	Overview	
34.2	Process Groups	
34.3	Sessions	
34.4 34.5	Controlling Terminals and Controlling Processes	
34.6	The SIGHUP Signal	
54.0	34.6.1 Handling of SIGHUP by the Shell	
	34.6.2 SIGHUP and Termination of the Controlling Process	
34.7	Job Control	
	34.7.1 Using Job Control Within the Shell	
	34.7.2 Implementing Job Control	
	34.7.3 Handling Job-Control Signals	
	34.7.4 Orphaned Process Groups (and SIGHUP Revisited)	
34.8	Summary	
34.9	Exercises	
35	PROCESS PRIORITIES AND SCHEDULING	733
35.1	Process Priorities (Nice Values)	733
	Process Priorities (Nice Values)	733 737
35.1	Process Priorities (Nice Values)	
35.1	Process Priorities (Nice Values)	
35.1 35.2	Process Priorities (Nice Values)	
35.1	Process Priorities (Nice Values)	
35.1 35.2	Process Priorities (Nice Values) Overview of Realtime Process Scheduling	
35.1 35.2	Process Priorities (Nice Values) Overview of Realtime Process Scheduling	
35.1 35.2	Process Priorities (Nice Values) Overview of Realtime Process Scheduling	
35.1 35.2 35.3	Process Priorities (Nice Values) Overview of Realtime Process Scheduling	733 737 739 740 740 740 741 747 747
35.1 35.2 35.3 35.4 35.5	Process Priorities (Nice Values) Overview of Realtime Process Scheduling	733 737 739 740 740 740 741 747 747 748
35.1 35.2 35.3	Process Priorities (Nice Values) Overview of Realtime Process Scheduling	733 737 739 740 740 740 741 747 747 748
35.1 35.2 35.3 35.4 35.5	Process Priorities (Nice Values) Overview of Realtime Process Scheduling	733 737 739 740 740 740 741 747 747 748
35.1 35.2 35.3 35.4 35.5 35.6	Process Priorities (Nice Values) Overview of Realtime Process Scheduling. 35.2.1 The SCHED_RR Policy	733 737 739 740 740 740 741 747 747 748 751
35.1 35.2 35.3 35.4 35.5 35.6	Process Priorities (Nice Values) Overview of Realtime Process Scheduling	733 737 739 740 740 740 741 747 747 748 751
35.1 35.2 35.3 35.4 35.5 35.6	Process Priorities (Nice Values) Overview of Realtime Process Scheduling. 35.2.1 The SCHED_RR Policy	733 737 739 740 740 740 741 741 747 748 751
35.1 35.2 35.3 35.4 35.5 35.6 36.1 36.2	Process Priorities (Nice Values) Overview of Realtime Process Scheduling. 35.2.1 The SCHED_RR Policy. 35.2.2 The SCHED_BATCH and SCHED_IDLE Policies. Realtime Process Scheduling API. 35.3.1 Realtime Priority Ranges. 35.3.2 Modifying and Retrieving Policies and Priorities. 35.3.3 Relinquishing the CPU. 35.3.4 The SCHED_RR Time Slice. CPU Affinity. Summary. Exercises. PROCESS RESOURCES Process Resource Usage. Process Resource Limits Details of Specific Resource Limits Summary.	733 737 739 740 740 740 741 747 747 748 751 751 753 753 755 760
35.1 35.2 35.3 35.4 35.5 35.6 36.1 36.2 36.3	Process Priorities (Nice Values) Overview of Realtime Process Scheduling. 35.2.1 The SCHED_RR Policy	733 737 739 740 740 740 741 747 747 748 751 751 753 753 755 760
35.1 35.2 35.3 35.4 35.5 35.6 36.1 36.2 36.3 36.4	Process Priorities (Nice Values) Overview of Realtime Process Scheduling. 35.2.1 The SCHED_RR Policy. 35.2.2 The SCHED_BATCH and SCHED_IDLE Policies. Realtime Process Scheduling API. 35.3.1 Realtime Priority Ranges. 35.3.2 Modifying and Retrieving Policies and Priorities. 35.3.3 Relinquishing the CPU. 35.3.4 The SCHED_RR Time Slice. CPU Affinity. Summary. Exercises. PROCESS RESOURCES Process Resource Usage. Process Resource Limits Details of Specific Resource Limits Summary.	733 737 739 740 740 740 741 747 747 748 751 751 753 753 755 760
35.1 35.2 35.3 35.4 35.5 35.6 36.1 36.2 36.3 36.4 36.5	Process Priorities (Nice Values) Overview of Realtime Process Scheduling 35.2.1 The SCHED_RR Policy 35.2.2 The SCHED_FIFO Policy 35.2.3 The SCHED_BATCH and SCHED_IDLE Policies. Realtime Process Scheduling API 35.3.1 Realtime Priority Ranges 35.3.2 Modifying and Retrieving Policies and Priorities 35.3.3 Relinquishing the CPU 35.3.4 The SCHED_RR Time Slice CPU Affinity Summary Exercises PROCESS RESOURCES Process Resource Usage Process Resource Limits Details of Specific Resource Limits Summary Exercises	733 737 739 740 740 740 741 747 747 748 751 751 753 753 755 760 765

37.3	Guidelines for Writing Daemons	
37.4	Using SIGHUP to Reinitialize a Daemon	
37.5	Logging Messages and Errors Using syslog	
	37.5.1 Overview	
	37.5.2 The syslog API	<i>777</i>
	37.5.3 The /etc/syslog.conf File	<i>7</i> 81
37.6	Summary	782
37.7	Exercise	782
38	WRITING SECURE PRIVILEGED PROGRAMS	783
38.1	Is a Set-User-ID or Set-Group-ID Program Required?	784
38.2	Operate with Least Privilege	
38.3	Be Careful When Executing a Program	
38.4	Avoid Exposing Sensitive Information	
38.5	Confine the Process	
38.6	Beware of Signals and Race Conditions	
38.7	Pitfalls When Performing File Operations and File I/O	
38.8	Don't Trust Inputs or the Environment	
38.9	Beware of Buffer Overruns	
38.10	Beware of Denial-of-Service Attacks	
38.11	Check Return Statuses and Fail Safely	
38.12	Summary	
38.13		
50.15	LACICISCS	7 70
39	CAPABILITIES	797
39.1	Rationale for Capabilities	
39.2	The Linux Capabilities	
39.3	Process and File Capabilities	
	39.3.1 Process Capabilities	
	39.3.2 File Capabilities	
	39.3.3 Purpose of the Process Permitted and Effective Capability Sets	
	39.3.4 Purpose of the File Permitted and Effective Capability Sets	
	39.3.5 Purpose of the Process and File Inheritable Sets	
	39.3.6 Assigning and Viewing File Capabilities from the Shell	
39.4	The Modern Capabilities Implementation	
39.5	Transformation of Process Capabilities During exec()	
	39.5.1 Capability Bounding Set	
	39.5.2 Preserving <i>root</i> Semantics	806
39.6	Effect on Process Capabilities of Changing User IDs	806
39. <i>7</i>	Changing Process Capabilities Programmatically	807
39.8	Creating Capabilities-Only Environments	811
39.9	Discovering the Capabilities Required by a Program	813
39.10	Older Kernels and Systems Without File Capabilities	814
39.11	Summary	
39.12		
40	LOGIN ACCOUNTING	817
40.1	Overview of the utmp and wtmp Files	817
40.2	The utmpx API	
40.3	The utmpx Structure	
40.4	Retrieving Information from the utmp and wtmp Files	
40.5	Retrieving the Login Name: $getlogin()$	
40.6	Updating the utmp and wtmp Files for a Login Session	825

40.7	The lastlog File	
40.8	Summary	
40.9	Exercises	832
41	FUNDAMENTALS OF SHARED LIBRARIES	833
41.1	Object Libraries	
41.2	Static Libraries	
41.3	Overview of Shared Libraries.	
41.4	Creating and Using Shared Libraries—A First Pass	
	41.4.1 Creating a Shared Library	
	41.4.2 Position-Independent Code	
	41.4.3 Using a Shared Library	
	41.4.4 The Shared Library Soname	
41.5	Useful Tools for Working with Shared Libraries	
41.6	Shared Library Versions and Naming Conventions	
41.7	Installing Shared Libraries	
41.8	Compatible Versus Incompatible Libraries	
41.9	Upgrading Shared Libraries	
41.10		
41.11	Finding Shared Libraries at Run Time	
41.12	Run-Time Symbol Resolution	
41.12	Using a Static Library Instead of a Shared Library	
41.13		
	Exercise	
42	ADVANCED FEATURES OF SHARED LIBRARIES	859
42 42.1	Dynamically Loaded Libraries	859
	Dynamically Loaded Libraries	859 860
	Dynamically Loaded Libraries	859 860 862
	Dynamically Loaded Libraries	
	Dynamically Loaded Libraries	
	Dynamically Loaded Libraries	859 860 862 862 866
	Dynamically Loaded Libraries	859 860 862 862 866
	Dynamically Loaded Libraries	859 860 862 862 866 866 867
42.1	Dynamically Loaded Libraries	859 860 862 862 866 866 867 867
42.1 42.2	Dynamically Loaded Libraries	859 860 862 862 866 866 867 867 868
42.1 42.2	Dynamically Loaded Libraries	859 860 862 862 866 866 867 867 868 868
42.1 42.2 42.3	Dynamically Loaded Libraries 42.1.1 Opening a Shared Library: dlopen()	859 860 862 862 866 867 867 868 868 870
42.1 42.2 42.3 42.4 42.5	Dynamically Loaded Libraries 42.1.1 Opening a Shared Library: dlopen()	859 860 862 862 866 866 867 867 868 870 872
42.1 42.2 42.3 42.4 42.5 42.6	Dynamically Loaded Libraries 42.1.1 Opening a Shared Library: dlopen()	859 860 862 862 866 866 867 867 868 870 872
42.1 42.2 42.3 42.4 42.5 42.6 42.7	Dynamically Loaded Libraries 42.1.1 Opening a Shared Library: dlopen()	859 860 862 862 866 866 867 867 868 870 872 873 874
42.1 42.2 42.3 42.4 42.5	Dynamically Loaded Libraries 42.1.1 Opening a Shared Library: dlopen()	859 860 862 862 866 866 867 867 868 870 872 873 874
42.2 42.3 42.4 42.5 42.6 42.7 42.8	Dynamically Loaded Libraries 42.1.1 Opening a Shared Library: dlopen()	859 860 862 862 866 866 867 867 868 870 872 873 874
42.2 42.3 42.4 42.5 42.6 42.7 42.8	Dynamically Loaded Libraries 42.1.1 Opening a Shared Library: dlopen(). 42.1.2 Diagnosing Errors: dlerror() 42.1.3 Obtaining the Address of a Symbol: dlsym(). 42.1.4 Closing a Shared Library: dlclose(). 42.1.5 Obtaining Information About Loaded Symbols: dladdr(). 42.1.6 Accessing Symbols in the Main Program. Controlling Symbol Visibility. Linker Version Scripts. 42.3.1 Controlling Symbol Visibility with Version Scripts 42.3.2 Symbol Versioning. Initialization and Finalization Functions. Preloading Shared Libraries. Monitoring the Dynamic Linker: LD_DEBUG. Summary. Exercises.	859 860 862 864 866 867 867 868 870 873 874 875
42.1 42.2 42.3 42.4 42.5 42.6 42.7 42.8 43 43.1	Dynamically Loaded Libraries 42.1.1 Opening a Shared Library: dlopen() 42.1.2 Diagnosing Errors: dlerror() 42.1.3 Obtaining the Address of a Symbol: dlsym() 42.1.4 Closing a Shared Library: dlclose() 42.1.5 Obtaining Information About Loaded Symbols: dladdr() 42.1.6 Accessing Symbols in the Main Program Controlling Symbol Visibility Linker Version Scripts 42.3.1 Controlling Symbol Visibility with Version Scripts 42.3.2 Symbol Versioning Initialization and Finalization Functions. Preloading Shared Libraries Monitoring the Dynamic Linker: LD_DEBUG Summary Exercises INTERPROCESS COMMUNICATION OVERVIEW A Taxonomy of IPC Facilities	859 860 862 862 866 867 867 868 870 875 876
42.1 42.2 42.3 42.4 42.5 42.6 42.7 42.8 43.1 43.1	Dynamically Loaded Libraries 42.1.1 Opening a Shared Library: dlopen() 42.1.2 Diagnosing Errors: dlerror() 42.1.3 Obtaining the Address of a Symbol: dlsym() 42.1.4 Closing a Shared Library: dlclose() 42.1.5 Obtaining Information About Loaded Symbols: dladdr() 42.1.6 Accessing Symbols in the Main Program Controlling Symbol Visibility Linker Version Scripts 42.3.1 Controlling Symbol Visibility with Version Scripts 42.3.2 Symbol Versioning Initialization and Finalization Functions Preloading Shared Libraries Monitoring the Dynamic Linker: LD_DEBUG. Summary Exercises INTERPROCESS COMMUNICATION OVERVIEW A Taxonomy of IPC Facilities Communication Facilities	859 860 862 862 866 866 867 868 870 872 873 874 875
42.2 42.3 42.4 42.5 42.6 42.7 42.8 43.1 43.2 43.3	Dynamically Loaded Libraries 42.1.1 Opening a Shared Library: dlopen()	859 860 862 862 866 866 867 868 870 872 873 874 875 877 879
42.1 42.2 42.3 42.4 42.5 42.6 42.7	Dynamically Loaded Libraries 42.1.1 Opening a Shared Library: dlopen() 42.1.2 Diagnosing Errors: dlerror() 42.1.3 Obtaining the Address of a Symbol: dlsym() 42.1.4 Closing a Shared Library: dlclose() 42.1.5 Obtaining Information About Loaded Symbols: dladdr() 42.1.6 Accessing Symbols in the Main Program Controlling Symbol Visibility Linker Version Scripts 42.3.1 Controlling Symbol Visibility with Version Scripts 42.3.2 Symbol Versioning Initialization and Finalization Functions Preloading Shared Libraries Monitoring the Dynamic Linker: LD_DEBUG. Summary Exercises INTERPROCESS COMMUNICATION OVERVIEW A Taxonomy of IPC Facilities Communication Facilities	859 860 862 862 866 866 867 868 868 870 872 873 874 875 876

44	PIPES AND FIFOS	889
44.1	Overview	889
44.2	Creating and Using Pipes	
44.3	Pipes as a Method of Process Synchronization	
44.4	Using Pipes to Connect Filters	
44.5	Talking to a Shell Command via a Pipe: popen()	
44.6	Pipes and stdio Buffering	
44.7	FIFOs	
44.8	A Client-Server Application Using FIFOs	
44.9	Nonblocking I/O	
44.10	Semantics of <i>read()</i> and <i>write()</i> on Pipes and FIFOs	
44.11	Summary	
44.12	Exercises	
45	INTRODUCTION TO SYSTEM V IPC	921
45.1	API Overview	922
45.2	IPC Keys	
45.3	Associated Data Structure and Object Permissions.	
45.4	IPC Identifiers and Client-Server Applications	
45.5	Algorithm Employed by System V IPC get Calls	
45.6	The ipcs and ipcrm Commands	
45.7	Obtaining a List of All IPC Objects	
45.8	IPC Limits	
45.9	Summary	
45.10	Exercises	
46	SYSTEM V MESSAGE QUEUES	937
46.1	Creating or Opening a Message Queue	938
	Exchanging Messages	940
46.1		940
46.1	Exchanging Messages	940 940
46.1	Exchanging Messages	940 940 943
46.1 46.2	Exchanging Messages	940 940 943 947
46.1 46.2 46.3	Exchanging Messages 46.2.1 Sending Messages 46.2.2 Receiving Messages Message Queue Control Operations. Message Queue Associated Data Structure Message Queue Limits	940 943 947 948 950
46.1 46.2 46.3 46.4	Exchanging Messages 46.2.1 Sending Messages 46.2.2 Receiving Messages Message Queue Control Operations Message Queue Associated Data Structure Message Queue Limits Displaying All Message Queues on the System	940 940 943 947 950 951
46.1 46.2 46.3 46.4 46.5 46.6 46.7	Exchanging Messages 46.2.1 Sending Messages 46.2.2 Receiving Messages Message Queue Control Operations Message Queue Associated Data Structure Message Queue Limits Displaying All Message Queues on the System Client-Server Programming with Message Queues	940 943 947 948 950 951
46.1 46.2 46.3 46.4 46.5 46.6 46.7 46.8	Exchanging Messages 46.2.1 Sending Messages 46.2.2 Receiving Messages Message Queue Control Operations Message Queue Associated Data Structure Message Queue Limits Displaying All Message Queues on the System Client-Server Programming with Message Queues A File-Server Application Using Message Queues	940 943 947 948 950 951 953
46.1 46.2 46.3 46.4 46.5 46.6 46.7	Exchanging Messages 46.2.1 Sending Messages 46.2.2 Receiving Messages Message Queue Control Operations Message Queue Associated Data Structure Message Queue Limits Displaying All Message Queues on the System Client-Server Programming with Message Queues	940 943 947 948 950 951 953
46.1 46.2 46.3 46.4 46.5 46.6 46.7 46.8 46.9 46.10	Exchanging Messages 46.2.1 Sending Messages 46.2.2 Receiving Messages Message Queue Control Operations Message Queue Associated Data Structure Message Queue Limits Displaying All Message Queues on the System Client-Server Programming with Message Queues A File-Server Application Using Message Queues Disadvantages of System V Message Queues Summary	940 943 947 948 950 953 955 961
46.1 46.2 46.3 46.4 46.5 46.6 46.7 46.8 46.9 46.10	Exchanging Messages 46.2.1 Sending Messages 46.2.2 Receiving Messages Message Queue Control Operations Message Queue Associated Data Structure Message Queue Limits Displaying All Message Queues on the System Client-Server Programming with Message Queues A File-Server Application Using Message Queues Disadvantages of System V Message Queues	940 943 947 948 950 953 955 961
46.1 46.2 46.3 46.4 46.5 46.6 46.7 46.8 46.9 46.10	Exchanging Messages 46.2.1 Sending Messages 46.2.2 Receiving Messages Message Queue Control Operations Message Queue Associated Data Structure Message Queue Limits Displaying All Message Queues on the System Client-Server Programming with Message Queues A File-Server Application Using Message Queues Disadvantages of System V Message Queues Summary	940 943 947 948 950 953 955 961
46.1 46.2 46.3 46.4 46.5 46.6 46.7 46.8 46.9 46.10 46.11	Exchanging Messages 46.2.1 Sending Messages 46.2.2 Receiving Messages Message Queue Control Operations. Message Queue Associated Data Structure Message Queue Limits Displaying All Message Queues on the System Client-Server Programming with Message Queues A File-Server Application Using Message Queues Disadvantages of System V Message Queues Summary Exercises	940 943 947 948 950 951 955 961 962
46.1 46.2 46.3 46.4 46.5 46.6 46.7 46.8 46.9 46.10 46.11	Exchanging Messages 46.2.1 Sending Messages 46.2.2 Receiving Messages Message Queue Control Operations. Message Queue Associated Data Structure Message Queue Limits Displaying All Message Queues on the System Client-Server Programming with Message Queues A File-Server Application Using Message Queues Disadvantages of System V Message Queues Summary Exercises SYSTEM V SEMAPHORES Overview	940 940 943 947 950 951 955 961 963
46.1 46.2 46.3 46.4 46.5 46.6 46.7 46.8 46.9 46.10 46.11	Exchanging Messages 46.2.1 Sending Messages 46.2.2 Receiving Messages Message Queue Control Operations. Message Queue Associated Data Structure Message Queue Limits Displaying All Message Queues on the System Client-Server Programming with Message Queues A File-Server Application Using Message Queues Disadvantages of System V Message Queues Summary. Exercises SYSTEM V SEMAPHORES Overview Creating or Opening a Semaphore Set	940 940 943 947 950 951 955 961 963 963
46.1 46.2 46.3 46.4 46.5 46.6 46.7 46.8 46.9 46.10 46.11	Exchanging Messages 46.2.1 Sending Messages 46.2.2 Receiving Messages Message Queue Control Operations. Message Queue Associated Data Structure Message Queue Limits Displaying All Message Queues on the System Client-Server Programming with Message Queues A File-Server Application Using Message Queues Disadvantages of System V Message Queues Summary. Exercises SYSTEM V SEMAPHORES Overview Creating or Opening a Semaphore Set Semaphore Control Operations.	940 940 943 947 950 951 955 961 963 965 966
46.1 46.2 46.3 46.4 46.5 46.6 46.7 46.8 46.9 46.10 46.11	Exchanging Messages 46.2.1 Sending Messages 46.2.2 Receiving Messages Message Queue Control Operations. Message Queue Associated Data Structure Message Queue Limits Displaying All Message Queues on the System Client-Server Programming with Message Queues A File-Server Application Using Message Queues Disadvantages of System V Message Queues Summary. Exercises SYSTEM V SEMAPHORES Overview Creating or Opening a Semaphore Set Semaphore Control Operations. Semaphore Associated Data Structure.	940 940 943 947 950 951 953 961 963 965 966 969 969
46.1 46.2 46.3 46.4 46.5 46.6 46.7 46.8 46.9 46.10 46.11 47.1 47.1 47.2 47.3 47.4	Exchanging Messages 46.2.1 Sending Messages 46.2.2 Receiving Messages Message Queue Control Operations. Message Queue Associated Data Structure Message Queue Limits Displaying All Message Queues on the System Client-Server Programming with Message Queues A File-Server Application Using Message Queues Disadvantages of System V Message Queues Summary. Exercises SYSTEM V SEMAPHORES Overview Creating or Opening a Semaphore Set Semaphore Control Operations. Semaphore Associated Data Structure. Semaphore Initialization.	940 940 943 947 950 951 955 961 963 965 966 969 969
46.1 46.2 46.3 46.4 46.5 46.6 46.7 46.8 46.9 46.10 46.11 47 47.1 47.2 47.3 47.4 47.5	Exchanging Messages 46.2.1 Sending Messages. 46.2.2 Receiving Messages. Message Queue Control Operations. Message Queue Associated Data Structure Message Queue Limits Displaying All Message Queues on the System Client-Server Programming with Message Queues A File-Server Application Using Message Queues Disadvantages of System V Message Queues Summary. Exercises. SYSTEM V SEMAPHORES Overview Creating or Opening a Semaphore Set. Semaphore Control Operations. Semaphore Associated Data Structure. Semaphore Initialization. Semaphore Operations	940 940 943 947 950 951 961 963 963 966 969 969 972
46.1 46.2 46.3 46.4 46.5 46.6 46.7 46.8 46.9 46.10 46.11 47.1 47.2 47.3 47.4 47.5 47.6	Exchanging Messages 46.2.1 Sending Messages. 46.2.2 Receiving Messages. Message Queue Control Operations. Message Queue Associated Data Structure Message Queue Limits Displaying All Message Queues on the System Client-Server Programming with Message Queues A File-Server Application Using Message Queues Disadvantages of System V Message Queues Summary. Exercises. SYSTEM V SEMAPHORES Overview Creating or Opening a Semaphore Set. Semaphore Control Operations. Semaphore Associated Data Structure. Semaphore Initialization. Semaphore Operations. Handling of Multiple Blocked Semaphore Operations.	940 943 947 948 950 951 961 963 965 966 969 969 972 978
46.1 46.2 46.3 46.4 46.5 46.6 46.7 46.8 46.9 46.10 46.11 47.1 47.2 47.3 47.4 47.5 47.6 47.7	Exchanging Messages 46.2.1 Sending Messages. 46.2.2 Receiving Messages. Message Queue Control Operations. Message Queue Associated Data Structure Message Queue Limits Displaying All Message Queues on the System Client-Server Programming with Message Queues A File-Server Application Using Message Queues Disadvantages of System V Message Queues Summary. Exercises. SYSTEM V SEMAPHORES Overview Creating or Opening a Semaphore Set. Semaphore Control Operations. Semaphore Associated Data Structure. Semaphore Initialization. Semaphore Operations	940 943 947 948 950 951 963 965 966 969 969 972 978 986

47.10	Semaphore Li	imits	991
47.11	Disadvantage	es of System V Semaphores	993
47.12	Summary		993
47.13	Exercises		994
48	SYSTEM V	SHARED MEMORY	997
48.1 48.2		D	
48.2		Dpening a Shared Memory Segment	
48.4		Memory	
48.5		nsferring Data via Shared Memory	
48.6		hared Memory in Virtual Memory	
48.7		ers in Shared Memoryory Control Operations	
48.8		ory Associated Data Structure	
48.9		ory Limits	
48.10		OI Y LIIIIIS	
48.11			
40.11	LXercises		. 1010
49	MEMORY	MAPPINGS	1017
49.1	Overview		. 1017
49.2		lapping: mmap()	
49.3		Mapped Region: $munmap()$	
49.4		S	
	49.4.1	Private File Mappings	
	49.4.2	Shared File Mappings	
	49.4.3	Boundary Cases	
	49.4.4	Memory Protection and File Access Mode Interactions	
49.5	Synchronizing	g a Mapped Region: msync()	
49.6		map() Flags	
49.7		Mappings	
49.8		Mapped Region: mremap()	
49.9		E and Swap Space Overcommitting	
49.10		D Flag	
49.11		appings: remap_file_pages()	
49.12	Summary		. 1043
49.13	,		
50	VIRTUAL A	MEMORY OPERATIONS	1045
50.1		emory Protection: mprotect()	
50.1		sing: $mlock()$ and $mlockall()$	
50.2			
50.3		Memory Residence: mincore()	
50.4			
50.5			
50.0	LXercises		. 1036
51	INTRODUC	CTION TO POSIX IPC	1057
_			
51.1		/	
51.2		of System V IPC and POSIX IPC	
51.3	Summary		. 1062

52	POSIX ME	ESSAGE QUEUES	1063
52.1	Overview		1064
52.2	Opening, Cl	osing, and Unlinking a Message Queue	1064
52.3		Between Descriptors and Message Queues	
52.4		ueue Attributes	
52.5		Messages	
	52.5.1	Sending Messages	
	52.5.2	Receiving Messages	
	52.5.3	Sending and Receiving Messages with a Timeout	
52.6		otification	
32.0	52.6.1	Receiving Notification via a Signal	
	52.6.2	Receiving Notification via a Thread	
52.7		c Features	
52.8		veue Limits	
52.9		of POSIX and System V Message Queues	
52.10			
52.11			
53	POSIX SE	MAPHORES	1089
53.1	Overview		1089
53.2	Named Sem	aphores	1090
	53.2.1	Opening a Named Semaphore	
	53.2.2	Closing a Semaphore	1093
	53.2.3	Removing a Named Semaphore	
53.3	Semaphore (Operations	1094
	53.3.1	Waiting on a Semaphore	
	53.3.2	Posting a Semaphore	
	53.3.3	Retrieving the Current Value of a Semaphore	
53.4	Unnamed Se	emaphores	
	53.4.1	Initializing an Unnamed Semaphore	
	53.4.2	Destroying an Unnamed Semaphore	
53.5	Comparisons	s with Other Synchronization Techniques	
53.6		Limits	
53.7			
53.8			
54		ARED MEMORY	1107
54.1			
54.2	Creating Sho	ared Memory Objects	1109
54.3	Using Shared	d Memory Objects	1112
54.4		nared Memory Objects	
54.5		s Between Shared Memory APIs	
54.6	Summary		1116
54.7	Exercise		1116
5.5	FILE LOCK	(INC	1117
55			1117
55.1	Overview		111 <i>7</i>
55.2		with flock()	
	55.2.1	Semantics of Lock Inheritance and Release	
	55.2.2	Limitations of $flock()$	1123

55.3	Record Locking with fcntl()	1128
	55.3.2 Example: An Interactive Locking Program	
	55.3.3 Example: A Library of Locking Functions	
	55.3.4 Lock Limits and Performance	1135
	55.3.5 Semantics of Lock Inheritance and Release	
	55.3.6 Lock Starvation and Priority of Queued Lock Requests	
55.4	Mandatory Locking	
55.5	The /proc/locks File	
55.6	Running Just One Instance of a Program	
55.7	Older Locking Techniques	
55.8	Summary	
55.9	Exercises	1147
56	SOCKETS: INTRODUCTION	1149
56.1	Overview	1150
56.2	Creating a Socket: socket()	
56.3	Binding a Socket to an Address: bind()	
56.4	Generic Socket Address Structures: struct sockaddr	
56.5	Stream Sockets	
00.0	56.5.1 Listening for Incoming Connections: <i>listen()</i>	
	56.5.2 Accepting a Connection: accept()	
	56.5.3 Connecting to a Peer Socket: connect()	
	56.5.4 I/O on Stream Sockets	
	56.5.5 Connection Termination: close()	
56.6	Datagram Sockets	
00.0	56.6.1 Exchanging Datagrams: recvfrom() and sendto()	
	56.6.2 Using <i>connect()</i> with Datagram Sockets	
56.7	Summary	
57	SOCKETS: UNIX DOMAIN	1165
57.1	UNIX Domain Socket Addresses: struct sockaddr_un	
57.2	Stream Sockets in the UNIX Domain	
57.3	Datagram Sockets in the UNIX Domain	
57.4	UNIX Domain Socket Permissions	
57.5	Creating a Connected Socket Pair: socketpair()	
57.6	The Linux Abstract Socket Namespace	
57.7	Summary	
57.8	Exercises	1177
58	SOCKETS: FUNDAMENTALS OF TCP/IP NETWORKS	1179
58.1	Internets	1170
58.2	Networking Protocols and Layers	
58.3	The Data-Link Layer	
58.4	The Network Layer: IP	
58.5	IP Addresses	
58.6	The Transport Layer	
50.0	• •	
	58.6.1 Port Numbers	
	58.6.3 Transmission Control Protocol (TCP)	
58.7	Requests for Comments (RFCs)	
58.8	Summary	
JU.U	QUIIIIIQI V	1 7.1

59	SOCKETS: INTERNET DOMAINS	1197
59.1	Internet Domain Sockets	. 1197
59.2	Network Byte Order	
59.3	Data Representation	
59.4	Internet Socket Addresses	
59.5	Overview of Host and Service Conversion Functions	. 1204
59.6	The inet_pton() and inet_ntop() Functions	. 1206
59.7	Client-Server Example (Datagram Sockets)	. 1207
59.8	Domain Name System (DNS)	. 1209
59.9	The /etc/services File	
59.10	Protocol-Independent Host and Service Conversion	
	59.10.1 The getaddrinfo() Function	. 1213
	59.10.2 Freeing addrinfo Lists: freeaddrinfo()	
	59.10.3 Diagnosing Errors: gai_strerror()	
	59.10.4 The getnameinfo() Function	
59.11	Client-Server Example (Stream Sockets)	
	An Internet Domain Sockets Library	. 1225
59.13	Obsolete APIs for Host and Service Conversions	
	59.13.1 The inet_aton() and inet_ntoa() Functions	
	59.13.2 The gethostbyname() and gethostbyaddr() Functions	
50.14	59.13.3 The getservbyname() and getservbyport() Functions	. 1234
59.14	UNIX Versus Internet Domain Sockets	
	Further Information	
	Summary	
37.17	LXEICISES	. 1230
60		1239
60.1	Iterative and Concurrent Servers	
60.2	An Iterative UDP echo Server	
60.3	A Concurrent TCP echo Server	
60.4	Other Concurrent Server Designs	
60.5	The inetd (Internet Superserver) Daemon	
60.6	Summary	
60.7	Exercises	. 1252
61		1253
61.1	Partial Reads and Writes on Stream Sockets	
61.2	The shutdown() System Call	
61.3	Socket-Specific I/O System Calls: recv() and send()	
61.4	The sendfile() System Call	
61.5	Retrieving Socket Addresses	
61.6	A Closer Look at TCP	
	61.6.1 Format of a TCP Segment	
	61.6.2 TCP Sequence Numbers and Acknowledgements	
	61.6.3 TCP State Machine and State Transition Diagram	1209
	61.6.5 TCP Connection Termination	
	61.6.7 The TIME_WAIT State	
61.7	Monitoring Sockets: netstat	
61.8	Using tcpdump to Monitor TCP Traffic	
61.9	Socket Options	
61.10	The SO REUSEADDR Socket Option.	
61 11	Inheritance of Flags and Options Across accept()	1281

	TCP Versus UDP	
61.13	Advanced Features	
	61.13.1 Out-of-Band Data	
	61.13.2 The sendmsg() and recomsg() System Calls	
	61.13.3 Passing File Descriptors	
	61.13.4 Receiving Sender Credentials	
	61.13.5 Sequenced-Packet Sockets	
	61.13.6 SCTP and DCCP Transport-Layer Protocols	
	Summary	
61.15	Exercises	1287
62	TERMINALS	1289
62.1	Overview	1200
62.1	Retrieving and Modifying Terminal Attributes	
62.3	The stty Command	
62.3	Terminal Special Characters	
62.4 62.5	Terminal Special Characters Terminal Flags	
62.6	Terminal I/O Modes	
02.0	62.6.1 Canonical Mode.	
	62.6.2 Noncanonical Mode	
62.7		
62.7 62.8	Terminal Line Speed (Bit Rate)	
62.6 62.9	Terminal Line Control Terminal Window Size	
62.10		
62.10	Terminal Identification	
	Summary Exercises	
63	ALTERNATIVE I/O MODELS	1325
63.1	Overview	1325
00.1	63.1.1 Level-Triggered and Edge-Triggered Notification	1329
	63.1.2 Employing Nonblocking I/O with Alternative I/O Models	
63.2	I/O Multiplexing	
00.2	63.2.1 The select() System Call	
	63.2.2 The poll() System Call	1337
	63.2.2 The <i>poll()</i> System Call	133 <i>7</i> 1341
	 63.2.2 The poll() System Call	133 <i>7</i> 1341 1344
63 3	 63.2.2 The poll() System Call 63.2.3 When Is a File Descriptor Ready? 63.2.4 Comparison of select() and poll() 63.2.5 Problems with select() and poll() 	1337 1341 1344 1346
63.3	63.2.2 The poll() System Call 63.2.3 When Is a File Descriptor Ready? 63.2.4 Comparison of select() and poll() 63.2.5 Problems with select() and poll() Signal-Driven I/O	
63.3	63.2.2 The poll() System Call 63.2.3 When Is a File Descriptor Ready? 63.2.4 Comparison of select() and poll() 63.2.5 Problems with select() and poll(). Signal-Driven I/O. 63.3.1 When Is "I/O Possible" Signaled?	
	63.2.2 The poll() System Call 63.2.3 When Is a File Descriptor Ready? 63.2.4 Comparison of select() and poll() 63.2.5 Problems with select() and poll(). Signal-Driven I/O. 63.3.1 When Is "I/O Possible" Signaled? 63.3.2 Refining the Use of Signal-Driven I/O.	
63.3 63.4	63.2.2 The poll() System Call 63.2.3 When Is a File Descriptor Ready? 63.2.4 Comparison of select() and poll() 63.2.5 Problems with select() and poll(). Signal-Driven I/O. 63.3.1 When Is "I/O Possible" Signaled? 63.3.2 Refining the Use of Signal-Driven I/O. The epoll API.	
	63.2.2 The poll() System Call 63.2.3 When Is a File Descriptor Ready? 63.2.4 Comparison of select() and poll() 63.2.5 Problems with select() and poll(). Signal-Driven I/O. 63.3.1 When Is "I/O Possible" Signaled? 63.3.2 Refining the Use of Signal-Driven I/O. The epoll API. 63.4.1 Creating an epoll Instance: epoll_create().	
	63.2.2 The poll() System Call 63.2.3 When Is a File Descriptor Ready? 63.2.4 Comparison of select() and poll() 63.2.5 Problems with select() and poll(). Signal-Driven I/O. 63.3.1 When Is "I/O Possible" Signaled? 63.3.2 Refining the Use of Signal-Driven I/O. The epoll API. 63.4.1 Creating an epoll Instance: epoll_create() 63.4.2 Modifying the epoll Interest List: epoll_ctl()	
	63.2.2 The poll() System Call 63.2.3 When Is a File Descriptor Ready? 63.2.4 Comparison of select() and poll() 63.2.5 Problems with select() and poll(). Signal-Driven I/O. 63.3.1 When Is "I/O Possible" Signaled? 63.3.2 Refining the Use of Signal-Driven I/O. The epoll API. 63.4.1 Creating an epoll Instance: epoll_create() 63.4.2 Modifying the epoll Interest List: epoll_ctl() 63.4.3 Waiting for Events: epoll_wait().	
	63.2.2 The poll() System Call 63.2.3 When Is a File Descriptor Ready? 63.2.4 Comparison of select() and poll() 63.2.5 Problems with select() and poll(). Signal-Driven I/O. 63.3.1 When Is "I/O Possible" Signaled? 63.3.2 Refining the Use of Signal-Driven I/O. The epoll API. 63.4.1 Creating an epoll Instance: epoll_create() 63.4.2 Modifying the epoll Interest List: epoll_ctl() 63.4.3 Waiting for Events: epoll_wait() 63.4.4 A Closer Look at epoll Semantics	
	63.2.2 The poll() System Call 63.2.3 When Is a File Descriptor Ready? 63.2.4 Comparison of select() and poll() 63.2.5 Problems with select() and poll(). Signal-Driven I/O 63.3.1 When Is "I/O Possible" Signaled? 63.3.2 Refining the Use of Signal-Driven I/O. The epoll API 63.4.1 Creating an epoll Instance: epoll_create(). 63.4.2 Modifying the epoll Interest List: epoll_ctl(). 63.4.3 Waiting for Events: epoll_wait(). 63.4.4 A Closer Look at epoll Semantics. 63.4.5 Performance of epoll Versus I/O Multiplexing.	
63.4	63.2.2 The poll() System Call 63.2.3 When Is a File Descriptor Ready? 63.2.4 Comparison of select() and poll() 63.2.5 Problems with select() and poll(). Signal-Driven I/O 63.3.1 When Is "I/O Possible" Signaled? 63.3.2 Refining the Use of Signal-Driven I/O. The epoll API 63.4.1 Creating an epoll Instance: epoll_create(). 63.4.2 Modifying the epoll Interest List: epoll_ctl(). 63.4.3 Waiting for Events: epoll_wait(). 63.4.4 A Closer Look at epoll Semantics. 63.4.5 Performance of epoll Versus I/O Multiplexing. 63.4.6 Edge-Triggered Notification	
	63.2.2 The poll() System Call 63.2.3 When Is a File Descriptor Ready? 63.2.4 Comparison of select() and poll() 63.2.5 Problems with select() and poll(). Signal-Driven I/O 63.3.1 When Is "I/O Possible" Signaled? 63.3.2 Refining the Use of Signal-Driven I/O The epoll API 63.4.1 Creating an epoll Instance: epoll_create(). 63.4.2 Modifying the epoll Interest List: epoll_ctl(). 63.4.3 Waiting for Events: epoll_wait(). 63.4.4 A Closer Look at epoll Semantics 63.4.5 Performance of epoll Versus I/O Multiplexing. 63.4.6 Edge-Triggered Notification Waiting on Signals and File Descriptors.	
63.4	63.2.2 The poll() System Call 63.2.3 When Is a File Descriptor Ready? 63.2.4 Comparison of select() and poll() 63.2.5 Problems with select() and poll(). Signal-Driven I/O. 63.3.1 When Is "I/O Possible" Signaled? 63.3.2 Refining the Use of Signal-Driven I/O. The epoll API. 63.4.1 Creating an epoll Instance: epoll_create() 63.4.2 Modifying the epoll Interest List: epoll_ctl() 63.4.3 Waiting for Events: epoll_wait() 63.4.4 A Closer Look at epoll Semantics 63.4.5 Performance of epoll Versus I/O Multiplexing. 63.4.6 Edge-Triggered Notification Waiting on Signals and File Descriptors. 63.5.1 The pselect() System Call	
63.4 63.5	63.2.2 The poll() System Call 63.2.3 When Is a File Descriptor Ready? 63.2.4 Comparison of select() and poll() 63.2.5 Problems with select() and poll(). Signal-Driven I/O. 63.3.1 When Is "I/O Possible" Signaled? 63.3.2 Refining the Use of Signal-Driven I/O. The epoll API. 63.4.1 Creating an epoll Instance: epoll_create() 63.4.2 Modifying the epoll Interest List: epoll_ctl() 63.4.3 Waiting for Events: epoll_wait() 63.4.4 A Closer Look at epoll Versus I/O Multiplexing. 63.4.5 Performance of epoll Versus I/O Multiplexing. 63.4.6 Edge-Triggered Notification Waiting on Signals and File Descriptors. 63.5.1 The pselect() System Call. 63.5.2 The Self-Pipe Trick.	
63.4	63.2.2 The poll() System Call 63.2.3 When Is a File Descriptor Ready? 63.2.4 Comparison of select() and poll() 63.2.5 Problems with select() and poll(). Signal-Driven I/O. 63.3.1 When Is "I/O Possible" Signaled? 63.3.2 Refining the Use of Signal-Driven I/O. The epoll API. 63.4.1 Creating an epoll Instance: epoll_create() 63.4.2 Modifying the epoll Interest List: epoll_ctl() 63.4.3 Waiting for Events: epoll_wait() 63.4.4 A Closer Look at epoll Semantics 63.4.5 Performance of epoll Versus I/O Multiplexing. 63.4.6 Edge-Triggered Notification Waiting on Signals and File Descriptors. 63.5.1 The pselect() System Call	

64	PSEUDOTERMINALS	1375
64.1	Overview	1375
64.2	UNIX 98 Pseudoterminals	1380
	64.2.1 Opening an Unused Master: posix_openpt()	1380
	64.2.2 Changing Slave Ownership and Permissions: grantpt()	
	64.2.3 Unlocking the Slave: unlockpt()	
	64.2.4 Obtaining the Name of the Slave: ptsname()	
64.3	Opening a Master: ptyMasterOpen()	
64.4	Connecting Processes with a Pseudoterminal: ptyFork()	1385
64.5	Pseudoterminal I/O	
64.6	Implementing script(1)	
64.7	Terminal Attributes and Window Size	
64.8	BSD Pseudoterminals	1395
64.9	Summary	
64.10		
A	TRACING SYSTEM CALLS	1401
В	PARSING COMMAND-LINE OPTIONS	1405
С	CASTING THE NULL POINTER	1413
D	KERNEL CONFIGURATION	1417
E	FURTHER SOURCES OF INFORMATION	1419
F	SOLUTIONS TO SELECTED EXERCISES	1425
BIBLI	OGRAPHY	1437
INDE	x	1447