



# The Design and Implementation of the FreeBSD Operating System (2nd Edition)

*By Marshall Kirk McKusick, George V. Neville-Neil, Robert N.M. Watson*

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The most complete, authoritative technical guide to the FreeBSD kernel's internal structure has now been extensively updated to cover all major improvements between Versions 5 and 11. Approximately one-third of this edition's content is completely new, and another one-third has been extensively rewritten.

Three long-time FreeBSD project leaders begin with a concise overview of the FreeBSD kernel's current design and implementation. Next, they cover the FreeBSD kernel from the system-call level down—from the interface to the kernel to the hardware. Explaining key design decisions, they detail the concepts, data structures, and algorithms used in implementing each significant system facility, including process management, security, virtual memory, the I/O system, filesystems, socket IPC, and networking.

This Second Edition

- Explains highly scalable and lightweight virtualization using FreeBSD jails, and virtual-machine acceleration with Xen and Virtio device paravirtualization
- Describes new security features such as Capsicum sandboxing and GELI cryptographic disk protection
- Fully covers NFSv4 and Open Solaris ZFS support
- Introduces FreeBSD's enhanced volume management and new journaled soft updates
- Explains DTrace's fine-grained process debugging/profiling
- Reflects major improvements to networking, wireless, and USB support

Readers can use this guide as both a working reference and an in-depth study of a leading contemporary, portable, open source operating system. Technical and sales support professionals will discover both FreeBSD's capabilities and its limitations. Applications developers will learn how to effectively and efficiently interface with it; system administrators will learn how to maintain, tune, and configure it; and systems programmers will learn how to extend, enhance, and interface with it.

**Marshall Kirk McKusick** writes, consults, and teaches classes on UNIX- and BSD-related subjects. While at the University of California, Berkeley, he implemented the 4.2BSD fast filesystem. He was research computer scientist at the Berkeley Computer Systems Research Group (CSRG), overseeing development and release of 4.3BSD and 4.4BSD. He is a FreeBSD Foundation board member and a long-time FreeBSD committer. Twice president of the Usenix Association, he is also a member of ACM, IEEE, and AAAS.

**George V. Neville-Neil** hacks, writes, teaches, and consults on security, networking, and operating systems. A FreeBSD Foundation board member, he served on the FreeBSD Core Team for four years. Since 2004, he has written the "Kode Vicious" column for *Queue* and *Communications of the ACM*. He is vice chair of ACM's Practitioner Board and a member of Usenix Association, ACM, IEEE, and AAAS.

**Robert N.M. Watson** is a University Lecturer in systems, security, and architecture in the Security Research Group at the University of Cambridge Computer Laboratory. He supervises advanced research in computer architecture, compilers, program analysis, operating systems, networking, and security. A FreeBSD Foundation board member, he served on the Core Team for ten years and has been a committer for fifteen years. He is a member of Usenix Association and ACM.

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## **Editorial Review**

### About the Author

**Marshall Kirk McKusick** writes books and articles, consults, and teaches classes on UNIX- and BSD-related subjects. While at the University of California at Berkeley, he implemented the 4.2BSD fast filesystem and was the Research Computer Scientist at the Berkeley Computer Systems Research Group (CSRG), overseeing the development and release of 4.3BSD and 4.4BSD. His particular areas of interest are the virtual-memory system and the filesystem. He earned his undergraduate degree in electrical engineering from Cornell University and did his graduate work at the University of California at Berkeley, where he received master's degrees in computer science and business administration, and a doctoral degree in computer science. He has twice been president of the board of the Usenix Association, is currently a member of the FreeBSD Foundation Board of Directors, a member of the editorial board of ACM's *Queue* magazine, a senior member of the IEEE, and a member of the Usenix Association, ACM, and AAAS. In his spare time, he enjoys swimming, scuba diving, and wine collecting. The wine is stored in a specially constructed wine cellar (accessible from the Web at <http://www.McKusick.com/cgi-bin/readhouse>) in the basement of the house that he shares with Eric Allman, his partner of 35-and-some-odd years and husband since 2013.

**George V. Neville-Neil** hacks, writes, teaches, and consults in the areas of Security, Networking, and Operating Systems. Other areas of interest include embedded and real-time systems, network time protocols, and code spelunking. In 2007, he helped start the AsiaBSDCon series of conferences in Tokyo, Japan, and has served on the program committee every year since then. He is a member of the FreeBSD Foundation Board of Directors, and was a member of the FreeBSD Core Team for 4 years. Contributing broadly to open source, he is the lead developer on the Precision Time Protocol project (<http://ptpd.sf.net>) and the developer of the Packet Construction Set (<http://pcs.sf.net>). Since 2004, he has written a monthly column, "Kode Vicious," that appears both in ACM's *Queue* and *Communications of the ACM*. He serves on the editorial board of ACM's *Queue* magazine, is vice-chair of ACM's *Practitioner Board*, and is a member of the Usenix Association, ACM, IEEE, and AAAS. He earned his bachelor's degree in computer science at Northeastern University in Boston, Massachusetts. He is an avid bicyclist, hiker, and traveler who has lived in Amsterdam, The Netherlands, and Tokyo, Japan. He is currently based in Brooklyn, New York, where he lives with his husband, Kaz Senju.

**Robert N.M. Watson** is a University Lecturer in Systems, Security, and Architecture in the Security Research Group at the University of Cambridge Computer Laboratory. He supervises doctoral students and postdoctoral researchers in cross-layer research projects spanning computer architecture, compilers, program analysis, program transformation, operating systems, networking, and security. Dr. Watson is a member of the FreeBSD Foundation Board of Directors, was a member of the FreeBSD Core Team for 10 years, and has been a FreeBSD committer for 15 years. His open-source contributions include work on FreeBSD networking, security, and multiprocessing. Having grown up in Washington, D. C., he earned his undergraduate degree in Logic and Computation, with a double major in Computer Science, at Carnegie Mellon University in Pittsburgh, Pennsylvania, and then worked at a series of industrial research labs investigating computer security. He earned his doctoral degree at the University of Cambridge, where his graduate research was in extensible operating system access control. Dr. Watson and his wife Dr. Leigh Denault have lived in Cambridge, England, for 10 years.

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