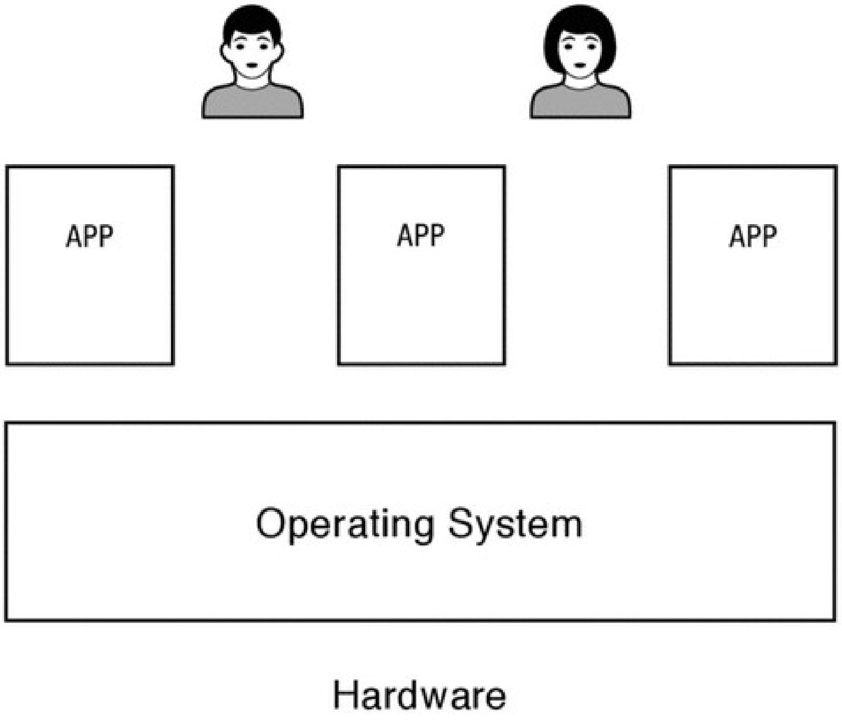
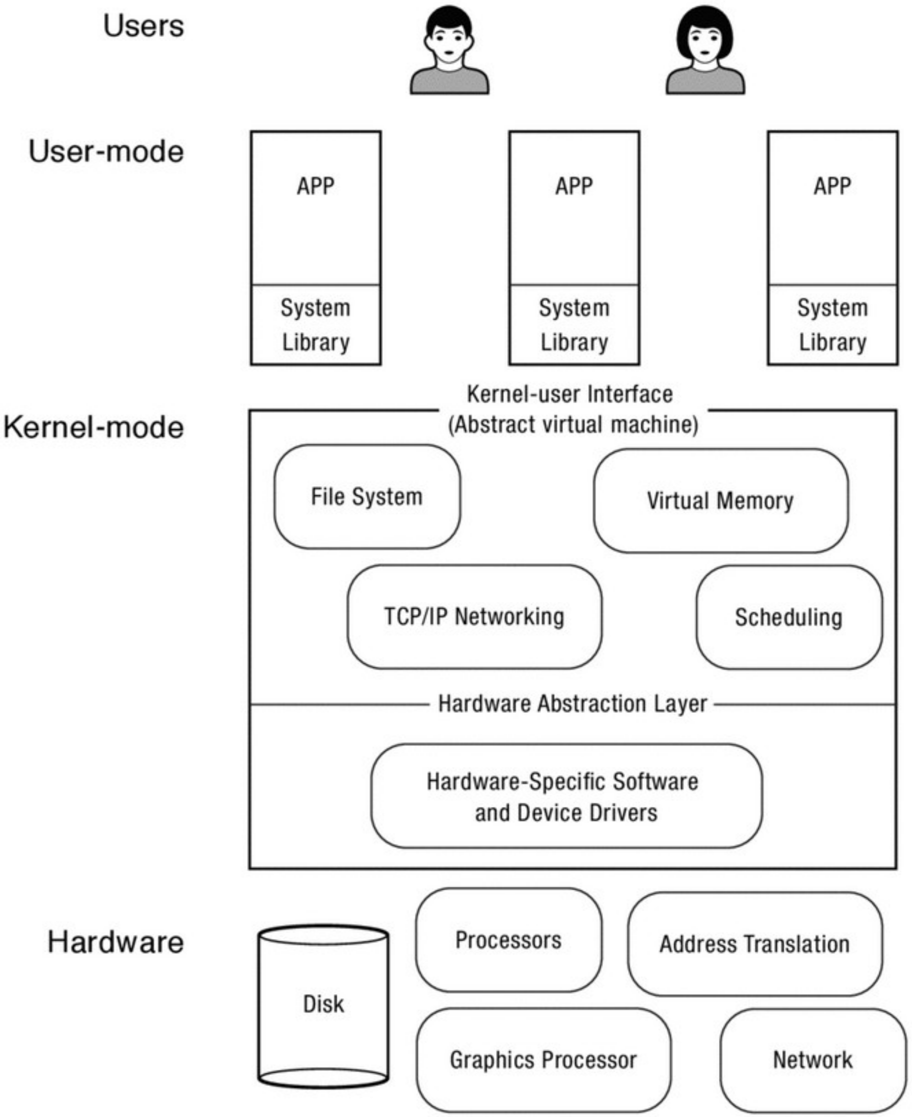
Operating Systems

- Low level software system that
  - manages all applications
  - implements an interface between applications and resources
  - manages available resources
- Resource manager
- Interface
- Virtual Machine

Operating System





Operating System

- OS kernel
  - Code executed in privileged mode
- User space
  - Code executed in non privileged mode
- Service / daemons
  - Application that executed in the background (server)
- Utility programs
  - Application provided by the OS and executed by the user (editor, shell, compiler()
- System calls
  - functions that implement parts of the OS services or utilities
  - can be used inside the kernel
  - Manage and change internal structure.

Operating System Roles

- Referee
  - management of resources shared between application
  - Isolation of applications from each other
  - Decide which applications get which resources
- Illusionist
  - Provides abstraction of physical hardware
    - I/O, available memory, ...
- Glue
  - Provide standard common services
    - I/O (disk, network, ...)
    - Service implementation

Operating System requirements

- Reliability
- Availability
- Security
- Portability
- Performance
- Adoption

Operating System requirements

- Reliability
  - Capacity to work correctly
  - Hide HW faults
  - Reduce SW bugs
  - Handle attacks
- Availability
  - Time the system is working
  - Affected by frequency of failures (MTBF) and time to restore system

- Buggy system that crashes frequently but never looses information
  - Reliable but not available
- Subverted system that appears to be working correctly
  - Available but not reliable

Operating System requirements

- Security
  - Guarantee that operations are not compromised by malicious attacks
  - Privacy
    - guarantee that data is only accessible to authorized users
- SW has bugs that can be exploited
- Administrator can be untrustworthy
- SW developer can be untrustworthy
- OS Design should minimize vulnerabilities
  - Computer virus
  - Downloaded code

Operating System requirements

- Portability
  - Applications are given an abstraction for the HW
    - Resources
    - Access
- Portable abstractions do not change with time
- Abstract virtual machines
  - WIN32
  - POSIX

Operating System requirements

- Performance
  - Efficient use of of available resources
- Overhead
  - added cost of implementing an abstraction
  - Efficiency
    - lack of overhead
- Fairness
  - how to divide resources (memory, CPU) to multiple applications
- Response Time
  - how long a task takes to run
- Throughput
  - rate at which tasks are completed
- Performance predictability

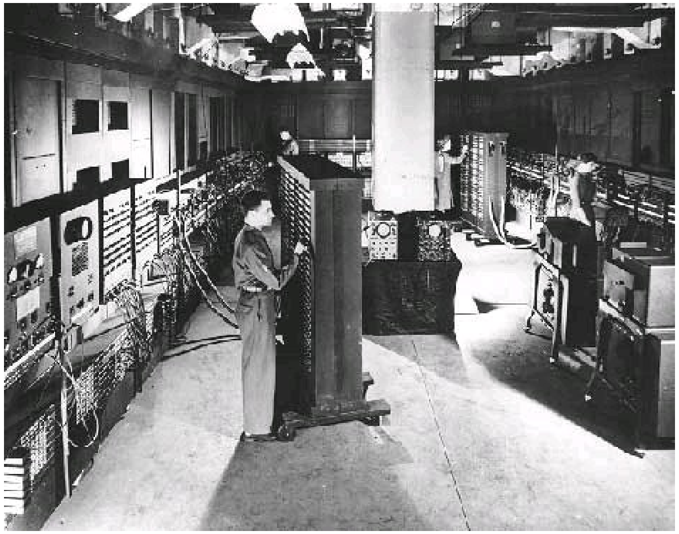
Operating System requirements

- Adoption rate
  - depend on
    - Availability of Applications
    - Availability of hardware

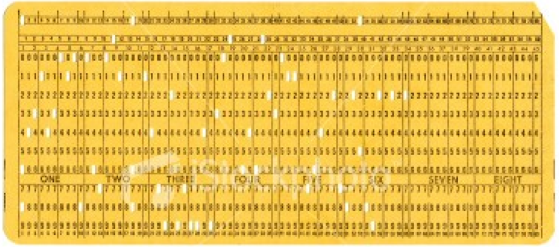
- Open vs closed
- Standardized API
  - more guaranteed of stability
  - more guarantees of portability
- Interoperability

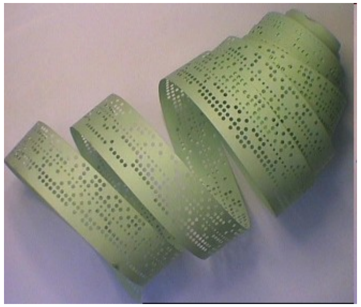
Past, Present Future

- 1945: ENIAC-Electronic Numerical INtegrator And Computer,
  - 19K valves e 1K relays
  - 200 KW
  - 167 m2



- Numeric computations
  - 5000 sums per second or 357 mult per second or 38 divs per second





PDP-7

- First computer to run UNIX
- Introduced in 1965
- Less expensive alternative to the PDP-4
  - price of only U.S.$72,000
- 18-bit word length
- Standard main memory was 4K words (equivalent to nine kilobytes)
  - 64K words (144 KB)

Motorola 68000

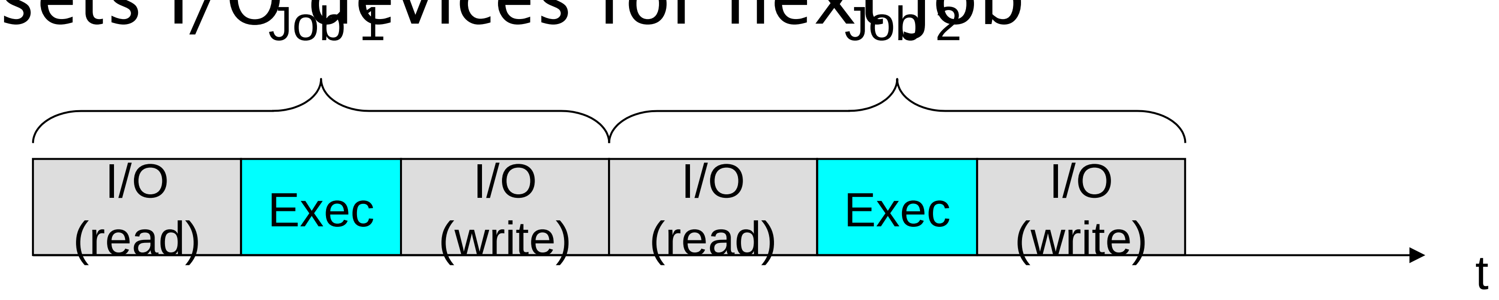
- Developed in the start of 80’s
- Used by HP, SUN, DEC, CGI, Apple
- 32-bit
  - instruction setm registers and internal data bus
  - 16-bit external data bus
- Virtual memory
- Frequency < 10Mhz

Speed/Price

		CPU	• RAm	Price	MIPS
1945	ENIAC			6 936 746	0.0000182
1965	DEC PDP-8		• 200kb	146 508	
1983	IBM PC/XT	i8088	16 kB – 256 kB	12 870	0.25
1984	Apple Macintosh	6800	128 KB	6100	0.50
1989	Sun SS1	Sparc	64 MB	18 598	10
1991	Dell 433P	i486DX	32Mb	5 645	11
1991	HP 730	HP-PA7000	32	28,029	78
2001	SUN Blade 1000	UltraSPARC	1 Gb	14 477	4200
2001		2xPentium 4	1Gb	1,447	2500

Past, Present Future

- Processor idle while reading data
- Batch processing
  - Load
  - Run
  - Unload
- While a job was running
  - OS sets I/O devices for next job



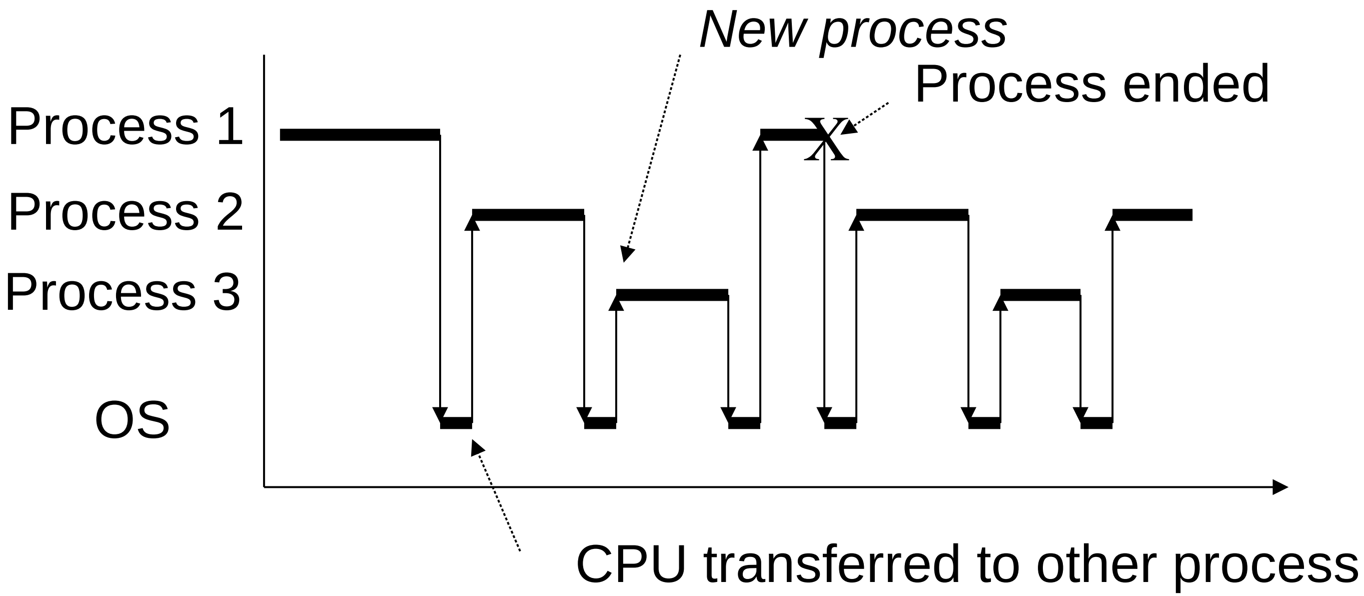
Past, Present Future

- Processor idle while reading data
- Multitasking / multiprocessing
  - multiple programs loaded into memory
  - OS selects program to execute
  - Blocking programs (I/O) do not use CPU
- Efficeint
  - if queue of tasks is long
  - I/O devices feed processor
- requires program isolation

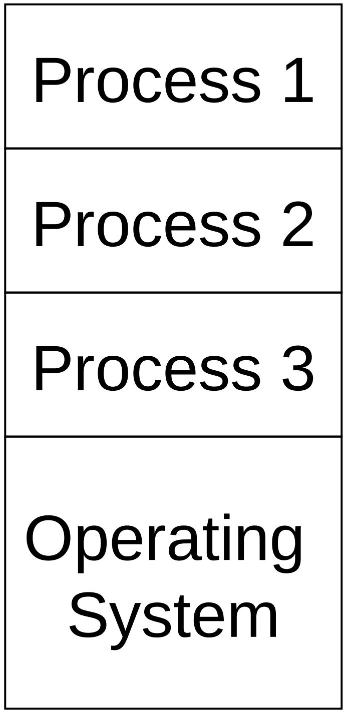
Past, Present Future

- Processor idle while reading data
- User can interact with the programs
  - multiple display/keyboards
  - make program idle most of the time
- Time-sharing
  - multiple programs loaded into memory
  - Programs from different users
  - OS selects program to execute
  - Blocking programs (I/O) do not use CPU
- Efficient
  - if programs require I/O
- Requires program isolation
- Requires user isolation

- CPU Usage



- Memory usage



History of UNIX

Past, Present Future

- Modern OS
  - Desktop
  - Smartphone
  - Server
  - Embedded
  - Virtual machines
  - Server clusters
  - Cloud

- Future OS
  - VLS datacenters
  - VLS Multicore systems
  - Mobile computing
  - Heterogenous systems
  - Large Storage
  - IoT

The UNIX Time-Sharing System

- Most important achievement
  - demonstrate that powerful operating system for interac-tive use need not be expensive
    - neither in equipment or in human effort:
- UNIX can run on hardware costing as
  - little as $40,000,
- the main system software development
  - less than two man years

The UNIX Time-Sharing System

- The PDP-11/45
  - $40,000
  - 16-bit word (8-bit byte)
  - 144Kbytes of core memory
  - 1M byte fixed-head disk
  - 2.5M bytes on removable disk car-tridges
  - console typewriter

The UNIX Time-Sharing System

- Most important job of UNIX is to provide a file system.
  - Ordinary Files
  - Directories
  - Special Files
- Removable File Systems
- Protection
- I/O Calls
  - designed to eliminate thedifferences between the various devices and styles ofaccess

The UNIX Time-Sharing System

- Processes and Images
  - An image is a computer execution environment. Iti
  - core image (memory)
  - general register values
  - status of open files, current directory, and the like.
- An image is the current state of a pseudo computer.

The UNIX Time-Sharing System

- Processes and Images
  - A process is the execution of an image.
  - While the processor is executing on behalf of a process
    - the image must reside in core
  - Segment organization
    - text segment begins at location 0 in the virtual address space.
      - During execution, this segment is write-protected and a single copy of it is shared among all processes executing the same program.
    - At the first 8K byte boundary above the program text segment
      - begins a non-shared, writable data segment, the size of which may be extended by a systemcall.
    - Starting at the highest address
      - stack segment, which automatically grows down-ward as the hardware’s stack pointer fluctuates.

The UNIX Time-Sharing System

- Processes communciation
  - Processes may communicate with related processes through pipes
  - Using he same system read and write calls that are used for file system I/O:
- Traps
  - The PDP-11 hardware detects a number of program faults
    - such as references to nonexistent memory, unimplemented instructions, and odd addresses used where an even address is required.
  - Such faults cause the processor to trapto a system routine
  - Programs which are looping,
    - may be halted by the use of the interrupt signal,

The UNIX Time-Sharing System

- 1969:
  - Bell withdraws from Multics;
  - Thompson starts pondering new os
  - ARPAnet
  - Thompson writes 1st Unix on PDP-7 in one month based on Multics
- 1970
  - Kernighan suggests name 'UNICS' (Uniplexed Information & Computing Service)
  - Thompson writes B language
  - DEC announces PDP-11 [fansite] (will sell 250k)
  - Bell orders $65k PDP-11/20 w/24kb RAM and 500k disk

The UNIX Time-Sharing System

- 1971
  - Unix rewritten for PDP-11/20
    - os uses 16k, files limited to 64kb
  - **adds pathnames**
  - Unix version 1 written in B
- 1972
  - Ritchie creates C language
  - Unix version 2 written mostly by Thompson in C
- 1973
  - Unix version 3 introduces **pipes text streams** as universal interface
  - multiprogramming added
  - #include and #define added to C
  - Unix kernel rewritten in C
  - Berkeley gets interested in Unix

The UNIX Time-Sharing System

- 1974
  - AT&T decides to supply Unix-source free to academia
- 1976
  - Xerox invents Ethernet
  - Unix licensed by 138 institutions
- 1977
  - Berkeley Software Distribution (Pascal and ex editor)
  - Unix v6 ported for first time
  - Unix clone 'Coherent'

The UNIX Time-Sharing System

- 1978
  - Unix Timesharing System version 7 (UTS)
  - K&R's "The C Programming Language"
  - 'Idris' is Unix clone for PDP-11 purposely incompatible
  - Bill Joy writes **vi** [story]
  - Second Berkeley Software Distribution (2BSD)
    - with **Pascal, vi, termcap, Mail, more, csh, ex**
  - **Berkeley adds virtual memory to Unix 7**
-

The UNIX Time-Sharing System

- 1979
  - **Unix version 7**
    - **Bourne shell, awk, lint, make, uucp; find, cpio, expr;**
    - **large file-systems,**
    - **unlimited users**
    - kernel is still just 40kb
  - Santa Cruz Operation (SCO) founded by Doug and Larry Michels to create Unix ports
  - 1979: Motorola introduces 68000 16-bit CPU
  - IBM prototypes PC using still-scarce 68000
  - Intel introduces 8088 as discount 8-bit version of 8086
  - IBM chooses 8088 for 'short run' PC
  - Unix 32V for VAX [source code]
  - 3BSD is 32-bit port of 2BSD w/ **virtual memory and C shell**

The UNIX Time-Sharing System

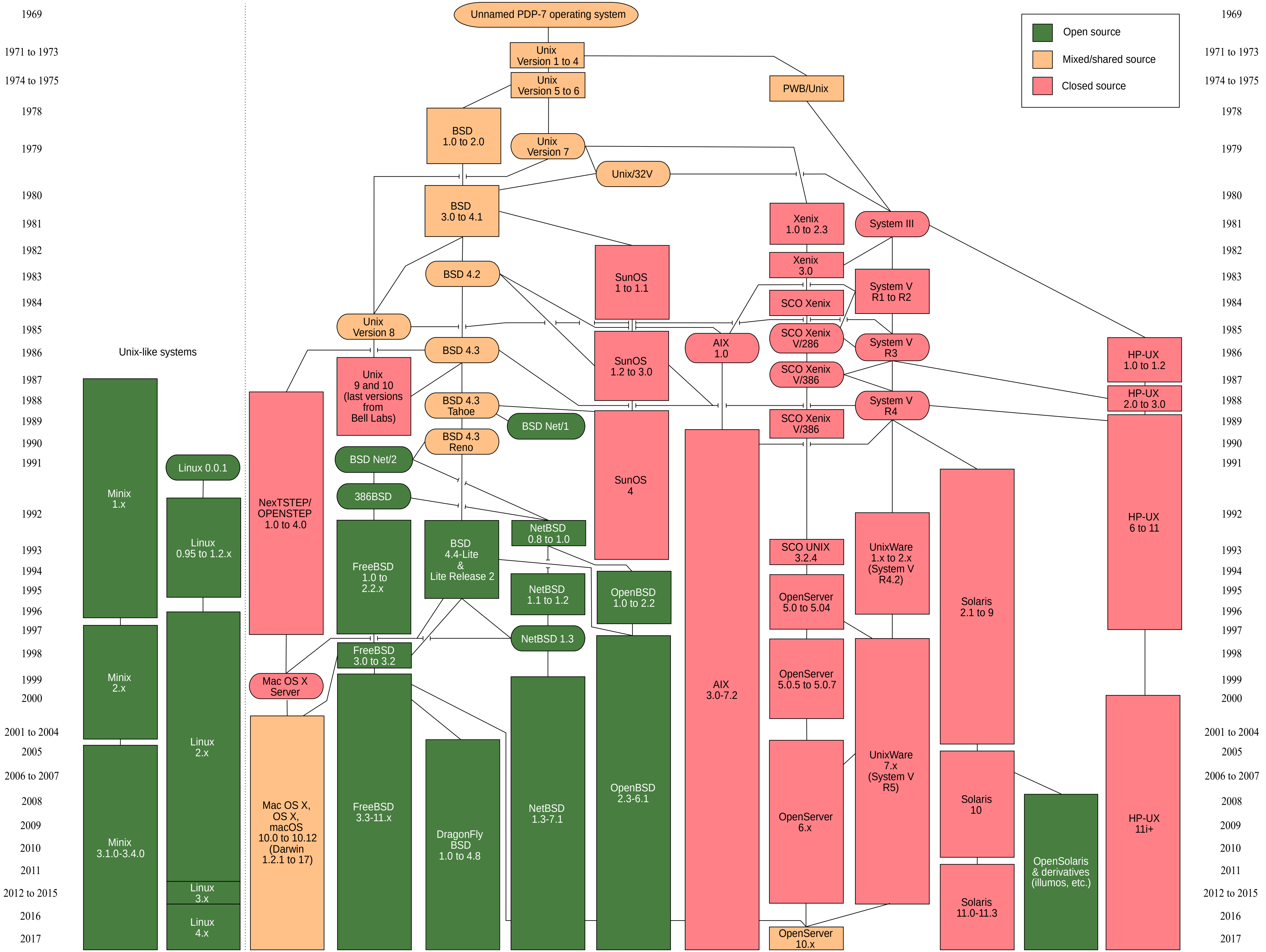
- 1980
  - Bell Labs finally shows interest in BSD Unix
  - Berkeley gets DARPA money because of VAX experience (Comp Systems Research Group)
  - users group for unlicensed (binary-only) users called '**usr**' (later UniForum)
  - Microsoft's 1st-ever os 'Xenix' announced for 8086-et-al,
    - based partly on BSD
    - heavily used at MS for software development and documentation
  - 4BSD incl Franz Lisp, **DARPA enhancements**, curses

The UNIX Time-Sharing System

- 1981
  - '4.1BSD includes speed tweaks and Delivermail
  - no-date: Unix lookalikes include: Onyx, Zeus, Cromix, Omnyx
  - 37yo professor Andy Tanenbaum of Free University in Amsterdam starts work on Minix teaching-system in response to AT&T's stricter license
- 1982
  - Intel intros 80286 with protected memory mode
  - AT&T's 1st commercial Unix, System III
  - AT&T 6300 w/PC Unix
  - no-date: Inix
  - MS Xenix 3.0 will be based on System III but include some 4.1BSD?
  - IBM's version for AT will be called IBM Xenix 1.0;
  - '4.1aBSD' adds TCP/IP and rlogin, etc sendmail?
  - Microsoft promises Xenix ports for PDP-11, 8086, Z8000, and 68000

The UNIX Time-Sharing System

- 1983
  - Apple Lisa runs MS Xenix?
  - DEC abandons PDP-10, MIT shifts to VAX w/Unix
  - MIT launches Project Athena
    - networked workstations to replace Multics
  - 4.2BSD released
  - Stallman announces GNU project
- 1984
  - AT&T divested, Unix becomes commercial product;
    - source code restricted
  - 750 universities have Unix licenses
  - X/Open formed by 5 European computer manufacturers: Bull, ICL, Siemens, Olivetti, and Nixdorf (BISON)
  - MS Xenix System V begins new numbering scheme: IBM calls it IBM Xenix 2.0, SCO calls it SCO Xenix 2.0
  - Earliest SCO copyrights on Xenix 3.x
  - Stallman starts GNU Emacs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Mixed/shared source
Closed source
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BSD 4.3
SunOS 1.2 to 3.0
HP-UX 1.0 to 1.2
Unix 9 and 10 (last versions from Bell Labs)
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BSD 4.3 Tahoe
System V R4
HP-UX 2.0 to 3.0
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SCO Xenix V/386
BSD 4.3 Reno
Minix 1.x
Linux 0.0.1
BSD Net/2
NeXTSTEP/ OPENSTEP 1.0 to 4.0
SunOS 4
386BSD
NetBSD 0.8 to 1.0
HP-UX 6 to 11
Linux 0.95 to 1.2.x
FreeBSD 1.0 to 2.2.x
BSD 4.4-Lite & Lite Release 2
SCO UNIX 3.2.4
UnixWare 1.x to 2.x (System V R4.2)
Solaris 2.1 to 9
NetBSD 1.1 to 1.2
OpenBSD 1.0 to 2.2
OpenServer 5.0 to 5.04
AIX 3.0-7.2
Minix 2.x
Linux 2.x
NetBSD 1.3
FreeBSD 3.0 to 3.2
Mac OS X Server
OpenServer 5.0.5 to 5.0.7
Mac OS X, OS X, macOS 10.0 to 10.12 (Darwin 1.2.1 to 17)
FreeBSD 3.3-11.x
DragonFly BSD 1.0 to 4.8
NetBSD 1.3-7.1
OpenBSD 2.3-6.1
OpenServer 6.x
UnixWare 7.x (System V R5)
Solaris 10
OpenSolaris & derivatives (illumos, etc.)
HP-UX 11i+
Minix 3.1.0-3.4.0
Linux 3.x
Linux 4.x
Solaris 11.0-11.3
OpenServer 10.x

The UNIX Time-Sharing System

- 1985
  - Stallman founds Free Software Foundation
  - POSIX standard (Portable Operating System) to reconcile BSD and AT&T variants
  - X-Windows distributed as free
  - X/Open Portability Guide
  - Intel 80386DX can address 4 gigabyte of memory
- 1986
  - 4.3BSD adds speed tweaks
  - Andy Tanenbaum rewrites Unix from scratch
    - for a teaching system on PC/XT/AT/386

The UNIX Time-Sharing System

- 1988
  - AT&T invests in Sun, threatening Unix dominance
  - Open Software Foundation (IBM, DEC, HP, et al)
    - builds on Mach and IBM's AIX; develops Motif
  - NeXT chooses Mach kernel
- 1989
  - open-source components of 4.3BSD released as Networking Release 1
  - AT&T System V v4.0 unifies Xenix, SunOS, 4.3BSD
  - Bill and Lynne Jolitz conceive free 386BSD

The UNIX Time-Sharing System

- 1990
  - 4.3BSD-Reno includes improved virtual memory via Mach
  - Linus takes first C programming class,
    - learns Digital Unix
- 1991
  - Berkeley includes Jolitz's free-but-incomplete 386 BSD on updated Networking Release 2
  - BSD Networking Release 2 includes all but six Unix files
  - linux 0.01 (64kb) 0.02 0.11

Linux

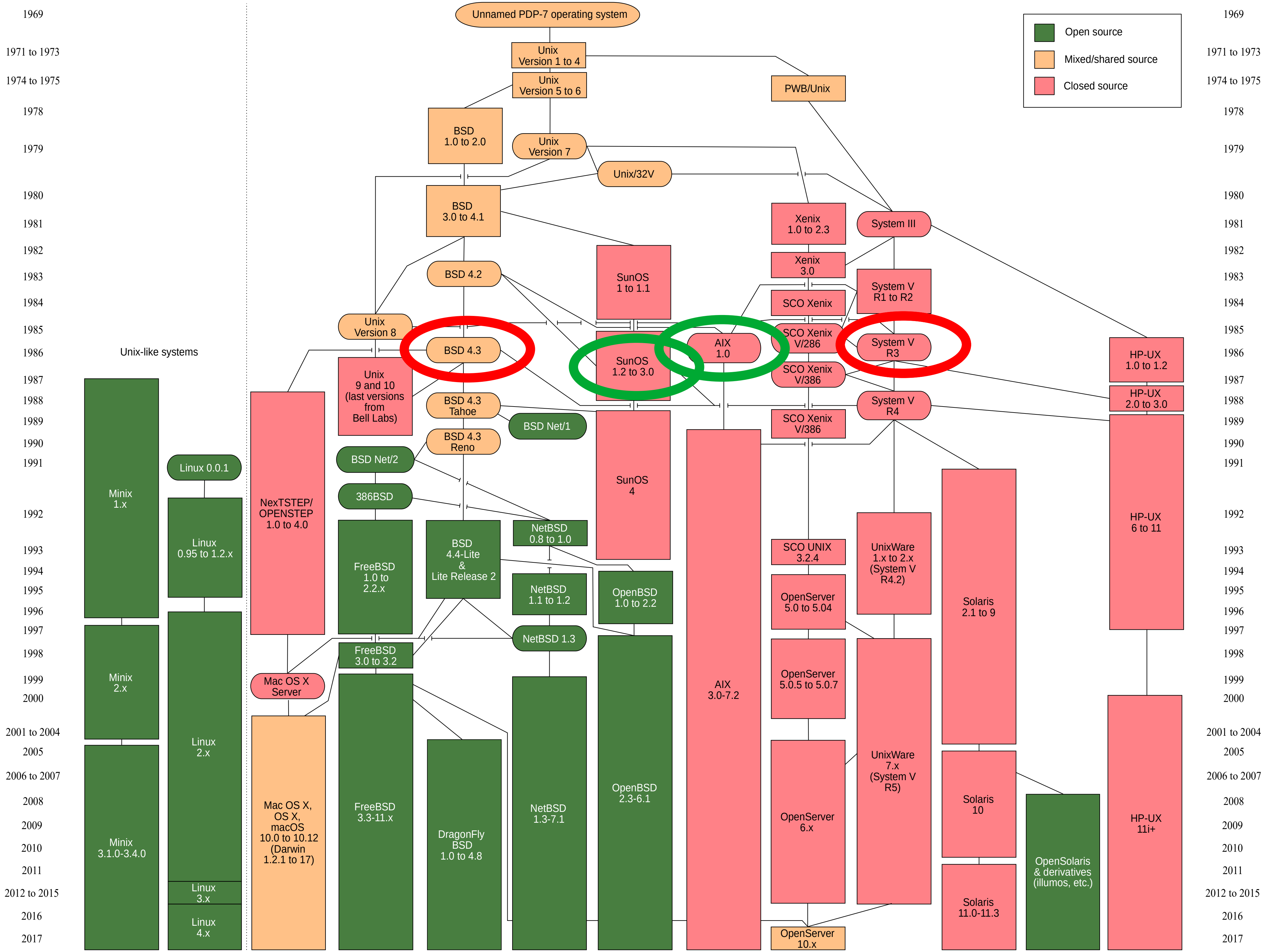
- In 1991, Linus Torvalds announced the Linux project
  - A free Unix kernel for x86 systems
  - Used Gnu tools from the very beginning
- By 1993, Linux had both internet capability and X capability
  - Just in time for the big internet boom

Standartization

June 1986 USENIX conference in Atlanta

- Many AT&T staff wore buttons which read,
  - “System V: Consider it Standard,”
- and a number of major vendors were promoting products based on System V.

- On the other hand, System V did not yet have TCP/IP networking built innd
  - BSD 4.2 did;
- vendors of engineering workstations were nearly all using BSD, and buttons and posters that said
  - “4.2 > V”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OpenServer 5.0.5 to 5.0.7
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FreeBSD 3.3-11.x
DragonFly BSD 1.0 to 4.8
NetBSD 1.3-7.1
OpenBSD 2.3-6.1
UnixWare 7.x (System V R5)
OpenServer 6.x
Solaris 10
OpenSolaris & derivatives (illumos, etc.)
HP-UX 11i+
Minix 3.1.0-3.4.0
Linux 3.x
Linux 4.x
Solaris 11.0-11.3
OpenServer 10.x

- 1987, AT&T announced that it had purchased a large percentage of Sun Microsystems
  - Sun would receive preferential treatment as AT&T/UNIX Systems Labs developed new software.
- Sun announced that its next system would
  - not be a further extension of SunOS (BSD)
  - but would be derived from AT&T’s System V4.
- DEC, in particular, sensed that AT&T was no longer the benign, benevolent progenitor of UNIX

Open Software Foundation

- January 7, 1988 meeting
  - Apollo, DEC, Gould, Hewlett-Packard, Honeywell-Bull, InfoCorp, MIPS, NCR, Silicon Graphics, UniSoft, Unisys
- semi-secret meetings that included
  - HP, IBM, Bull (France), and Nixdorf and Siemens (Germany)
- May 1988,
  - announced the formation of the Open Software Foundation to be dedicated to the production
    - of an operating system, a user interface, a distributed environment,
    - and free cotton candy.

- 1991–92 the worldwide economy worsened.
  - Bull, DEC, IBM, and the computer side of Siemens all lost money.
  - AT&T resold its share of Sun.
- Sun (ATT) had adopted Motif (OSF);
- 1993 USL sold UNIX to Novell,
- OSF abandoned several of its previously announced products
  - shrink-wrapped software and the distributed management environment);
- Bull, Philips, and Siemens withdrew from sponsorship of OSF.

•1985-93's – FSF and Gnu

- Once you give people something for free, they don't want to have to pay for it
- The Free Software Foundation (1985)
  - Gnu (Gnu's not Unix)
  - Create free versions of popular tools
    - 1986 – gcc, 1987 – most tools
  - Overall goal was to develop a free kernel (It hadn't happened by 1993)
- Squabbling continued and Unix suffered

Free Software Foundation

- Founded by Richard Stallman
  - Wrote original version of gcc and gdb
  - Software should be free, because it should be free
    - As in “free speech, not free beer”
  - Wrote the General Public License (GPL)
    - You are free to do whatever you want as long as the source code goes with it no matter what
    - Controversy: Anything derived from a GPL’d work must itself be GPL’d

Open Source Movement

- Software should be free just because – FSF viewpoint
- Software should be free because free software is better – Open Source Movement viewpoint
  - Every problem can be eliminated if more people look at it

•Linux's Success

- Internet culture and newsgroup postings caused a group of similar minded people to contribute and create a worthwhile kernel
- A competing free attempt had problems
  - The free BSD attempt was mired in a lawsuit (3 files were copied illegally)
  - The Berkeley development group disbanded

OS architectures

- A general purpose OS is composed of:
  - Process manager
    - multiplexes the CPU time between the multiple execution units (processes)
  - memory manager
    - controls, manages and multiplexes the access to physical and virtual memory
  - Inter-process comunication
    - Implements and handles mechanism for processes to comunicate
  - I/O manager
    - manages comunication with perifheral (keyboard/screen, disk, network)
  - User interface
    - command line interpreter
    - GUI

OS organization

- Layered
- Monolithic
- Micro kernel
- Distributed
- VM based

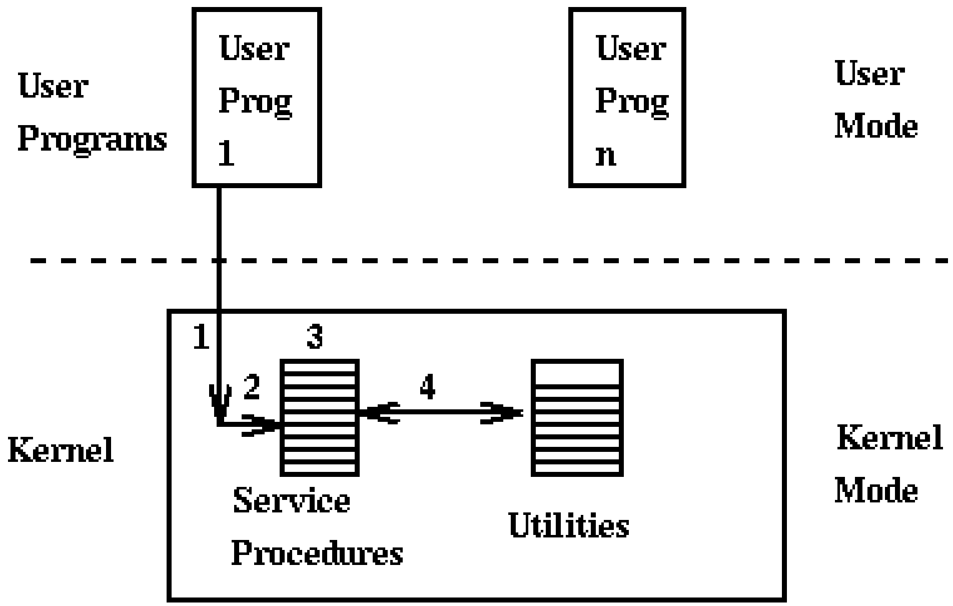
Monolithic architecture

- OS composed of a single module
  - Although using data abstraction
  - Although using layered approach
- All data and code use same memory space
  - low security mechanisms (one driver can mess other drivers)
  - Difficult to evolve (reboot of system needed)
- Easy to implement
- Low overhead

Monolithic architecture

- DOS
- First Unix versions

MONOLITHIC ARCHITECTURE

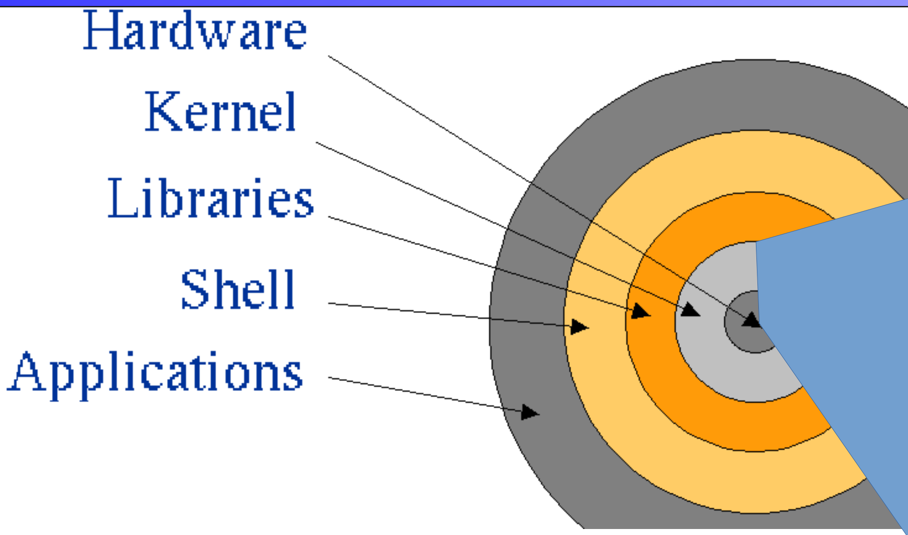


1. System call (User->Kernel Mode)
2. Check parameters
3. Call service routine
4. Service Routine call utilities

Reschedule/Return to user

Layered OS

- Components are divided into layers
  - grouping similar components
- Each layer only interacts with:
  - the bottom layer - requesting services
  - to top layer - answering requests
- Higher level layer
  - Applications
- lowest level layer
  - hardware
- Advantaged
  - good structure, well defined interface, ...
- Disadvantages
  - can be slow, may be difficult to define layers.



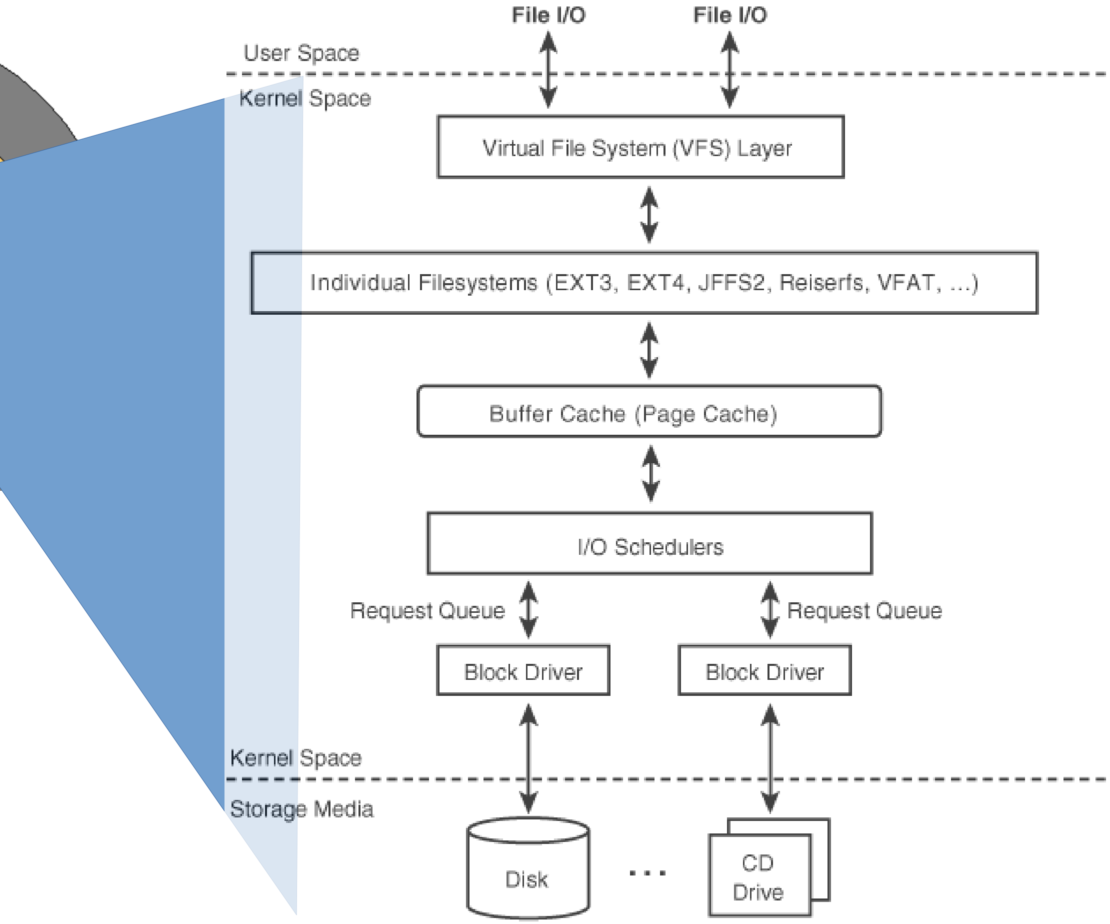
Hardware

Kernel

Libraries

Shell

Applications



File I/O

File I/O

User Space

Kernel Space

Virtual File System (VFS) Layer

Individual Filesystems (EXT3, EXT4, JFFS2, Reiserfs, VFAT, ...)

Buffer Cache (Page Cache)

I/O Schedulers

Request Queue

Request Queue

Block Driver

Block Driver

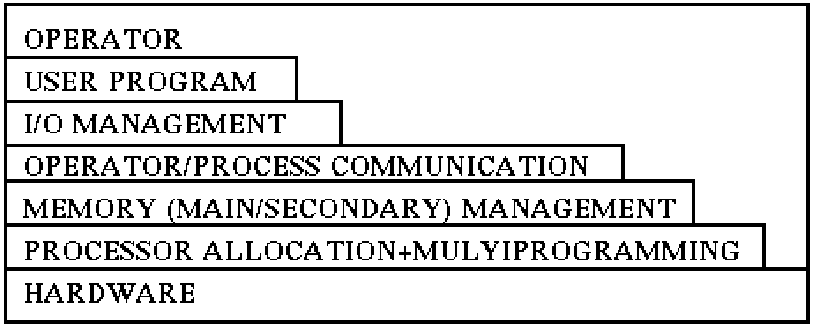
Kernel Space

Storage Media

Disk

. . .

CD Drive



OPERATOR

USER PROGRAM

I/O MANAGEMENT

OPERATOR/PROCESS COMMUNICATION

MEMORY (MAIN/SECONDARY) MANAGEMENT

PROCESSOR ALLOCATION+MULYIPROGRAMMING

HARDWARE

LAYERED SYSTEM (THE System, Dijkstra)

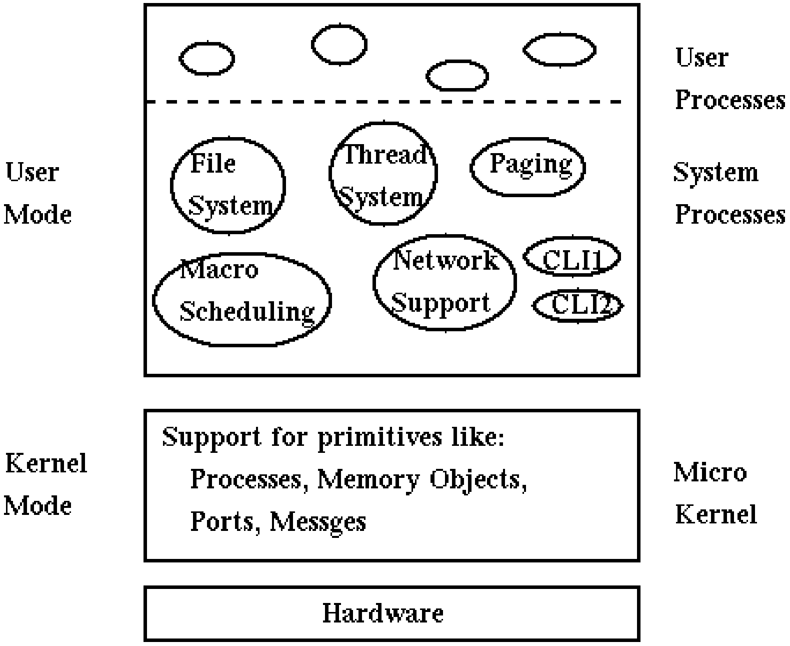
Microkernel

- Removes from kernel as much functionality as possible,
  - limiting the amount of code executed in privileged mode
  - allow easy modifications and extensions
- Most microkernels provide
  - process management
  - memory management
  - message passing between other services
- Security and protection can be enhanced
  - most services are performed in user mode, not kernel mode.
- System expansion can also be easier,
  - only involves adding more system applications, not rebuilding a new kernel.

Microkernel

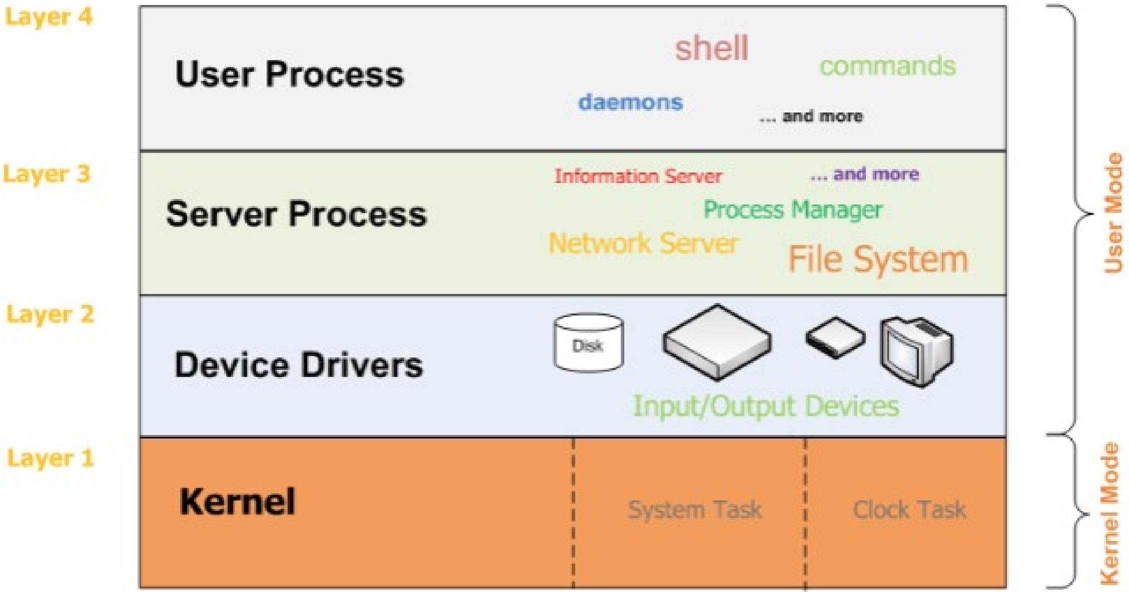
- Windows NT was originally microkernel
  - but suffered from performance problems relative to Windows 95.
  - NT 4.0 improved performance by moving more services into the kernel
- Multiple OSs can be buils on top of a micro-kernel
  - Each operating system will make use of different system processes.

Microkernel

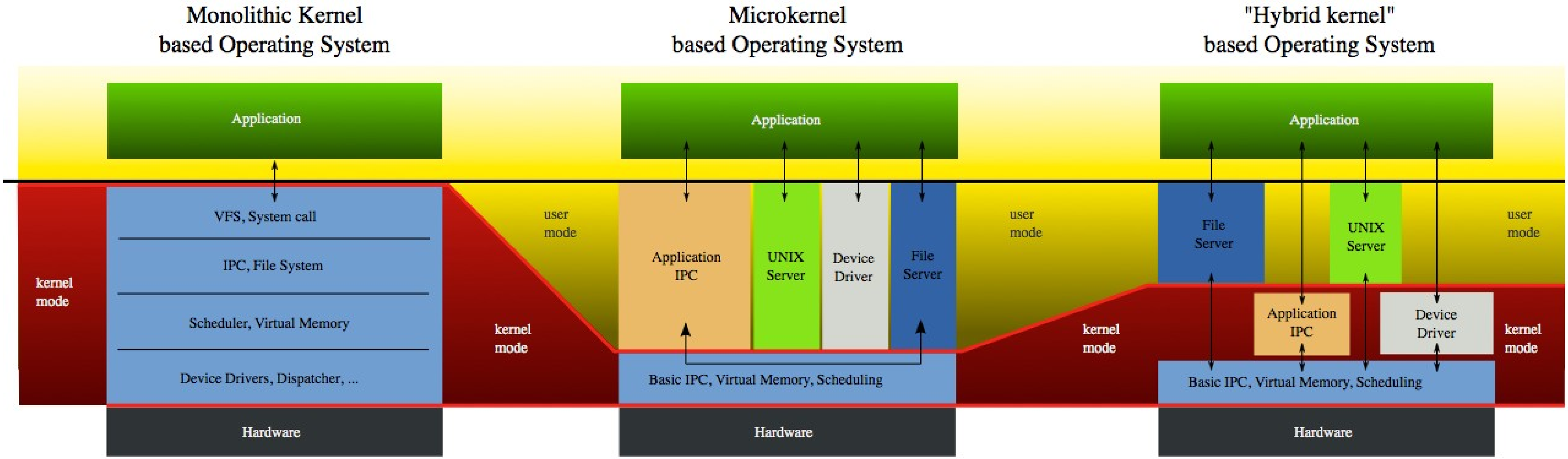


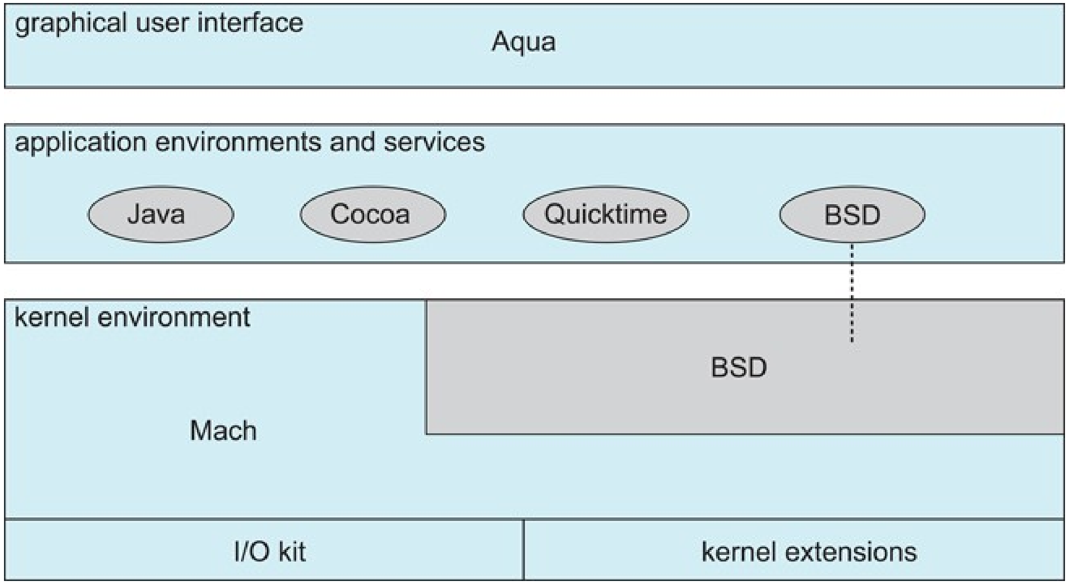
Micro–Kernel Architecture

Minix Layered Micro Kernel Architecture



Hibrid kernel



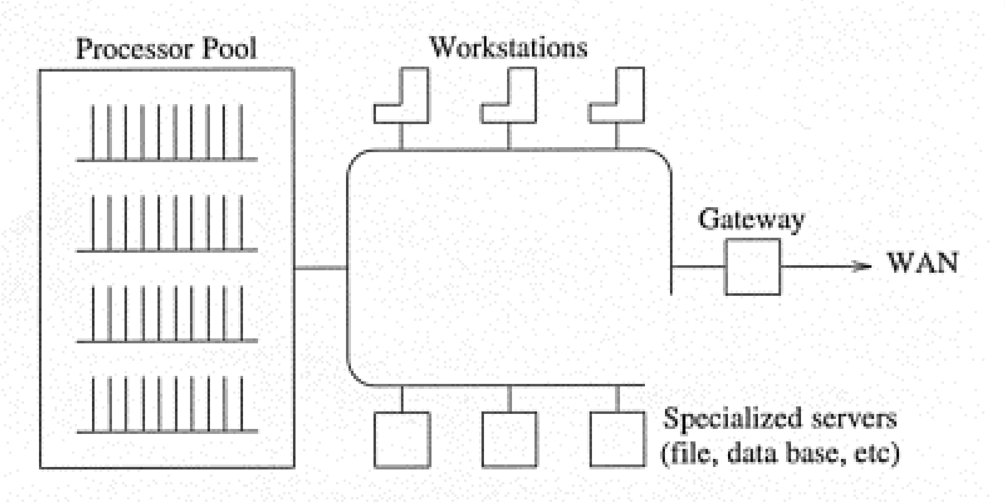


Distributed OS

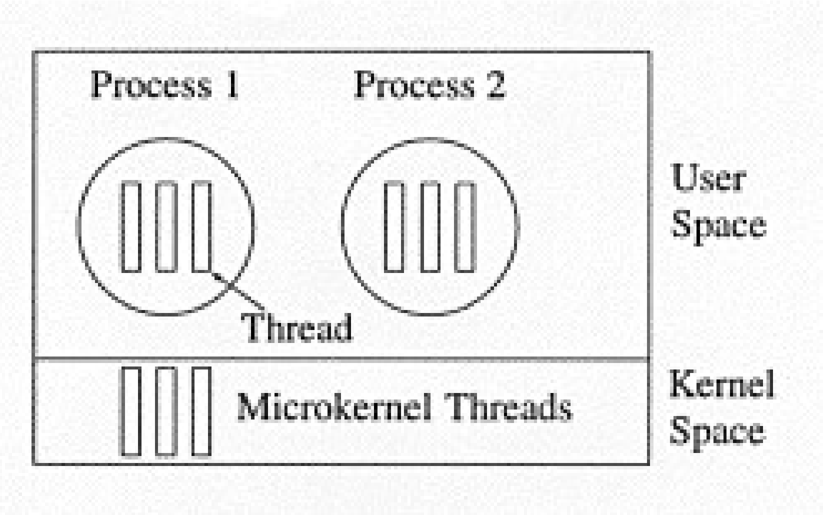
- Each component/service is a separated process
  - on the same machine
  - on different machines
- Components interactions
  - Messages / Remote procedures
- Distributed File System
- Distributed Memory
- Distributed Processes

Amoeba

- The Bullet Server
  - Used for file storage
- The Directory Server
  - Used for file naming
  - Maps from names to capabilities
- The Replication Server
  - Used for fault tolerence and performance
- The Run Server
  - Run server manages the processor pools
- The Boot Server
  - Ensures that servers are up and running
  - If it discovers that a server has crashed,
    - it attempts to restart it, otherwise selects another processor to provide the service



Processor Pool
Workstations
Gateway
WAN
Specialized servers
(file, data base, etc)



Process 1
Process 2
User
Space
Thread
Kernel
Space
Microkernel Threads