

# Structured Linux Kernel Projects for Teaching Operating Systems Concepts

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## ABSTRACT

Linux has emerged as a widely-used platform for enabling hands-on kernel programming experience to learn about operating system concepts. However, developing pedagogically-effective programming projects in the context of a complex, production operating system can be a challenge. We present a structured series of five Linux kernel programming projects suitable for a one semester introductory operating systems course to address this issue. Each assignment introduces students to a core topic and major component of an operating system while implicitly teaching them about various aspects of a real-world operating system. Projects are of modest coding complexity, but require students to understand and leverage core components of the Linux operating system. The learning benefits for students from this approach include learning from real-world operating systems code examples by expert kernel designers and gaining software engineering experience managing production code complexity. We have successfully used these structured Linux kernel projects to teach over a thousand students in the introductory operating systems course at Columbia University.

## Categories and Subject Descriptors

D.4.0 [Operating Systems]: General; K.3.2 [Computers and Education]: Computer and Information Science Education—computer science education

## General Terms

Design, Experimentation, Human Factors

## Keywords

Operating systems, computer science education, open-source

## 1. INTRODUCTION

Kernel programming projects provide crucial hands-on experience for helping students to understand operating system concepts. Linux has emerged as a widely-used platform

for teaching operating systems concepts because of its many advantages. Its open-source software base and widely available development tools make it easy for students to access its internals. It provides students the ability to explore a real production operating system, not just a toy system, thereby also enhancing skills that can be immediately applied in the workforce after graduation. It is already maintained by real developers for real users, so there is no need to invest any effort maintaining a separate pedagogical operating system. It provides real code examples by real developers for students to learn from by example.

However, developing effective programming projects that teach students systematically about real-world operating system design and implementation in the context of a production operating system can be a challenge. Production operating systems are large, complex pieces of software. To gain a broad understanding of operating systems, it is useful to have hands-on experience with several different major components of an operating system. However, the sheer size of these systems makes them difficult to understand. It may be tempting to create projects that only touch on fringe aspects of a production operating system to avoid its complexity. However, fringe projects do not provide the opportunity to learn about the core functionality of the kernel. Production operating systems are also not primarily designed as teaching tools, but instead to be used in commercial deployment. Such operating systems are already fully functional and do not have major missing subsystems that students can design and implement. Redesigning several major subsystems of a production kernel may also not be feasible in the time constraints of a course.

We present our efforts at Columbia University over the past decade to leverage the benefits of Linux and address the challenges of designing kernel programming projects that provide educational value for an operating systems course. We have developed a structured series of five Linux kernel programming projects that expose students to core components of a production operating system with modest coding complexity. These projects start with the basics of writing system calls and understanding the structure of processes, progress into synchronization which is necessary for understanding other aspects of operating system design and implementation, then explore three core operating system components in processor scheduling, virtual memory, and file systems.

Our projects are designed to require students to read and understand core components of the operating system, to make the modifications necessary to complete the projects. At

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# Solution Manual For Kernel Projects For Linux

**Pierre-Jean Texier, Petter Mabacker**

## **Solution Manual For Kernel Projects For Linux:**

**Building Embedded Systems** Changyi Gu,2016-05-26 Develop the software and hardware you never think about We're talking about the nitty gritty behind the buttons on your microwave inside your thermostat inside the keyboard used to type this description and even running the monitor on which you are reading it now Such stuff is termed embedded systems and this book shows how to design and develop embedded systems at a professional level Because yes many people quietly make a successful career doing just that Building embedded systems can be both fun and intimidating Putting together an embedded system requires skill sets from multiple engineering disciplines from software and hardware in particular Building Embedded Systems is a book about helping you do things in the right way from the beginning of your first project Programmers who know software will learn what they need to know about hardware Engineers with hardware knowledge likewise will learn about the software side Whatever your background is Building Embedded Systems is the perfect book to fill in any knowledge gaps and get you started in a career programming for everyday devices Author Changyi Gu brings more than fifteen years of experience in working his way up the ladder in the field of embedded systems He brings knowledge of numerous approaches to embedded systems design including the System on Programmable Chips SOPC approach that is currently growing to dominate the field His knowledge and experience make Building Embedded Systems an excellent book for anyone wanting to enter the field or even just to do some embedded programming as a side project What You Will Learn Program embedded systems at the hardware level Learn current industry practices in firmware development Develop practical knowledge of embedded hardware options Create tight integration between software and hardware Practice a work flow leading to successful outcomes Build from transistor level to the system level Make sound choices between performance and cost Who This Book Is For Embedded system engineers and intermediate electronics enthusiasts who are seeking tighter integration between software and hardware Those who favor the System on a Programmable Chip SOPC approach will in particular benefit from this book Students in both Electrical Engineering and Computer Science can also benefit from this book and the real life industry practice it provides

**Computer and Information Security Handbook** John R. Vacca,2012-11-05 The second edition of this comprehensive handbook of computer and information security provides the most complete view of computer security and privacy available It offers in depth coverage of security theory technology and practice as they relate to established technologies as well as recent advances It explores practical solutions to many security issues Individual chapters are authored by leading experts in the field and address the immediate and long term challenges in the authors respective areas of expertise The book is organized into 10 parts comprised of 70 contributed chapters by leading experts in the areas of networking and systems security information management cyber warfare and security encryption technology privacy data storage physical security and a host of advanced security topics New to this edition are chapters on intrusion detection securing the cloud securing web apps ethical hacking cyber forensics physical security

disaster recovery cyber attack deterrence and more Chapters by leaders in the field on theory and practice of computer and information security technology allowing the reader to develop a new level of technical expertise Comprehensive and up to date coverage of security issues allows the reader to remain current and fully informed from multiple viewpoints Presents methods of analysis and problem solving techniques enhancing the reader s grasp of the material and ability to implement practical solutions *Operating System Concepts* Abraham Silberschatz,Peter B. Galvin, Greg Gagne, 2005 This new seventh edition of the book has been brought up to date to include recent developments in operating systems such as Windows XP and the new small footprint operating systems that work in hand held devices such as the Palm and in cell phones Most of the book is on general purpose operating systems such as Linux and those from Microsoft But at the end of the book there are chapters on other types of operating such as Real Time Operating Systems and MultiMedia OS s Finally there are some chapters which the authors call case studies In these one chapter goes into a detailed discussion of Linux another chapter covers Windows XP Chapter 23 covers several early operating systems that helped to define the features that make up modern os s These include Atlas XDX 940 THE RC 4000 CTSS MULTICS OS 360 and MACH along with brief mentions of several others Note that this not a book on how to use operating systems this is a book on how operating systems are designed It is intended for upper level undergraduate students or first year graduate students

### **Understanding**

**Unix/Linux Programming** Bruce Molay, 2003 An accessible yet comprehensive text that clearly explains Unix programming and structuring by addressing the fundamentals of Unix and providing alternative solutions to problems in concrete terms

InfoWorld ,1999-11-15 InfoWorld is targeted to Senior IT professionals Content is segmented into Channels and Topic Centers InfoWorld also celebrates people companies and projects **Building Embedded Linux Systems** Karim Yaghmour, 2003 Linux is being adopted by an increasing number of embedded systems developers who have been won over by its sophisticated scheduling and networking its cost free license its open development model and the support offered by rich and powerful programming tools While there is a great deal of hype surrounding the use of Linux in embedded systems there is not a lot of practical information Building Embedded Linux Systems is the first in depth hard core guide to putting together an embedded system based on the Linux kernel This indispensable book features arcane and previously undocumented procedures for Building your own GNU development toolchain Using an efficient embedded development framework Selecting configuring building and installing a target specific kernel Creating a complete target root filesystem Setting up manipulating and using solid state storage devices Installing and configuring a bootloader for the target Cross compiling a slew of utilities and packages Debugging your embedded system using a plethora of tools and techniques Details are provided for various target architectures and hardware configurations including a thorough review of Linux s support for embedded hardware All explanations rely on the use of open source and free software packages By presenting how to build the operating system components from pristine sources and how to find more documentation or help this book greatly

simplifies the task of keeping complete control over one's embedded operating system whether it be for technical or sound financial reasons. Author Karim Yaghmour, a well known designer and speaker who is responsible for the Linux Trace Toolkit, starts by discussing the strengths and weaknesses of Linux as an embedded operating system. Licensing issues are included, followed by a discussion of the basics of building embedded Linux systems. The configuration, setup and use of over forty different open source and free software packages commonly used in embedded Linux systems are also covered. uClibc, BusyBox, U-Boot, OpenSSH, tftpd, strace and gdb are among the packages discussed.

**Red Hat Linux 9 Unleashed**  
Bill Ball, Hoyt Duff, 2003  
The best, most comprehensive coverage of the leading Linux distribution on the market.

**Yocto for Raspberry Pi**  
Pierre-Jean Texier, Petter Mabacker, 2016-06-29  
Create unique and amazing projects by using the powerful combination of Yocto and Raspberry Pi.

**About This Book**  
Set up and configure the Yocto Project efficiently with Raspberry Pi. Deploy multimedia applications from existing Yocto OE layers. An easy to follow guide to utilize your custom recipes on your Raspberry Pi.

**Who This Book Is For**  
If you are a student or a developer of embedded software, embedded Linux engineer or embedded systems in competence with Raspberry Pi and want to discover the Yocto Project then this book is for you.

**Experience with Yocto**  
Is not needed. **What You Will Learn**  
Explore the basic concept of Yocto's build system and how it is organized in order to use it efficiently with Raspberry Pi. Generate your first image with Yocto for the Raspberry Pi. Understand how to customize your Linux kernel within the Yocto Project. Customize your image in order to integrate your own applications. Write your own recipes for your graphical applications. Integrate a custom layer for the Raspberry Pi.

**In Detail**  
The Yocto Project is a Linux Foundation workgroup which produces tools, SDK and processes configuration compilation installation that will enable the creation of Linux distributions for embedded software independent of the architecture of embedded software. Raspberry Pi, i.MX6 and so on. It is a powerful build system that allows you to master your personal or professional development. This book presents you with the configuration of the Yocto Framework for the Raspberry Pi, allowing you to create amazing and innovative projects using the Yocto OpenEmbedded eco system. It starts with the basic introduction of Yocto's build system and takes you through the setup and deployment steps for Yocto. It then helps you to develop an understanding of Bitbake, the task scheduler and learn how to create a basic recipe through a GPIO application example. You can then explore the different types of Yocto recipe elements: LICENSE, FILES, SRC\_URI and so on. Next you will learn how to customize existing recipes in Yocto OE layers and add layers to your custom environment. For example, Style and approach. A step by step guide covering the fundamentals to create amazing new projects with Raspberry Pi and Yocto.

**Slackware Linux Unleashed**  
Tim Parker, 1997  
This book CD ROM package will get the reader instantly working on the popular 32 bit Slackware implementation of the UNIX operating system. This third edition follows in the tradition of the highly successful first two versions and includes all the latest features of Slackware Linux.

**Electronic Design**, 2001

**Ubuntu: The Complete Reference**  
Richard Petersen, 2008-09-14  
The Definitive Guide to Ubuntu. Covers Ubuntu 8.04

LTS Maximize the powerful features of Ubuntu with expert guidance tips and techniques from bestselling Linux author Richard Petersen Packed with clear explanations and detailed examples this comprehensive volume shows you how to get off the ground with Ubuntu set up hardware and Internet connections and use the latest system and network administration utilities Ubuntu The Complete Reference covers the desktops shells and administration tools for users printers services and networks Get full details on the latest Ubuntu compatible office mail Web and multimedia software along with remote access Vinagre virtualization KVM and Xen and service management Upstart You'll also learn how to interoperate with Windows networks and deploy reliable security using PolicyKit Seahorse AppArmor SELinux netfilter and the Secure Shell Install Ubuntu using Live CDs the Install DVD or Wubi Windows virtual disk Configure printers devices and network connections Access Linux using GNOME KDE KDE4 and XFce desktops Manage software with Synaptic Package Manager and APT Work with the BASH shell command configuration and file management capabilities Use office Web Firefox 3 mail and multimedia applications PulseAudio Manage file systems including RAID and LVM Secure Ubuntu using PolicyKit authentication Seahorse encryption SSH and Kerberos security AppArmor access controls and Firestarter and UFW firewalls Use SAMBA and NFS to share network resources

*Linux Journal*, 2005-07 **Running Linux** Matt Welsh, Lar Kaufman, 1995 A guide showing users and programmers how to install, maintain and network Linux, a free clone of the UNIX operating system that runs on a personal computer. Includes a short introduction to UNIX, a discussion of system administration and network administration tools users need to run the system and complete instructions for installing and configuring Version 3.1 of XFree86. Annotation copyright by Book News Inc Portland OR

**The Software Encyclopedia**, 1997 *Computer Safety, Reliability, and Security. SAFECOMP 2024 Workshops* Andrea Ceccarelli, Mario Trapp, Andrea Bondavalli, Erwin

Schoitsch, Barbara Gallina, Friedemann Bitsch, 2024-09-08 This book constitutes the proceedings of the Workshops held in conjunction with the 43rd International Conference on Computer Safety Reliability and Security SAFECOMP 2024 which took place in Florence Italy during September 2024. The 36 papers included in this book were carefully reviewed and selected from a total of 64 submissions to the following workshops: DECSoS 2024, 19th Workshop on Dependable Smart Embedded and Cyber Physical Systems and Systems of Systems; SASSUR 2024, 11th International Workshop on Next Generation of System Assurance Approaches for Critical Systems; TOASTS 2024, Towards A Safer Systems Architecture Through Security; WAISE 2024, 7th International Workshop on Artificial Intelligence Safety Engineering

[Mastering Linux Kernel Development](#) Raghu Bharadwaj, 2017-10-11 Explore Implementation of core kernel subsystems About This Book Master the design components and structures of core kernel subsystems Explore kernel programming interfaces and related algorithms under the hood Completely updated material for the 4.12.10 kernel Who This Book Is For If you are a kernel programmer with a knowledge of kernel APIs and are looking to build a comprehensive understanding and eager to explore the implementation of kernel subsystems this book is for you It sets out to unravel the underlying details of kernel APIs and data

structures piercing through the complex kernel layers and gives you the edge you need to take your skills to the next level What You Will Learn Comprehend processes and fles the core abstraction mechanisms of the Linux kernel that promote effective simplification and dynamism Decipher process scheduling and understand effective capacity utilization under general and real time dispositions Simplify and learn more about process communication techniques through signals and IPC mechanisms Capture the rudiments of memory by grasping the key concepts and principles of physical and virtual memory management Take a sharp and precise look at all the key aspects of interrupt management and the clock subsystem Understand concurrent execution on SMP platforms through kernel synchronization and locking techniques In Detail Mastering Linux Kernel Development looks at the Linux kernel its internal arrangement and design and various core subsystems helping you to gain significant understanding of this open source marvel You will look at how the Linux kernel which possesses a kind of collective intelligence thanks to its scores of contributors remains so elegant owing to its great design This book also looks at all the key kernel code core data structures functions and macros giving you a comprehensive foundation of the implementation details of the kernel s core services and mechanisms You will also look at the Linux kernel as well designed software which gives us insights into software design in general that are easily scalable yet fundamentally strong and safe By the end of this book you will have considerable understanding of and appreciation for the Linux kernel Style and approach Each chapter begins with the basic conceptual know how for a subsystem and extends into the details of its implementation We use appropriate code excerpts of critical routines and data structures for subsystems

**Red Hat**

**Linux Fedora 3 Unleashed** Bill Ball,2005      **1001 Programming Resources** Edward J. Renehan,Edward Renehan,1996 1001 Programming Resources features key Web sites programmers must visit and shows how to access product descriptions and detailed documentation in minutes Download sample programs in C C Java Perl Visual Basic and more The CD ROM contains programming tools Java and Perl an electronic book and demos      **Linux: The Complete Reference** John Purcell,1999-12 Learn to optimize Linux OS like a pro and get expert tips on DNS servers Sendmail qmail SCSI Programming I O Port Programming Java Programming Parallel Processing MySQL Database Virtual Private Networks and much more

**Linux Companion for System Administrators** Jochen Hein,1999 This practical reference is divided into two parts for ease of use showing how a Linux system might be configured to be employed by a wide range of different users The first part describes the operating system in detail while the second section explores Linux networking and Internet connectivity

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