Classic Systems:
Unix and THE

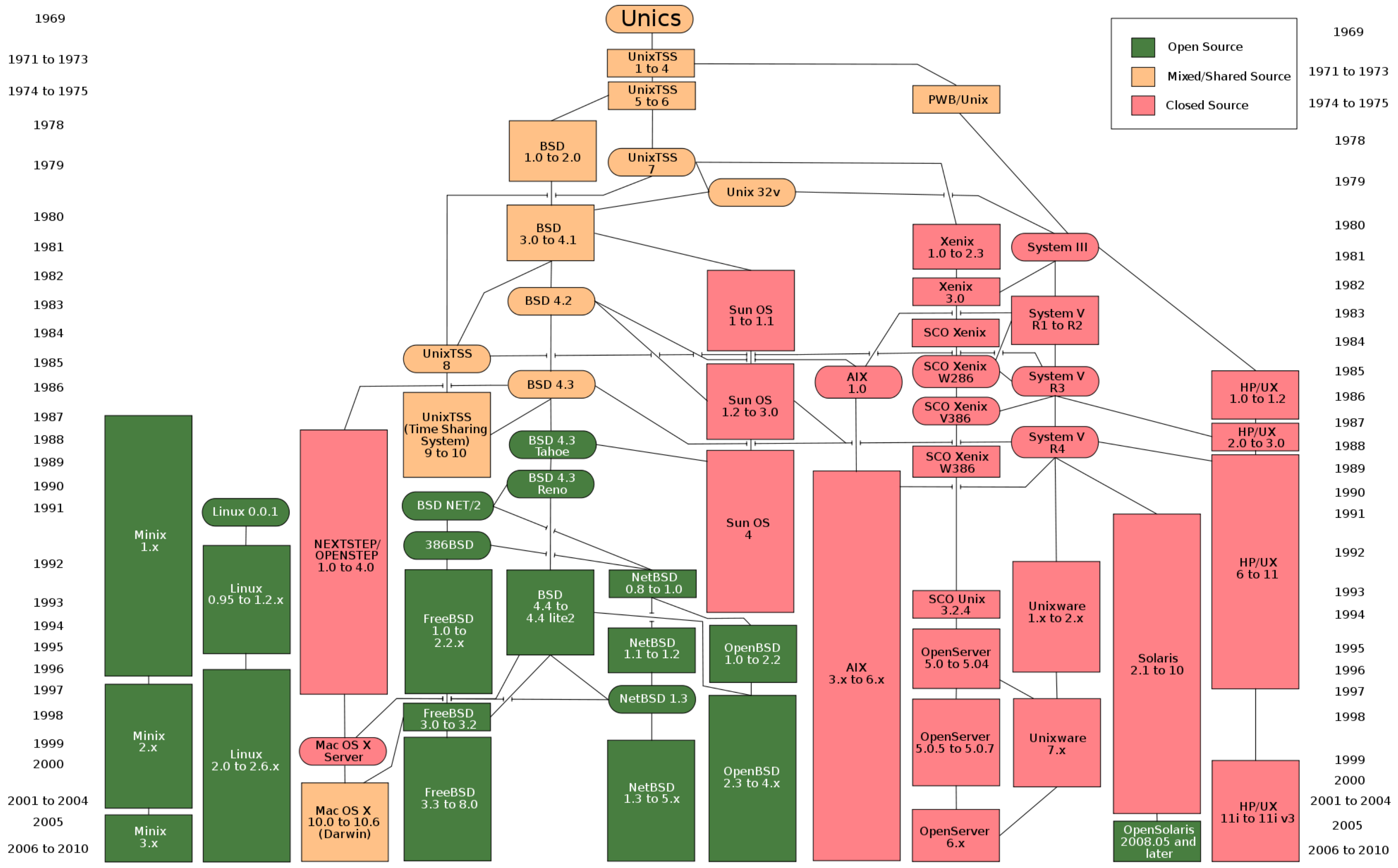
Presented by Hakim Weatherspoon

The UNIX Time-Sharing System
Dennis Ritchie and Ken Thompson

- Background of authors at Bell Labs
  - Both won Turing Awards in 1983
- Dennis Ritchie
  - Key developer of *The C Programming Lanuage*, Unix, and Multics
- Ken Thompson
  - Key developer of the B programming lanuage, Unix, Multics, and Plan 9
  - Also QED, ed, UTF-8

The UNIX Time-Sharing System

Dennis Ritchie and Ken Thompson



The UNIX Time-Sharing System

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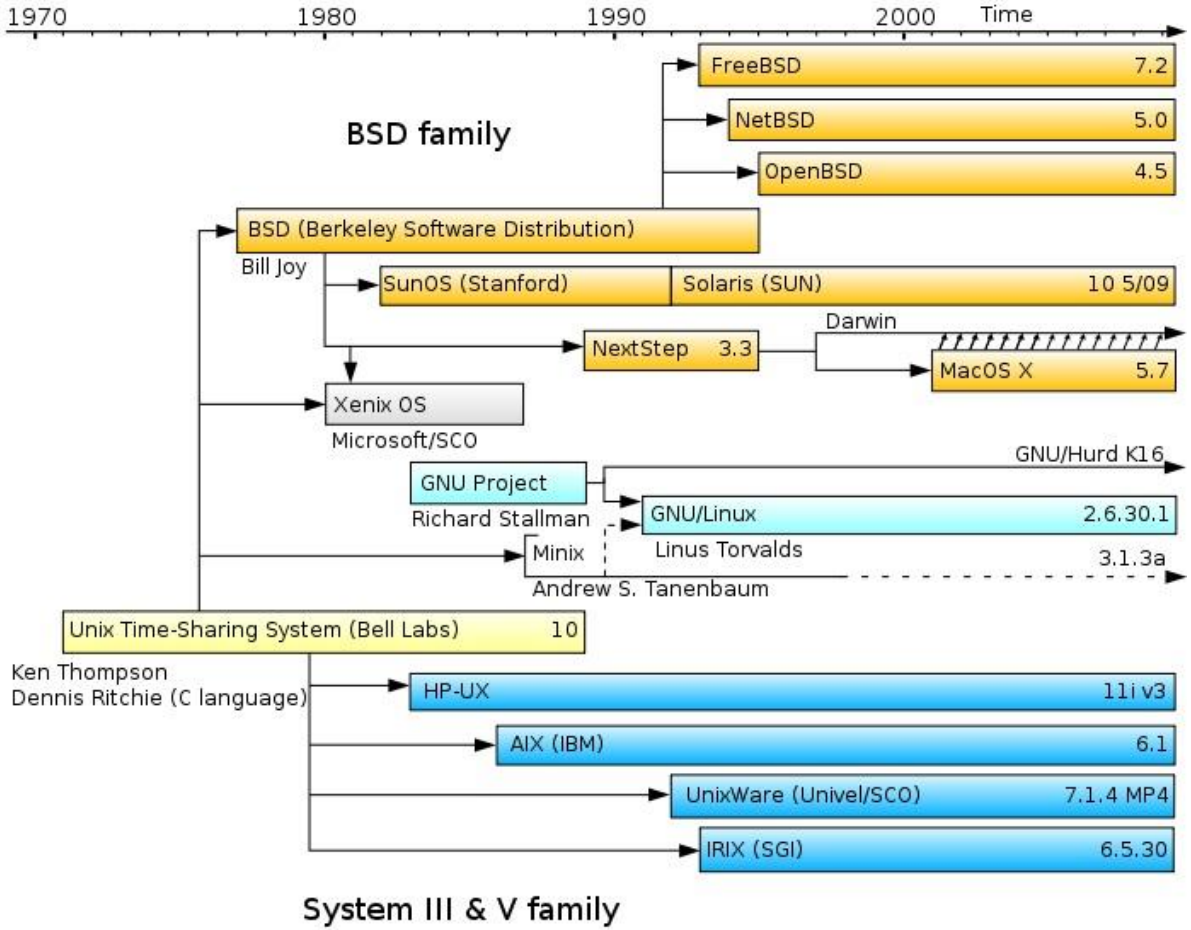


The UNIX Time-Sharing System
Dennis Ritchie and Ken Thompson

- Classic system and paper
  - described almost entirely in 10 pages
- Key idea
  - elegant combination of a few concepts that fit together well
  - API deliberately small
    - Instead of collection of specialized API's for each device/abstraction

System features

- Time-sharing system
- Hierarchical file system
- Device-independent I/O
- Shell-based, tty user interface
- Filter-based, record-less processing paradigm

- Major early innovations:
  - "fork" system call for process creation, file I/O via a single subsystem, pipes, I/O redirection to support chains

Version 3 Unix

- 1969: Version 1 ran PDP-7
- 1971: Version 3 Ran on PDP-11's
  - Costing as little as $40k!
- < 50 KB
- 2 man-years to write
- Written in C

PDP-7

PDP-11

File System

- Ordinary files (uninterpreted)
- Directories (protected ordinary files)
- Special files (I/O)

Uniform I/O Model

- open, close, read, write, seek
  - Uniform calls eliminates differences between devices
- other system calls
  - close, status, chmod, mkdir, ln
- bytes, no records

Directories

- root directory
- path names
- rooted tree
- current working directory
- back link to parent
- multiple links to ordinary files

Special Files

- Uniform I/O model
  - Each device associated with at least one file
  - But read or write of file results in activation of device
- Advantage: Uniform naming and protection model
  - File and device I/O are as similar as possible
  - File and device names have the same syntax and meaning, can pass as arguments to programs
  - Same protection mechanism as regular files

Removable File System

- Tree-structured
- *Mount*'ed on an ordinary file
  - Mount replaces a leaf of the hierarchy tree (the ordinary file) by a whole new subtree (the hierarchy stored on the removable volume)
  - After mount, virtually no distinction between files on permanent media or removable media

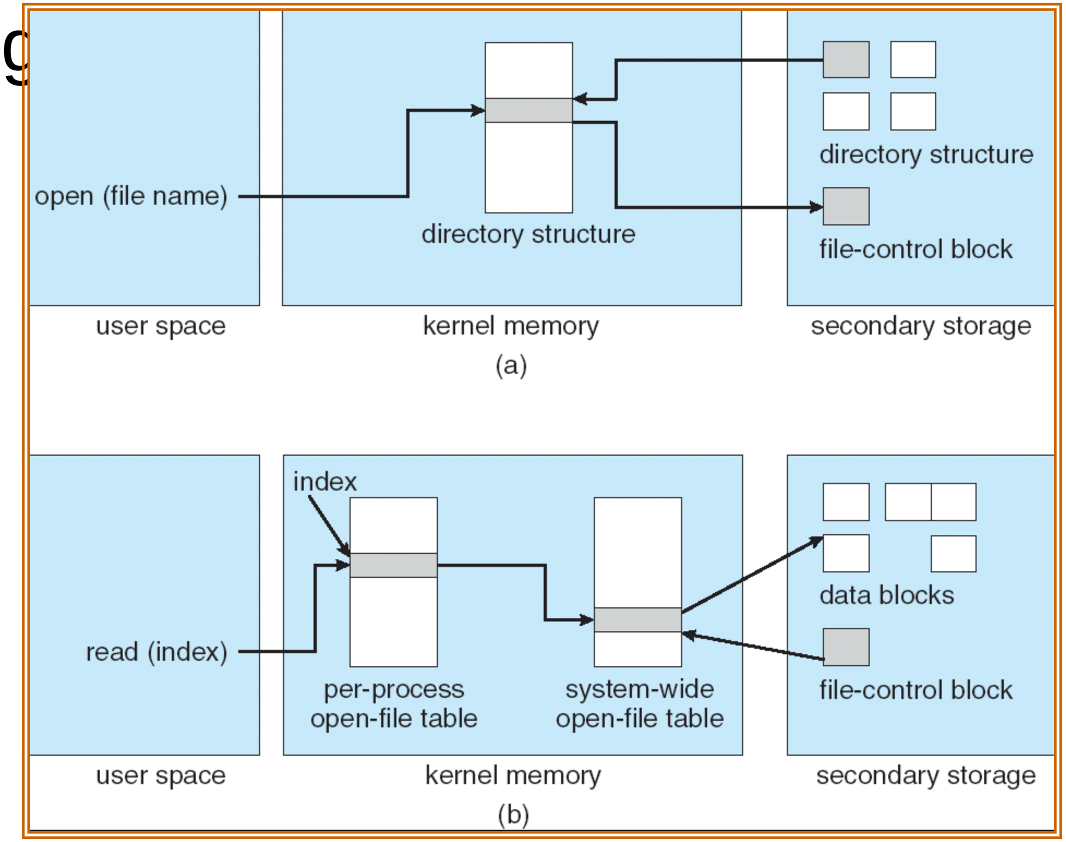
(a) (b)

Protection

- User-world, RWX bits
- set-user-id bit
- super user is just special user id

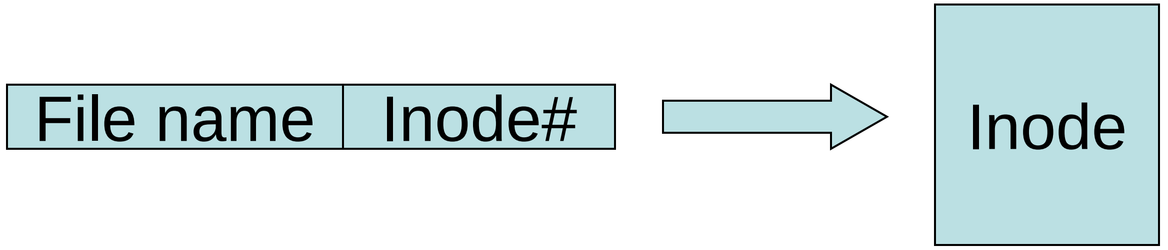
File System Implementation

- System table of i-numbers (i-list)
- i-nodes
- path name scanning
- mount table
- buffered data
- write-behind



I-node Table

- short, unique name that points at file info.
- allows simple & efficient fsck
- cannot handle accounting issues



Many devices fit the block model

- Disks
- Drums
- Tape drives
- USB storage

- Early version of the ethernet interface was presented as a kind of block device (seek disabled)

- But many devices used IOCTL operations heavily

Processes and images

- text, data & stack segments
- process swapping
- pid = fork()
- pipes
- exec(file, arg1, ..., argn)
- pid = wait()
- exit(status)

Easy to create pipelines

- A "pipe" is a process-to-process data stream, could be implemented via bounded buffers, TCP, etc
- One process can write on a connection that another reads, allowing chains of commands

```
% cat *.txt | grep foo | wc
```

- In combination with an easily programmable shell scripting model, very powerful!

The Shell

- cmd arg1 ... argn
- stdio & I/O redirection
- filters & pipes
- multi-tasking from a single shell
- shell is just a program

- Trivial to implement in shell
  - Redirection, background processes, cmd files, etc

Traps

- Hardware interrupts
- Software signals
- Trap to system routine

Perspective

- Not designed to meet predefined objective
- Goal: create a comfortable environment to explore machine and operating system
- Other goals
  - Programmer convenience
  - Elegance of design
  - Self-maintaining

Perspective

- But had many problems too. Here are a few:
  - File names too short and file system damaged on crash
  - Didn't plan for threads and never supported them well
  - "Select" system call and handling of "signals" was ugly and out of character w.r.t. other features
  - Hard to add dynamic libraries (poor handling of processes with lots of "segments")
  - Shared memory and mapped files fit model poorly
- ...in effect, the initial simplicity was at least partly because of some serious limitations!

“THE”-Multiprogramming System

Edsger W. Dijkstra

- Received Turing Award in 1972
- Contributions
  - Shortest Path Algorithm, Reverse Polish Notation, Bankers algorithm, semaphore’s, self-stabilization
- Known for disliking ‘goto’ statements and using computers!

“THE”-Multiprogramming System

Edsger W. Dijkstra

- Never named “THE” system; instead, abbreviation for "Technische Hogeschool Eindhoven”

- Batch system (no human intervention) that supported multitasking (processes share CPU)
  - THE was *not* multiuser

- Introduced
  - software-based memory segmentation
  - Cooperating sequential processes
  - semaphores

Design

- Layered structure
  - Later Multics has layered structure, ring segmentation
- Layer 0 – the scheduler
  - Allocated CPU to processes, accounted for blocked proc's
- Layer 1 – the pager
- Layer 2 – communication between OS and console
- Layer 3 – managed I/O
- Layer 4 – user programs
- Layer 5 – the user
  - "Not implemented by us"!

Perspective

- Layered approach
  - Design small, well defined layers
  - Higher layers dependent on lower ones
    - Helps prove correctness
    - Helps with debugging
- Sequential process and Semaphores

Next Time

- Read and write review:
  - *SEDA: An Architecture for Well Conditioned, Scalable Internet Services*, Matt Welsch, David Culler, and Eric Brewer. Proceedings of the Eighteenth ACM Symposium on Operating Systems Principles (Banff, Alberta, Canada, 2001), pages 230--243
  - *On the duality of operating system structures*, H. C. Lauer and R. M. Needham. ACM SIGOPS Operating Systems Review Volume 12, Issue 2 (April 1979), pages 3--19.

Next Time

- Read and write review:

- Lab 0 – finish today
- Lab 1 – available later today and due next Friday

- Project Proposal due in two weeks
  - talk to me and other faculty and email and talk to me

- Check website for updated schedule