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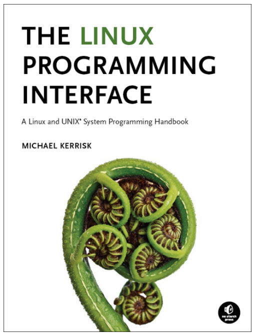
Training and Consulting

System Programming for Linux Containers

Course code: M7D-SPLC02

This course provides a deep understanding of the Linux technologies (namely, set-UID/set-GID programs, capabilities, namespaces, cgroups, and seccomp) used to implement container, virtualization, and sandboxing systems. (These are the technologies used to build systems such as Docker, LXC, Firejail, and Flatpak.) The course also provides an understanding of the core APIs used to build system-level applications that run on such systems. Detailed explanations and carefully designed practical exercises provide participants with the knowledge needed both to troubleshoot container and sandboxing systems and to write complex applications that run on those systems.


THE LINUX PROGRAMMING INTERFACE
A Linux and UNIX® System Programming Handbook
MICHAEL KERRISK

Audience and prerequisites

The audience for this course includes designers, developers, and DevOps who are building, troubleshooting, and administering container and sandboxing systems, as well as designers and developers who are implementing applications to run on such systems.

Participants should have a good reading knowledge of the C programming language and some programming experience in a language suitable for completing the course exercises (e.g., C, C++, Go, Rust). (Note, however, that, except on the first day of the course, most of the course exercises do not require writing programs.)

Previous system programming experience is *not* required.

Related courses

This course is equivalent to the combination of the following two courses:

- *Linux/UNIX System Programming Essentials*, M7D-SPESS01
- *Linux Security and Isolation APIs*, M7D-SECISOL02

Course duration and format

Five days, with up to 40% devoted to practical sessions.

Course materials

- Course books (written by the trainer) that include all slides and exercises presented in the course
- An electronic copy of the trainer's book, *The Linux Programming Interface*
- Numerous example programs written by the course trainer

Course inquiries and bookings

For inquiries about courses and consulting, you can contact us in the following ways:

- Email: training@man7.org
- Phone: +49 (89) 2488 6180 (German landline)

Prices, dates, and further details

For course prices, upcoming course dates, and further information about the course, please visit the course web page, `http://man7.org/training/splc/`.

About the trainer

Michael Kerrisk has a unique set of qualifications and experience that ensure that course participants receive training of a very high standard:

- He has been programming on UNIX systems since 1987 and began teaching UNIX system programming courses in 1989.
- He is the author of *The Linux Programming Interface*, a 1550-page book acclaimed as the definitive work on Linux system programming.
- He has been actively involved in Linux development, working with kernel developers on testing, review, and design of new Linux kernel–user-space APIs.
- Since 2000, he has been the involved in the Linux *man-pages* project, which provides the manual pages documenting Linux system calls and C library APIs, and was the project maintainer from 2004 to 2021.

System Programming for Linux Containers: course contents in detail

Topics marked with an asterisk (*) are optional, and will be covered as time permits

1. **Course Introduction**
2. **Fundamental Concepts**
   - Error handling
   - System data types
   - Notes on code examples
3. **File I/O**
   - File I/O overview
   - *open()*, *read()*, *write()*, and *close()*
4. **Processes**
   - Process IDs
   - Process memory layout
   - Command-line arguments
   - The environment list
   - The `/proc` filesystem
5. **Signals**
   - Overview of signals
   - Signal dispositions
   - Useful signal-related functions
   - Signal handlers
   - Designing signal handlers
6. **Process Lifecycle**
   - Creating a new process: *fork()*
   - Process termination
   - Monitoring child processes
   - Orphans and zombies
   - The `SIGCHLD` signal
   - Executing programs: *execve()*
7. **System Call Tracing with *strace* (*)**
   - Getting started
   - Tracing child processes
   - Filtering *strace* output
8. **Security and Isolation APIs Overview (*)**
   - Sandboxing
   - Containers
9. **Classical Privileged Programs**
   - A simple set-user-ID program
   - Saved set-user-ID and and saved set-group-ID
   - Changing process credentials
   - A few guidelines for writing privileged programs
10. **Capabilities**
    - Process and file capabilities
    - Permitted and effective capabilities
    - Setting and viewing file capabilities
    - Capabilities-dumb and capabilities-aware applications
    - Text-form capabilities
11. **Capabilities and *execve()***
    - Capabilities and *execve()*
    - The capability bounding set
    - Inheritable capabilities
    - Summary of process capability sets (so far)
    - Problems with inheritable capabilities
    - Ambient capabilities
    - An alternative summary of process capability sets
    - Summary remarks
12. **Capabilities and UID 0**
    - Capabilities and UID transitions
    - Capabilities, UID 0, and *execve()*
    - Making a capabilities-only environment: securebits (*)
13. **Programming with capabilities (*)**
    - Programming with capabilities
14. **Namespaces**
    - An example: UTS namespaces
    - Namespaces commands
    - Namespaces demonstration (UTS namespaces)
    - Namespace types and APIs
    - Namespaces, containers, and virtualization
15. **Mount Namespaces and Shared Subtrees**
    - Mount namespaces
    - Shared subtrees
    - Bind mounts
16. **Mount Namespaces: Further Details (*)**
    - Peer groups
    - Private mounts
    - Slave mounts
    - Unbindable mounts
    - Mounting a container filesystem
17. **PID Namespaces**
    - PID namespaces
18. **Other Namespaces**
    - IPC namespaces
    - Time namespaces
    - Cgroup namespaces
    - Network namespaces
19. **Namespaces APIs**
    - API Overview
    - Creating a child process in new namespaces: *clone()*
    - `/proc/PID/ns`
    - Entering a namespace: *setns()*
    - Creating a namespace: *unshare()*
    - PID namespaces idiosyncrasies
    - Namespace lifetime (*)
20. **User Namespaces**
    - Overview of user namespaces
    - Creating and joining a user namespace
    - User namespaces: UID and GID mappings
    - Accessing files (and other objects with UIDs/GIDs)
    - Security issues
    - Combining user namespaces with other namespaces
    - Use cases
21. **User namespaces, *execve()*, and user ID 0**
    - User namespaces, *execve()*, and user ID 0
22. **User Namespaces and Capabilities**
    - User namespaces and capabilities
    - What does it mean to be superuser in a namespace?
    - Discovering namespace relationships

- File-related capabilities (*)

23. **User Namespaces and Privileged Programs (*)**
    - User namespace “set-UID-root” programs
    - Namespaced file capabilities

24. **Seccomp**
    - Seccomp filtering and BPF
    - The BPF virtual machine and BPF instructions
    - BPF filter return values
    - Installing a BPF program
    - BPF program examples
    - Checking the architecture
    - Productivity aids (*libseccomp* and other tools)
    - Performance considerations
    - Applications and further information

25. **Seccomp: Further Details (*)**
    - Caveats
    - Discovering the system calls made by a program
    - Installing multiple filters
    - Interaction with *fork()* and *execve()*
    - Extended BPF (eBPF)
    - Other filter return actions
    - Further details on BPF programs
    - Recent seccomp features
    - Audit logging of filter actions

26. **Cgroups: Introduction**
    - Preamble
    - What are control groups?
    - An example: the `pids` controller
    - Creating and destroying cgroups
    - Populating a cgroup
    - Enabling and disabling controllers

27. **Cgroups: A Survey of the Controllers**
    - The `cpu`, `memory`, `freezer`, and `pids` controllers
    - Other controllers

28. **Cgroups: Advanced Features**
    - Cgroup namespaces
    - Release notification (`cgroup.events` file)
    - Delegation

29. **Cgroups: Thread Mode (*)**
    - Overview of thread mode
    - Creating and using a threaded subtree

30. **Cgroups Version 1 (*)**
    - Cgroups v1: hierarchies and controllers
    - Cgroups v1: populating a cgroup
    - Cgroups v1: release notification
    - Cgroups v1: delegation
    - Problems with cgroups v1; rationale for v2

31. **Linux containers in 100 lines of shell (*)**
    - Building a container from the shell
    - The container root filesystem (OverlayFS)
    - Isolating the container: namespaces
    - Isolating the container: cgroups
    - Container set-up stage 1: cgroups + namespaces
    - Container set-up stage 2: mounts and *pivot_root()*
    - Starting up the container
    - Namespaces inside the container
    - Superuser inside a container
    - Cgroups inside the container
    - Networking inside the container
    - One more thing...
    - Postscript: ID-mapped mounts