



M Beck, H Böhme, M Dziadzka,
U Kunitz, R Magnus, C Schröter, D Verworner

LINUX KERNEL PROGRAMMING

THIRD EDITION

O

i



CD-ROM INCLUDED

Now revised and updated
to cover Linux 2.4

CONTENTS

Preface to the 3rd edition	xi
Preface to the 1st edition	xii
Linus Torvalds' preface to the 1st edition	xiii
Acknowledgments	xiv

CHAPTER 1

1.1 Main characteristics	2
1.2 LINUX distributions	5

CHAPTER 2

2.1 Where is everything?	6
2.2 Compiling	8
2.3 Additional configuration facilities	10

CHAPTER 3

3.1 Important data structures	16
3.1.1 The task structure	16
3.1.2 The process table	24
3.1.3 Files and inodes	25
3.1.4 Dynamic memory management	27
3.1.5 Queues and semaphores	28
3.1.6 System time and timers	30
3.2 Main algorithms	31
3.2.1 Signals	31
3.2.2 Hardware interrupts	32
3.2.3 Software interrupts	33
3.2.4 Booting the system	34
3.2.5 Timer interrupts	36
3.2.6 The scheduler	39
3.3 Implementation of system calls	42
3.3.1 How do system calls actually work?	42
3.3.2 Examples of simple system calls	44
3.3.3 Examples of more complex system calls	45

- 4.1 The architecture-independent memory model 57**
 - 4.1.1 Pages of memory 57
 - 4.1.2 Virtual address space 57
 - 4.1.3 Converting the linear address 59
 - 4.1.4 Page directories 61
 - 4.1.5 The page table 63
- 4.2 The virtual address space of a process 65**
 - 4.2.1 The user segment 65
 - 4.2.2 Virtual memory areas 67
 - 4.2.3 The system call *brk* 70
 - 4.2.4 Mapping functions 71
 - 4.2.5 The kernel segment 71
 - 4.2.6 Memory allocation in the kernel segment during booting 72
 - 4.2.7 Dynamic memory management in the kernel segment 72
- 4.3 Block device caching 75**
 - 4.3.1 Block buffering 75
 - 4.3.2 *Bdflush* and *kupdate* 77
 - 4.3.3 List structures for the buffer cache 78
 - 4.3.4 Using the buffer cache 79
- 4.4 Paging under LINUX 80**
 - 4.4.1 Memory management and the memory cache 82
 - 4.4.2 Reserving a page of memory 84
 - 4.4.3 Optimization of memory page management via kernel threads 87
 - 4.4.4 Page errors and reloading a page 88

- 5.1 Synchronization in the kernel 92**
- 5.2 Communication via files 97**
 - 5.2.1 Locking entire files 98
 - 5.2.2 Locking file areas 99
- 5.3 Pipes 103**
- 5.4 Debugging using *ptrace* 105**
- 5.5 System V IPC 108**
 - 5.5.1 Access rights, numbers, and keys 109
 - 5.5.2 Semaphores 110
 - 5.5.3 Message queues 114
 - 5.5.4 Shared memory 117
 - 5.5.5 The *1pcs* and *1pcrm* commands 120

5.6 IPC with sockets 121

5.6.1 A simple example 122

5.6.2 The implemetation of UNIX domain sockets 126

CHAPTER 6

6.1 Basic principles 130

6.2 The representation of file systems in the kernel 132

6.2.1 Mounting 134

6.2.2 The superblock 134

6.2.3 Superblock operations 136

6.2.4 The directory cache 139

6.2.5 DEntry operations 141

6.2.6 The inode 142

6.2.7 Inode operations 144

6.2.8 The file structure 147

6.2.9 File operations 148

6.2.10 Opening a file 152

6.3 The *Ext2* file system 156

6.3.1 The structure of the *Ext2* file system 156

6.3.2 Directories in the *Ext2* file system 159

6.3.3 Block allocation in the *Ext2* file system 160

6.3.4 Extensions of the *Ext2* file system 161

6.4 The *Proc* file system 162

6.4.1 Structures of the *Proc* file system 163

6.4.2 Implementation of the *Proc* file system 164

CHAPTER 7

7.1 Character and block devices 171

7.2 Hardware 172

7.2.1 Port I/O 172

7.2.2 The PCI bus 173

7.2.3 The dinosaur – the ISA bus 184

7.2.4 ISA-PnP 193

7.3 Polling, interrupts, and waiting queues 198

7.3.1 Polling 199

7.3.2 Interrupt mode 200

7.3.3 Interrupt sharing 201

7.3.4 Software interrupts 202

7.3.5 Bottom halves – the lower interrupt halves 203

7.3.6 Task queues 204

7.3.7 Timers 206

7.4 Implementing a driver 207

7.4.1 Example of a PC loudspeaker driver 207

7.4.2 A simple driver 210

7.4.3 The setup function 212

7.4.4 Init 213

7.4.5 Open and release 215

7.4.6 Read and write 216

7.4.7 IOCTL 219

7.4.8 Poll 221

7.4.9 Lseek 223

7.4.10 Mmap 223

7.4.11 Fasync 225

7.4.12 Readdir, Fsync 228

7.5 Dynamic and static drivers 228

CHAPTER 8

8.1 Introduction and overview 231

8.1.1 The layer model of the network implementation 232

8.1.2 Getting the data from A to B 232

8.2 Important structures 236

8.2.1 The socket structure 236

8.2.2 The sk_buff structure – buffer management in the network 238

8.2.3 The INET socket – a special part of the socket 241

8.2.4 Protocol operations in the proto structure 246

8.2.5 The general structure of a socket address 248

8.3 Network devices under LINUX 248

8.3.1 Ethernet 255

8.3.2 SLIP and PLIP 256

8.3.3 The loopback device 257

8.3.4 The dummy device 257

8.3.5 An example device 257

CHAPTER 9

9.1 What are modules? 261

9.2 Implementation in the kernel 262

9.2.1 Signatures of symbols 264

9.3 The meaning of object sections for modules and kernels 264

9.4 Parameter transfer and examples 267

9.5 What can be implemented as a module? 268

9.6 The kernel daemon 270

9.7 Simple data swapping between modules	270
9.8 An example module	271
9.9 Debugging	272
9.9.1 Changes are the beginning of the end	272
9.9.2 The best debugger – <code>printf()</code>	273
9.9.3 Debugging with <code>gdb</code>	274

CHAPTER 10

10.1 The Intel multiprocessor specification	276
10.2 Problems with multiprocessor systems	277
10.3 Changes to the kernel	278
10.3.1 Kernel initialization	278
10.3.2 Scheduling	279
10.3.3 Interrupt handling	279
10.4 Atomic operations	279
10.4.1 The atomic data type	280
10.4.2 Accessing the atomic data type	280
10.4.3 Changing and testing atomic variables	280
10.5 Spin locks	281
10.5.1 Access functions	281
10.5.2 Read-write spin locks	282

APPENDIX A

SYSTEM CALLS	283
A.1 Process management	284
A.2 The file system	329
A.3 Communication	362
A.4 Memory management	365
A.5 All that remains	371

APPENDIX B

RELATED COMMANDS	373
B.1 <code>free</code> – overview of the system's memory	373
B.2 <code>ps</code> – output of process statistics	374
B.3 <code>top</code> – the CPU charts	378
B.4 <code>init</code> – primus inter pares	380
B.5 <code>shutdown</code> – shutting down the system	388
B.6 <code>strace</code> – monitoring a process	389
B.7 Configuring the network interface	392
B.8 <code>traceroute</code> – Ariadne's paths in the internet	393
B.9 Configuring a serial interface	395

B.10 Configuring a parallel interface 397

B.11 Building a directory tree 398

APPENDIX C

THE /PROC/ SYSTEM 403

C.1 The /PROC/ directory 406

C.2 The NET/ directory 414

C.3 The SELF/ directory 416

C.4 The SYS/ directory 420

APPENDIX D

CARRYING OUT THE BOOTING PROCESS 423

D.1 Carrying out the booting process 423

D.2 LILO – the LINUX loader 425

APPENDIX E

USEFUL KERNEL FUNCTIONS 434

REFERENCES 449

INDEX 455