

# Table of Contents

|   |           |
|---|-----------|
| <b>Preface</b> .....                              | <b>xi</b> |
| <b>1. An Introduction to Device Drivers</b> ..... | <b>1</b>  |
| The Role of the Device Driver                     | 2         |
| Splitting the Kernel                              | 4         |
| Classes of Devices and Modules                    | 5         |
| Security Issues                                   | 8         |
| Version Numbering                                 | 10        |
| License Terms                                     | 11        |
| Joining the Kernel Development Community          | 12        |
| Overview of the Book                              | 12        |
| <b>2. Building and Running Modules</b> .....      | <b>15</b> |
| Setting Up Your Test System                       | 15        |
| The Hello World Module                            | 16        |
| Kernel Modules Versus Applications                | 18        |
| Compiling and Loading                             | 22        |
| The Kernel Symbol Table                           | 28        |
| Preliminaries                                     | 30        |
| Initialization and Shutdown                       | 31        |
| Module Parameters                                 | 35        |
| Doing It in User Space                            | 37        |
| Quick Reference                                   | 39        |
| <b>3. Char Drivers</b> .....                      | <b>42</b> |
| The Design of scull                               | 42        |
| Major and Minor Numbers                           | 43        |
| Some Important Data Structures                    | 49        |

|   |            |
|---|------------|
| Char Device Registration                  | 55         |
| open and release                          | 58         |
| scull's Memory Usage                      | 60         |
| read and write                            | 63         |
| Playing with the New Devices              | 70         |
| Quick Reference                           | 70         |
| <b>4. Debugging Techniques</b>            | <b>73</b>  |
| Debugging Support in the Kernel           | 73         |
| Debugging by Printing                     | 75         |
| Debugging by Querying                     | 82         |
| Debugging by Watching                     | 91         |
| Debugging System Faults                   | 93         |
| Debuggers and Related Tools               | 99         |
| <b>5. Concurrency and Race Conditions</b> | <b>106</b> |
| Pitfalls in scull                         | 107        |
| Concurrency and Its Management            | 107        |
| Semaphores and Mutexes                    | 109        |
| Completions                               | 114        |
| Spinlocks                                 | 116        |
| Locking Traps                             | 121        |
| Alternatives to Locking                   | 123        |
| Quick Reference                           | 130        |
| <b>6. Advanced Char Driver Operations</b> | <b>135</b> |
| ioctl                                     | 135        |
| Blocking I/O                              | 147        |
| poll and select                           | 163        |
| Asynchronous Notification                 | 169        |
| Seeking a Device                          | 171        |
| Access Control on a Device File           | 173        |
| Quick Reference                           | 179        |
| <b>7. Time, Delays, and Deferred Work</b> | <b>183</b> |
| Measuring Time Lapses                     | 183        |
| Knowing the Current Time                  | 188        |
| Delaying Execution                        | 190        |
| Kernel Timers                             | 196        |
| Tasklets                                  | 202        |

|  |            |
|--|------------|
| Workqueues                               | 205        |
| Quick Reference                          | 208        |
| <b>8. Allocating Memory</b>              | <b>213</b> |
| The Real Story of kmalloc                | 213        |
| Lookaside Caches                         | 217        |
| get_free_page and Friends                | 221        |
| vmalloc and Friends                      | 224        |
| Per-CPU Variables                        | 228        |
| Obtaining Large Buffers                  | 230        |
| Quick Reference                          | 231        |
| <b>9. Communicating with Hardware</b>    | <b>235</b> |
| I/O Ports and I/O Memory                 | 235        |
| Using I/O Ports                          | 239        |
| An I/O Port Example                      | 245        |
| Using I/O Memory                         | 248        |
| Quick Reference                          | 255        |
| <b>10. Interrupt Handling</b>            | <b>258</b> |
| Preparing the Parallel Port              | 259        |
| Installing an Interrupt Handler          | 259        |
| Implementing a Handler                   | 269        |
| Top and Bottom Halves                    | 275        |
| Interrupt Sharing                        | 278        |
| Interrupt-Driven I/O                     | 281        |
| Quick Reference                          | 286        |
| <b>11. Data Types in the Kernel</b>      | <b>288</b> |
| Use of Standard C Types                  | 288        |
| Assigning an Explicit Size to Data Items | 290        |
| Interface-Specific Types                 | 291        |
| Other Portability Issues                 | 292        |
| Linked Lists                             | 295        |
| Quick Reference                          | 299        |
| <b>12. PCI Drivers</b>                   | <b>302</b> |
| The PCI Interface                        | 302        |
| A Look Back: ISA                         | 319        |
| PC/104 and PC/104+                       | 322        |

|                                   |            |
|-----------------------------------|------------|
| Other PC Buses                    | 322        |
| SBus                              | 323        |
| NuBus                             | 324        |
| External Buses                    | 325        |
| Quick Reference                   | 325        |
| <b>13. USB Drivers</b>            | <b>327</b> |
| USB Device Basics                 | 328        |
| USB and Sysfs                     | 333        |
| USB Urbs                          | 335        |
| Writing a USB Driver              | 346        |
| USB Transfers Without Urbs        | 356        |
| Quick Reference                   | 360        |
| <b>14. The Linux Device Model</b> | <b>362</b> |
| Kobjects, Ksets, and Subsystems   | 364        |
| Low-Level Sysfs Operations        | 371        |
| Hotplug Event Generation          | 375        |
| Buses, Devices, and Drivers       | 377        |
| Classes                           | 387        |
| Putting It All Together           | 391        |
| Hotplug                           | 397        |
| Dealing with Firmware             | 405        |
| Quick Reference                   | 407        |
| <b>15. Memory Mapping and DMA</b> | <b>412</b> |
| Memory Management in Linux        | 412        |
| The mmap Device Operation         | 422        |
| Performing Direct I/O             | 435        |
| Direct Memory Access              | 440        |
| Quick Reference                   | 459        |
| <b>16. Block Drivers</b>          | <b>464</b> |
| Registration                      | 465        |
| The Block Device Operations       | 471        |
| Request Processing                | 474        |
| Some Other Details                | 491        |
| Quick Reference                   | 494        |

|  |            |
|--|------------|
| <b>17. Network Drivers</b>             | <b>497</b> |
| How snull Is Designed                  | 498        |
| Connecting to the Kernel               | 502        |
| The net_device Structure in Detail     | 506        |
| Opening and Closing                    | 515        |
| Packet Transmission                    | 516        |
| Packet Reception                       | 521        |
| The Interrupt Handler                  | 523        |
| Receive Interrupt Mitigation           | 525        |
| Changes in Link State                  | 528        |
| The Socket Buffers                     | 528        |
| MAC Address Resolution                 | 532        |
| Custom ioctl Commands                  | 535        |
| Statistical Information                | 536        |
| Multicast                              | 537        |
| A Few Other Details                    | 540        |
| Quick Reference                        | 542        |
| <b>18. TTY Drivers</b>                 | <b>546</b> |
| A Small TTY Driver                     | 548        |
| tty_driver Function Pointers           | 553        |
| TTY Line Settings                      | 560        |
| ioctls                                 | 564        |
| proc and sysfs Handling of TTY Devices | 566        |
| The tty_driver Structure in Detail     | 567        |
| The tty_operations Structure in Detail | 569        |
| The tty_struct Structure in Detail     | 571        |
| Quick Reference                        | 573        |
| <b>Bibliography</b>                    | <b>575</b> |
| <b>Index</b>                           | <b>579</b> |

