CS5250: Advanced Operating Systems

AY2021-2022 Semester 2

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Objectives of CS5250

- Understand the user needs and environmental constraints that drive the design of operating systems
- Understand the overall structure and design of any modern operating system especially in how their interact
- Understand the tradeoffs in the core algorithms and extend or modify them according to user needs
- Be equipped to take on more complex systems by being exposed to some of workings of actual systems

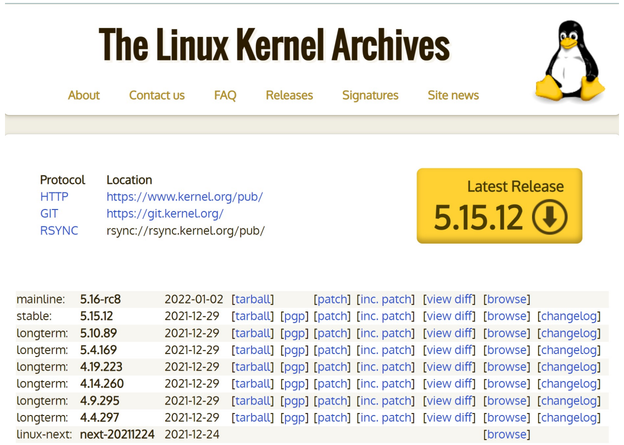
Syllabus

- Operating system design strategies including microkernels, mobile, embedded and real-time operating systems and the component’s interfaces
- Priority and resource allocation strategies
- Scheduling algorithms
- Naming, protection and security
- User interface, windowing systems
- Distributed and shared objects
- File system implementations including network and distributed file systems
- Failure and recovery
- Virtualization and the Internet-ready OS

But how exactly will we do it?

- The challenge: we can’t write a complex OS from scratch
  - Implementing the algorithms we will discuss often requires a lot of infrastructure support

- Deep dive into x86-Linux kernel source code
  - We will use Linux kernel 5.15.12



The Linux Kernel Archives

Protocol	Location
HTTP	https://www.kernel.org/pub/
GIT	https://git.kernel.org/
RSYNC	rsync://rsync.kernel.org/pub/

Latest Release
5.15.12

mainline:	5.16-rc8	2022-01-02	[tarball]		[patch]	[inc. patch]	[view diff]	[browse]	
stable:	5.15.12	2021-12-29	[tarball]	[pgp]	[patch]	[inc. patch]	[view diff]	[browse]	[changelog]
longterm:	5.10.89	2021-12-29	[tarball]	[pgp]	[patch]	[inc. patch]	[view diff]	[browse]	[changelog]
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linux-next:	next-20211224	2021-12-24						[browse]	

- Use hands-on assignment to advance our knowledge

Prerequisites

- C/C++ programming
- X86 assembly programming (if possible)
- A prior undergraduate course in operating systems

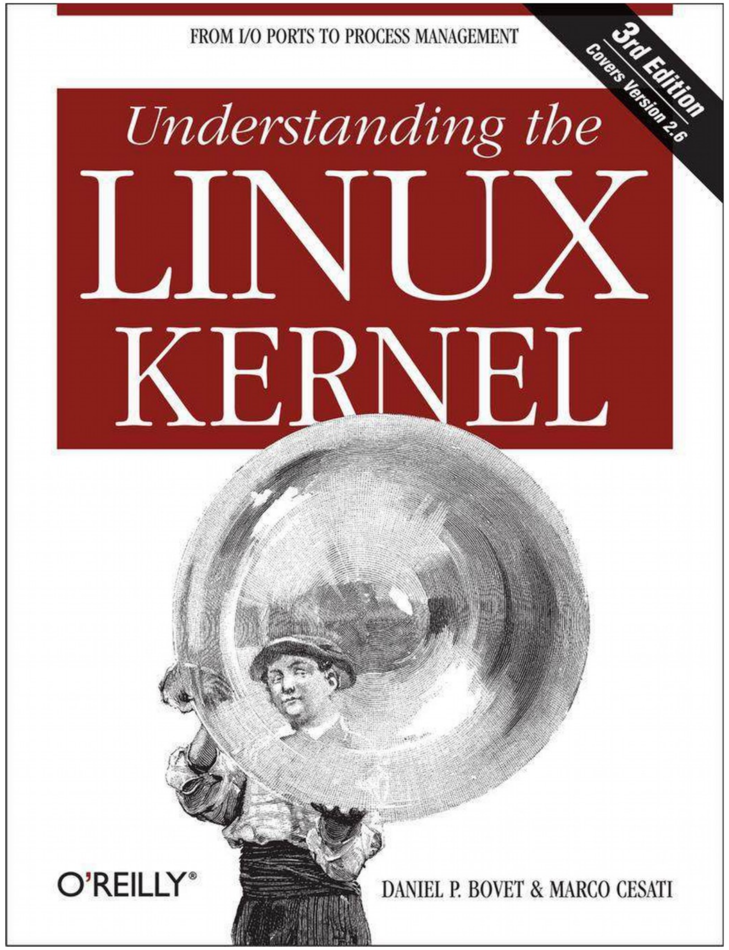
Assessments

- 60% continual assessment
  - Pop quizzes
  - No tutorial

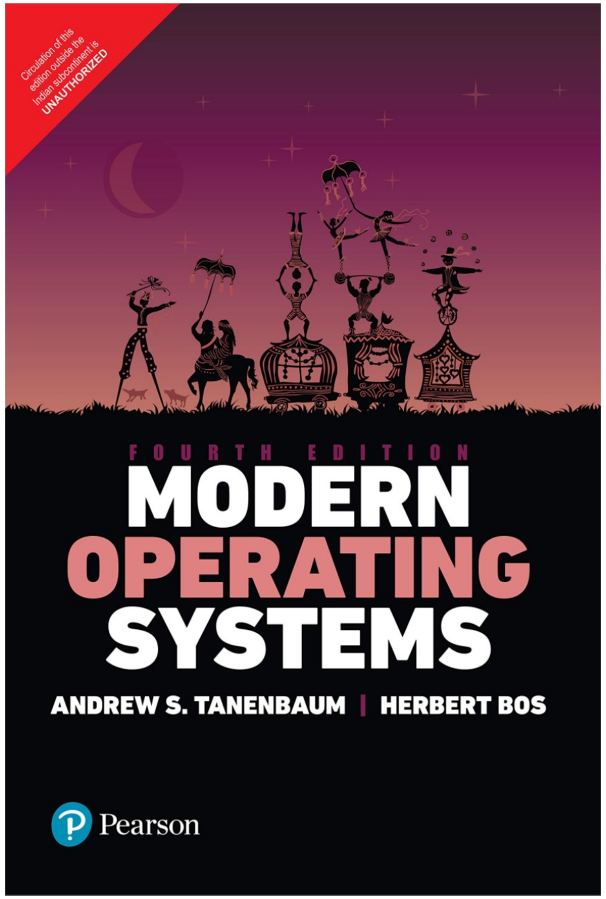
- 40% final assessment
  - Final assessment in the afternoon of Friday, 6 May 2022

- 4 take-home individual assignments

Reference Text


FROM I/O PORTS TO PROCESS MANAGEMENT
3rd Edition
Covers Version 2.6
Understanding the
LINUX
KERNEL
O'REILLY®
DANIEL P. BOVET & MARCO CESATI

Supplementary texts (revision)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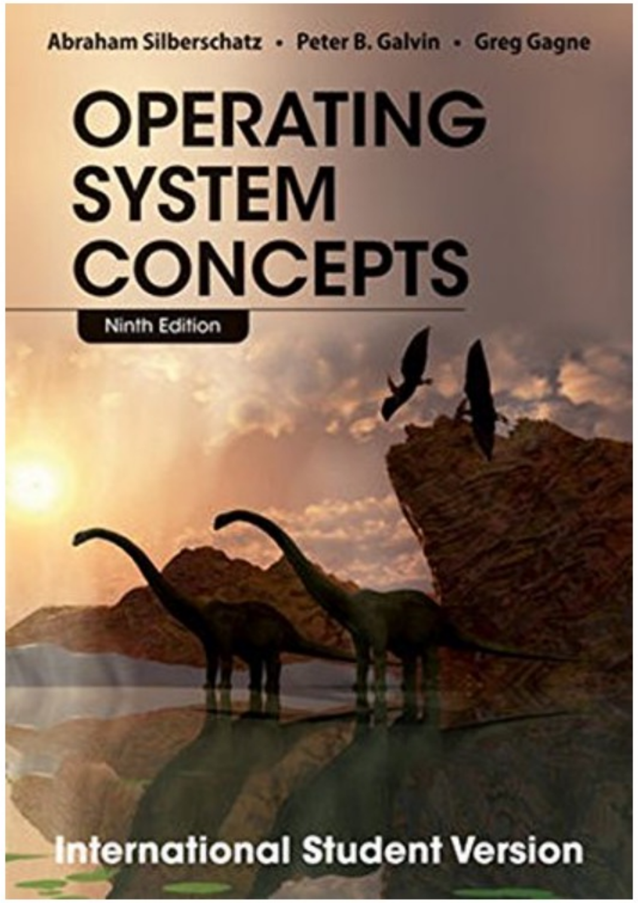
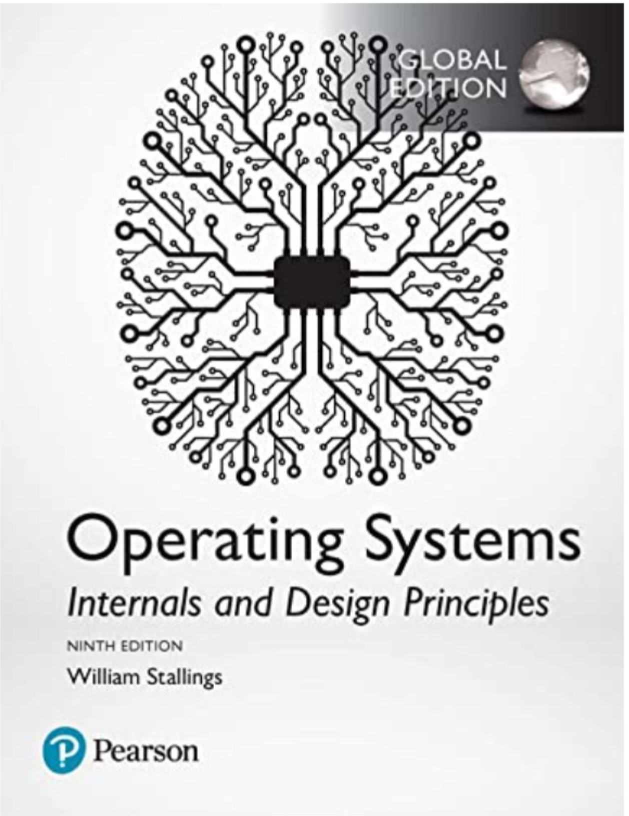
FOURTH EDITION
MODERN OPERATING SYSTEMS
ANDREW S. TANENBAUM | HERBERT BOS
Pearson

https://www.amazon.sg/Modern-Operating-Systems-Andrew-Tanenbaum/dp/9332575770


Abraham Silberschatz • Peter B. Galvin • Greg Gagne
OPERATING SYSTEM CONCEPTS
Ninth Edition
International Student Version

https://www.amazon.sg/Operating-System-Concepts-Abraham-Silberschatz/dp/1118093755



https://www.amazon.sg/Operating-Systems-Internals-Design-Principles/dp/1292214295

Also: https://pages.cs.wisc.edu/~remzi/OSTEP/

Introduction

What is an Operating Systems?

- Low level programs that sits between the hardware and user applications

Functions of an operating systems

- Manage a computer system’s resources
- Provide user interface
- Provide services for applications

Key system resources

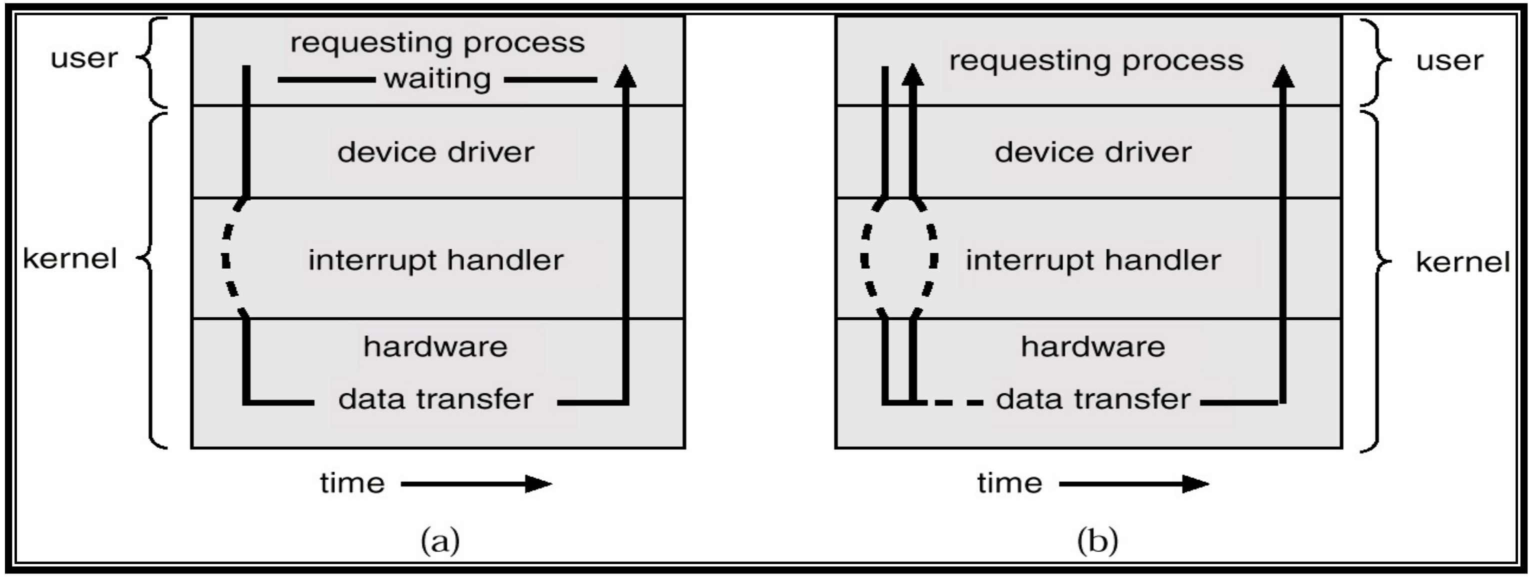
- Processors (cores)
- Memory
- Input/Output devices
  - Keyboard, mouse, monitor, and other human interface devices
  - Graphics card
  - Disk storage
  - Network
  - Printers, USB devices etc.
- Data and storage

Other key services

- Hardware abstraction
- Protection
- Sharing and data exchange
- Caching
- Interrupt handling

Hardware abstraction

- Provide regulated access to hardware
- Manufacturers provide “drivers” – software interfaces
- Provide book-keeping services



Protection

- Protect users (especially in a multiuser environment) against other users who may be malicious or plain ignorant

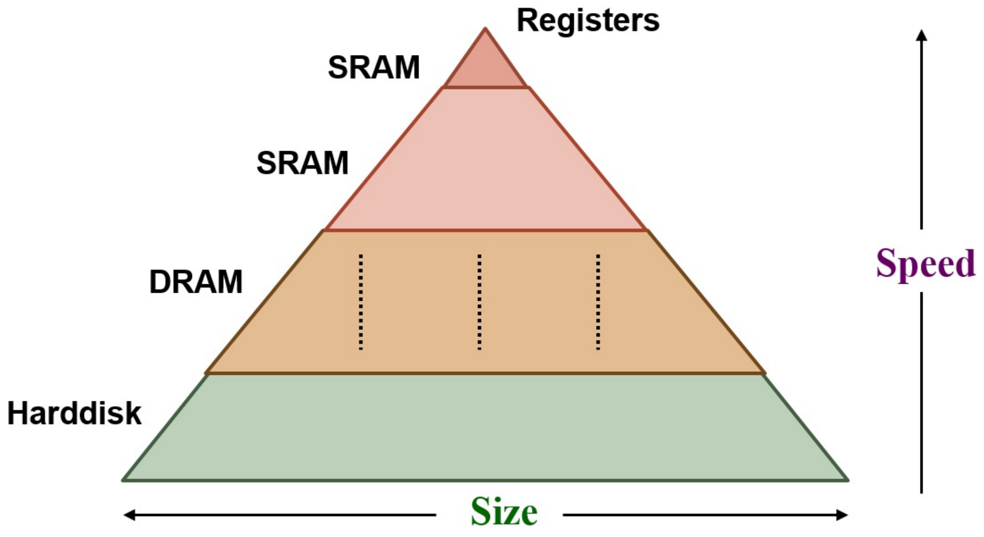
- At least two modes of protection enabled with hardware support:
  - User mode
  - Supervisor mode (root access)

Sharing

- Isolation vs sharing
- Need to establish that the sharing is legitimate
- Inter-process communication
- Via networking

Caching

- Caching is ubiquitous
  - To bridge differences in speeds and capacities
- Hardware caching
  - TLB, processor cache, disk caches
- Software caching
  - Page cache



Interrupt handling

- Interrupts – asynchronous to program execution
  - caused by external events
  - may be handled between instructions, so can let the instructions currently active in the pipeline *complete* before passing control to the OS interrupt handler
  - simply suspend and resume user program

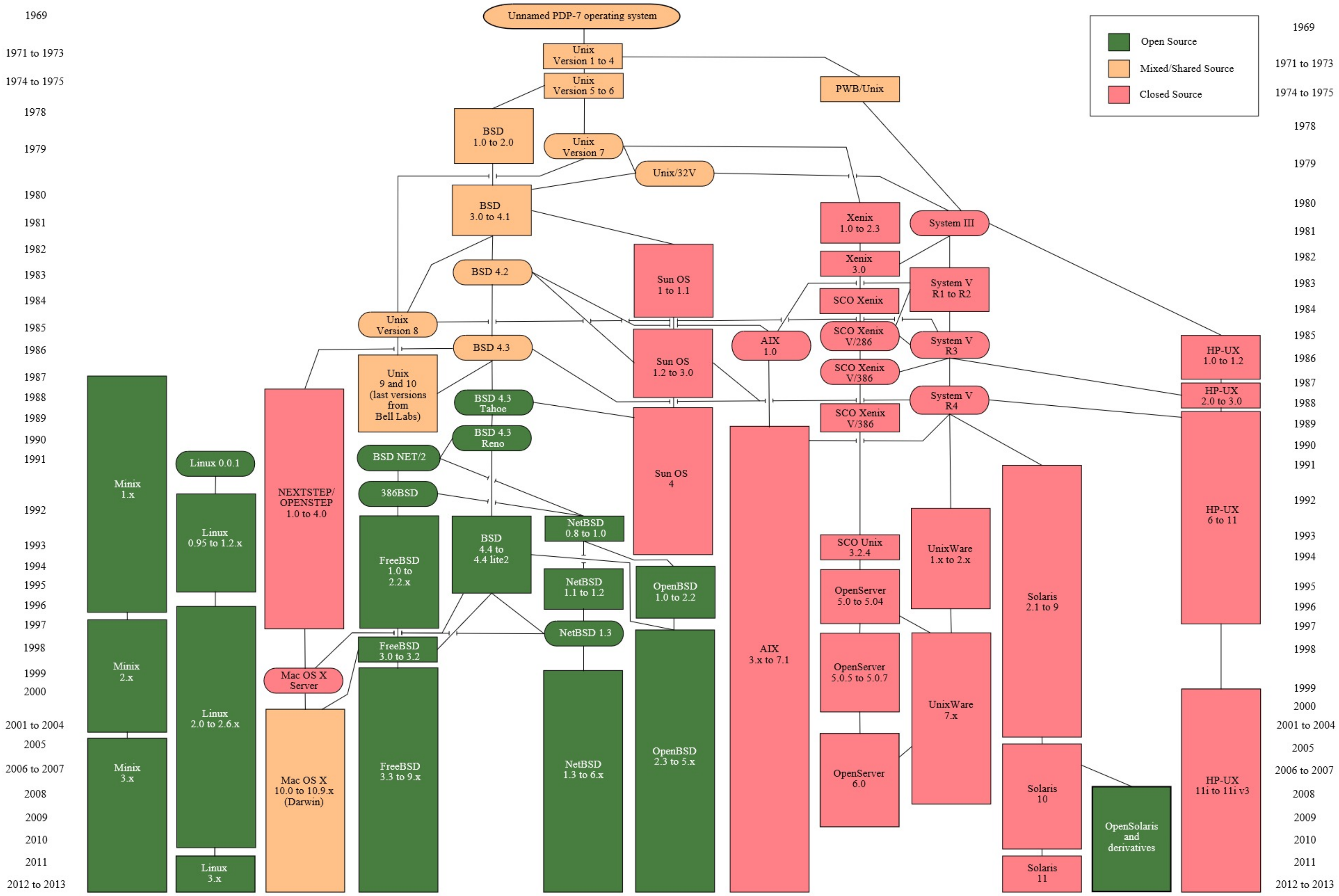
- Traps (Exception) – synchronous to program execution
  - caused by internal events
  - condition must be remedied by the trap handler for that instruction, so much stop the offending instruction *midstream* in the pipeline and pass control to the OS trap handler
  - the offending instruction may be retried (or simulated by the OS) and the program may continue or it may be aborted

Interrupt handling – examples

- Arithmetic overflow
- Undefined instruction
- TLB or page fault
- Segmentation fault
- I/O service request
- Hardware malfunction
- Timer

Key Operating Systems

Unix


1969
1971 to 1973
1974 to 1975
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1993
1994
1995
1996
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1998
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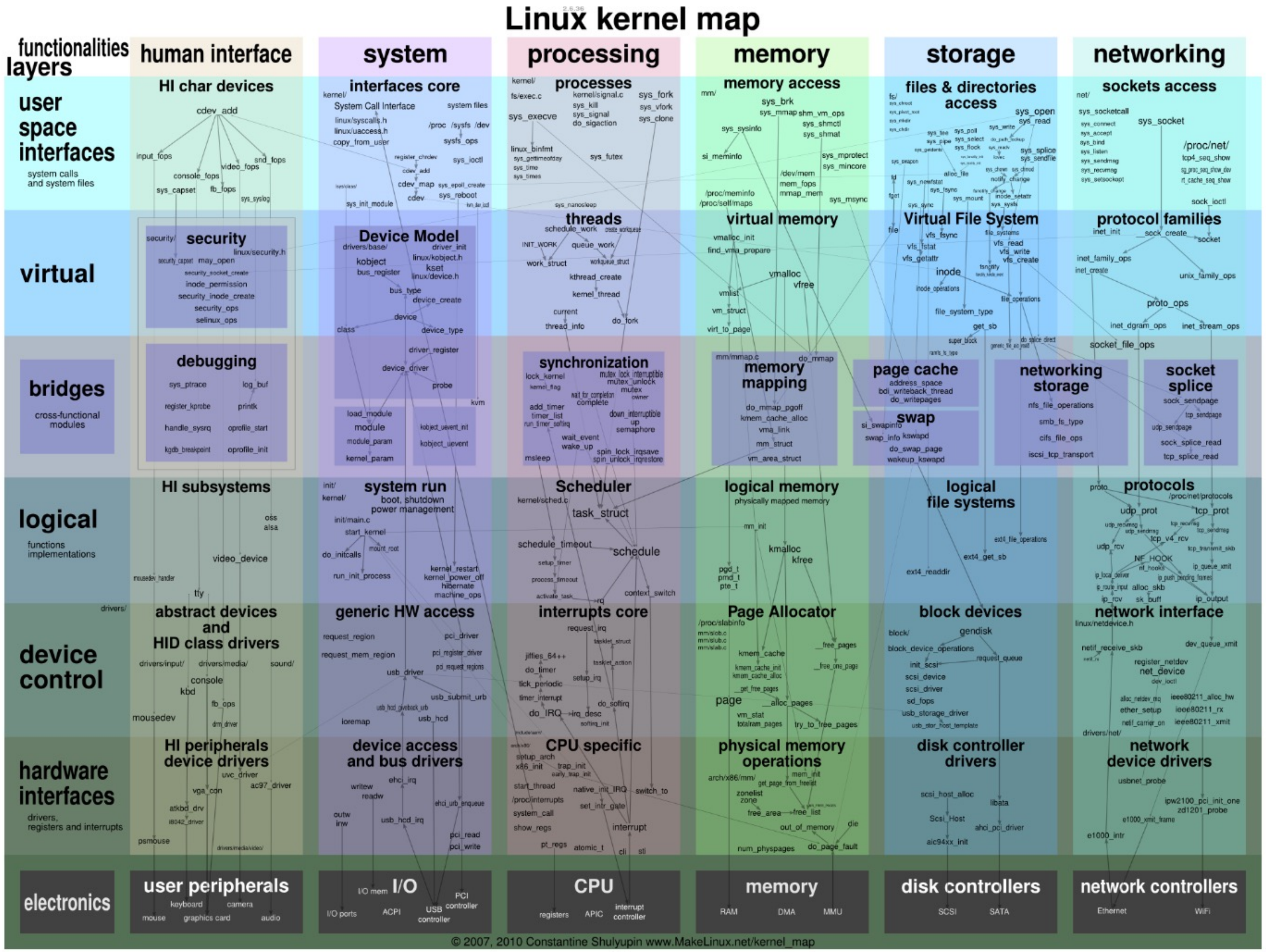
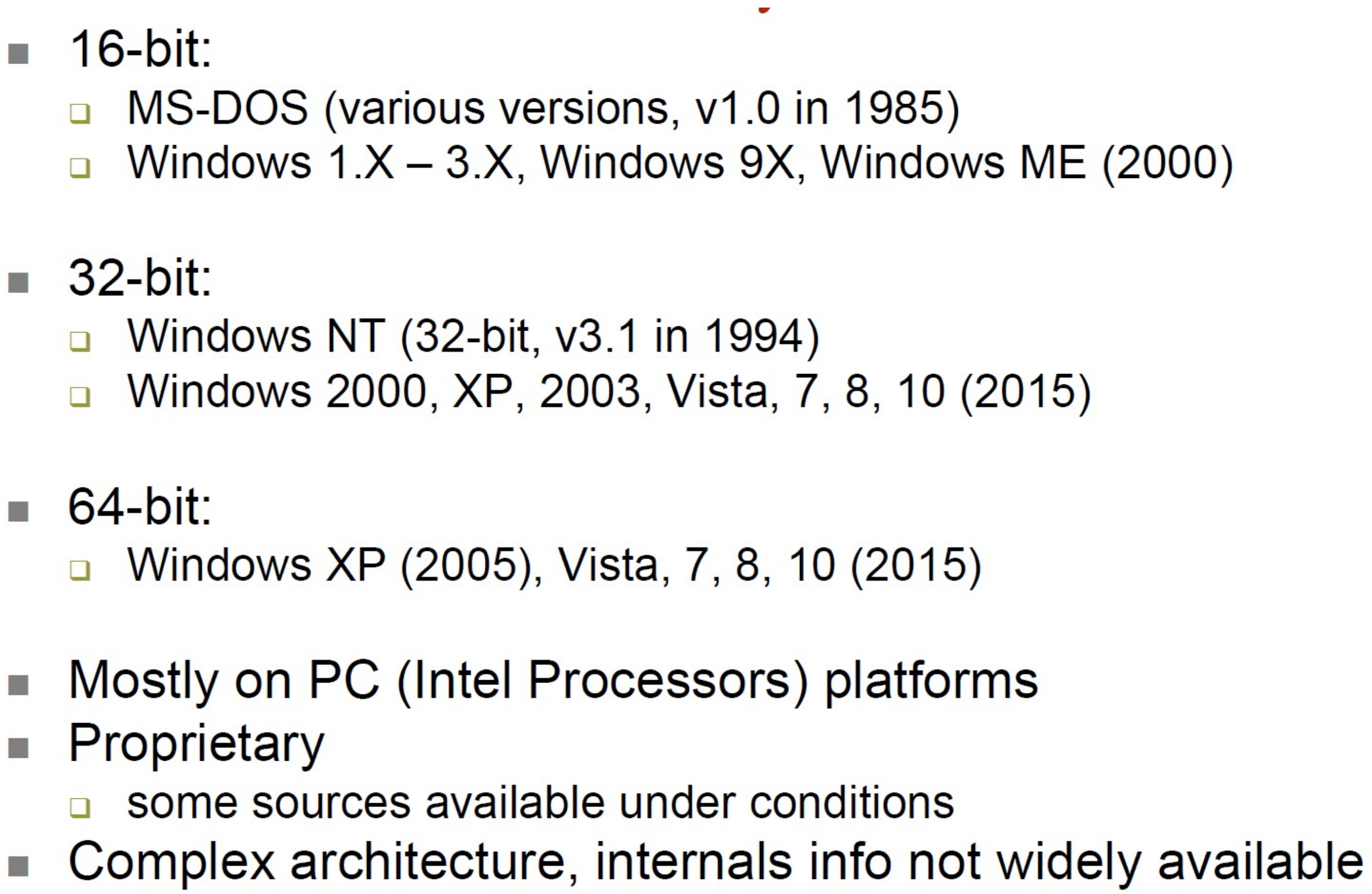
2000
2001 to 2004
2005
2006 to 2007
2008
2009
2010
2011
2012 to 2013
🟩 Open Source
🟧 Mixed/Shared Source
🟥 Closed Source
Unnamed PDP-7 operating system
Unix Version 1 to 4
Unix Version 5 to 6
PWB/Unix
BSD 1.0 to 2.0
Unix Version 7
Unix/32V
BSD 3.0 to 4.1
Xenix 1.0 to 2.3
System III
Xenix 3.0
BSD 4.2
Sun OS 1 to 1.1
System V R1 to R2
SCO Xenix
Unix Version 8
SCO Xenix V/286
AIX 1.0
System V R3
BSD 4.3
Sun OS 1.2 to 3.0
HP-UX 1.0 to 1.2
SCO Xenix V/386
Unix 9 and 10 (last versions from Bell Labs)
HP-UX 2.0 to 3.0
BSD 4.3 Tahoe
System V R4
SCO Xenix V/386
BSD 4.3 Reno
Minix 1.x
Linux 0.0.1
NEXTSTEP/ OPENSTEP 1.0 to 4.0
BSD NET/2
Sun OS 4
386BSD
Solaris 2.1 to 9
HP-UX 6 to 11
NetBSD 0.8 to 1.0
Linux 0.95 to 1.2.x
BSD 4.4 to 4.4 lite2
FreeBSD 1.0 to 2.2.x
SCO Unix 3.2.4
UnixWare 1.x to 2.x
NetBSD 1.1 to 1.2
OpenBSD 1.0 to 2.2
OpenServer 5.0 to 5.04
NetBSD 1.3
FreeBSD 3.0 to 3.2
AIX 3.x to 7.1
Minix 2.x
Mac OS X Server
OpenServer 5.0.5 to 5.0.7
Linux 2.0 to 2.6.x
UnixWare 7.x
OpenBSD 2.3 to 5.x
Mac OS X 10.0 to 10.9.x (Darwin)
FreeBSD 3.3 to 9.x
NetBSD 1.3 to 6.x
Minix 3.x
OpenServer 6.0
Solaris 10
HP-UX 11i to 11i v3
OpenSolaris and derivatives
Linux 3.x
Solaris 11

Linux

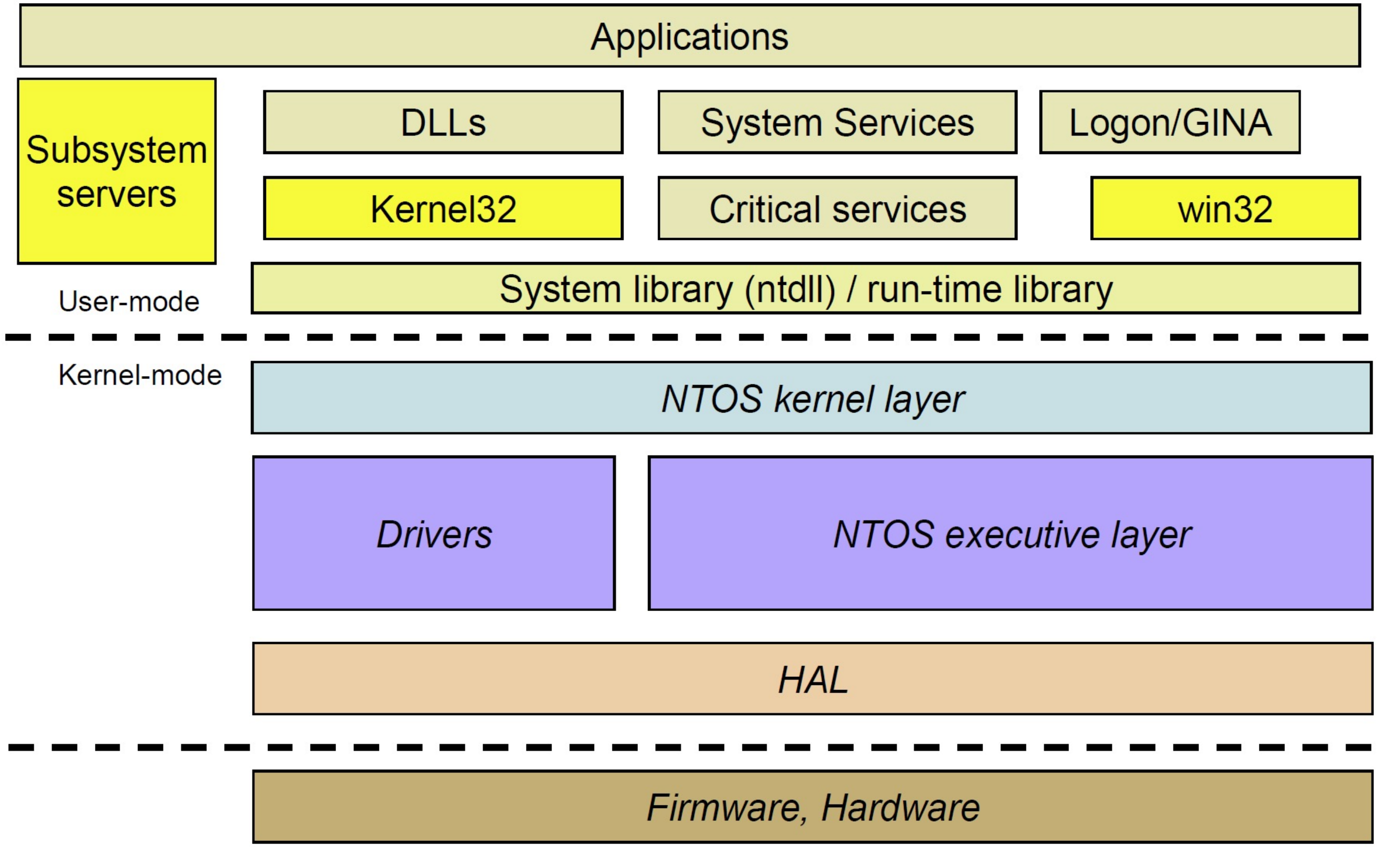

Linux kernel map
functionalities
layers
human interface
system
processing
memory
storage
networking
user space interfaces
system calls and system files
HI char devices
interfaces core
processes
memory access
files & directories access
sockets access
virtual
security
Device Model
threads
virtual memory
Virtual File System
protocol families
bridges
cross-functional modules
debugging
synchronization
memory mapping
page cache
swap
networking storage
socket splice
logical
functions implementations
HI subsystems
system run
boot, shutdown power management
Scheduler
logical memory
logical file systems
protocols
device control
abstract devices and HID class drivers
generic HW access
interrupts core
Page Allocator
block devices
network interface
hardware interfaces
drivers, registers and interrupts
HI peripherals device drivers
device access and bus drivers
CPU specific
physical memory operations
disk controller drivers
network device drivers
electronics
user peripherals
keyboard
camera
mouse
graphics card
audio
I/O
I/O mem
I/O ports
ACPI
USB controller
PCI controller
CPU
registers
APIC
interrupt controller
memory
RAM
DMA
MMU
disk controllers
SCSI
SATA
network controllers
Ethernet
WiFi
© 2007, 2010 Constantine Shulyupin www.MakeLinux.net/kernel_map

Microsoft Windows



- 16-bit:
  - MS-DOS (various versions, v1.0 in 1985)
  - Windows 1.X – 3.X, Windows 9X, Windows ME (2000)
- 32-bit:
  - Windows NT (32-bit, v3.1 in 1994)
  - Windows 2000, XP, 2003, Vista, 7, 8, 10 (2015)
- 64-bit:
  - Windows XP (2005), Vista, 7, 8, 10 (2015)
- Mostly on PC (Intel Processors) platforms
- Proprietary
  - some sources available under conditions
- Complex architecture, internals info not widely available

Microsoft Windows



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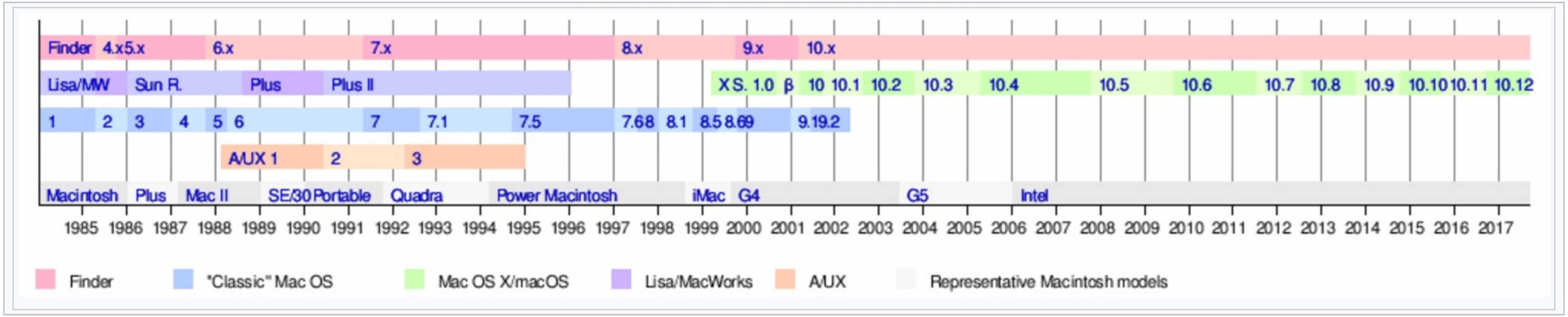
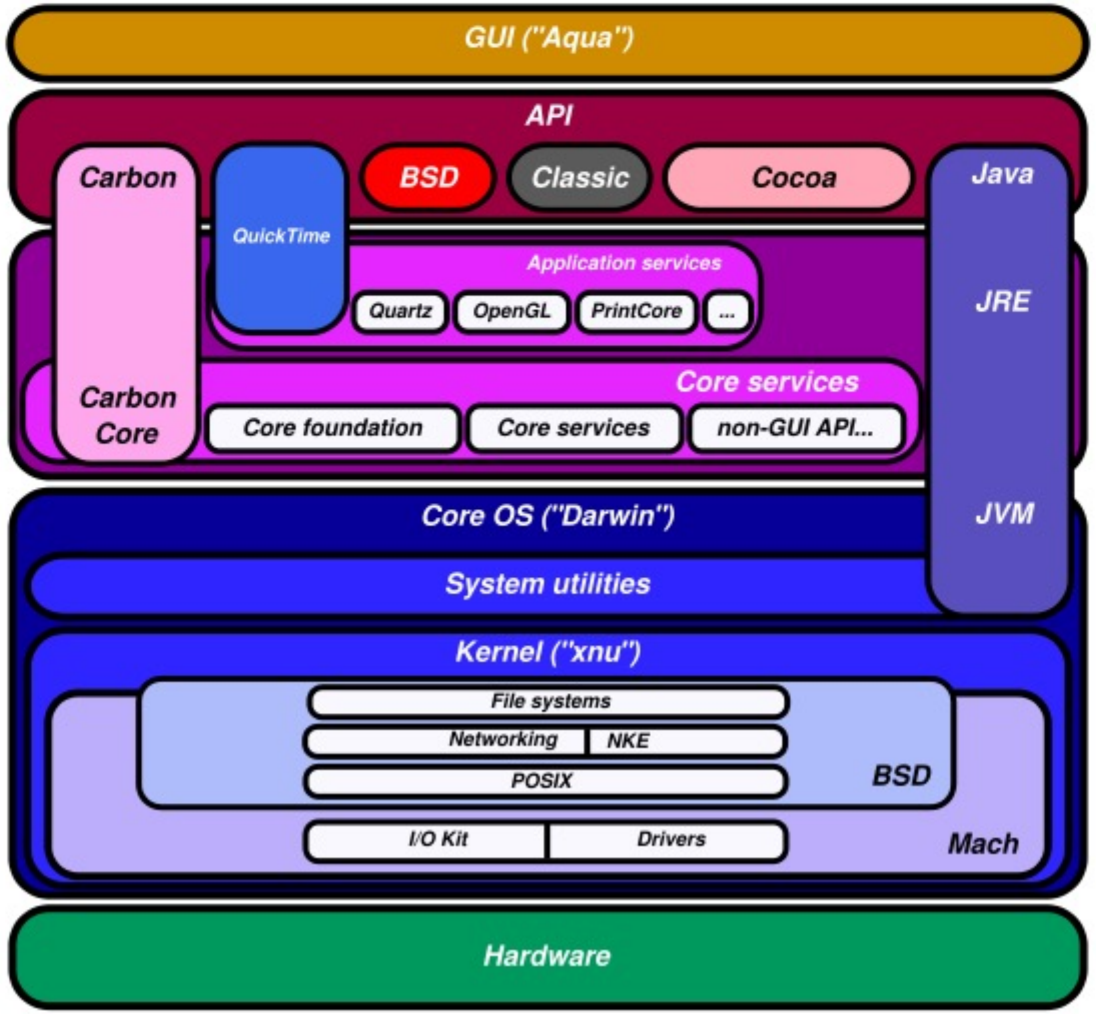
MacOS

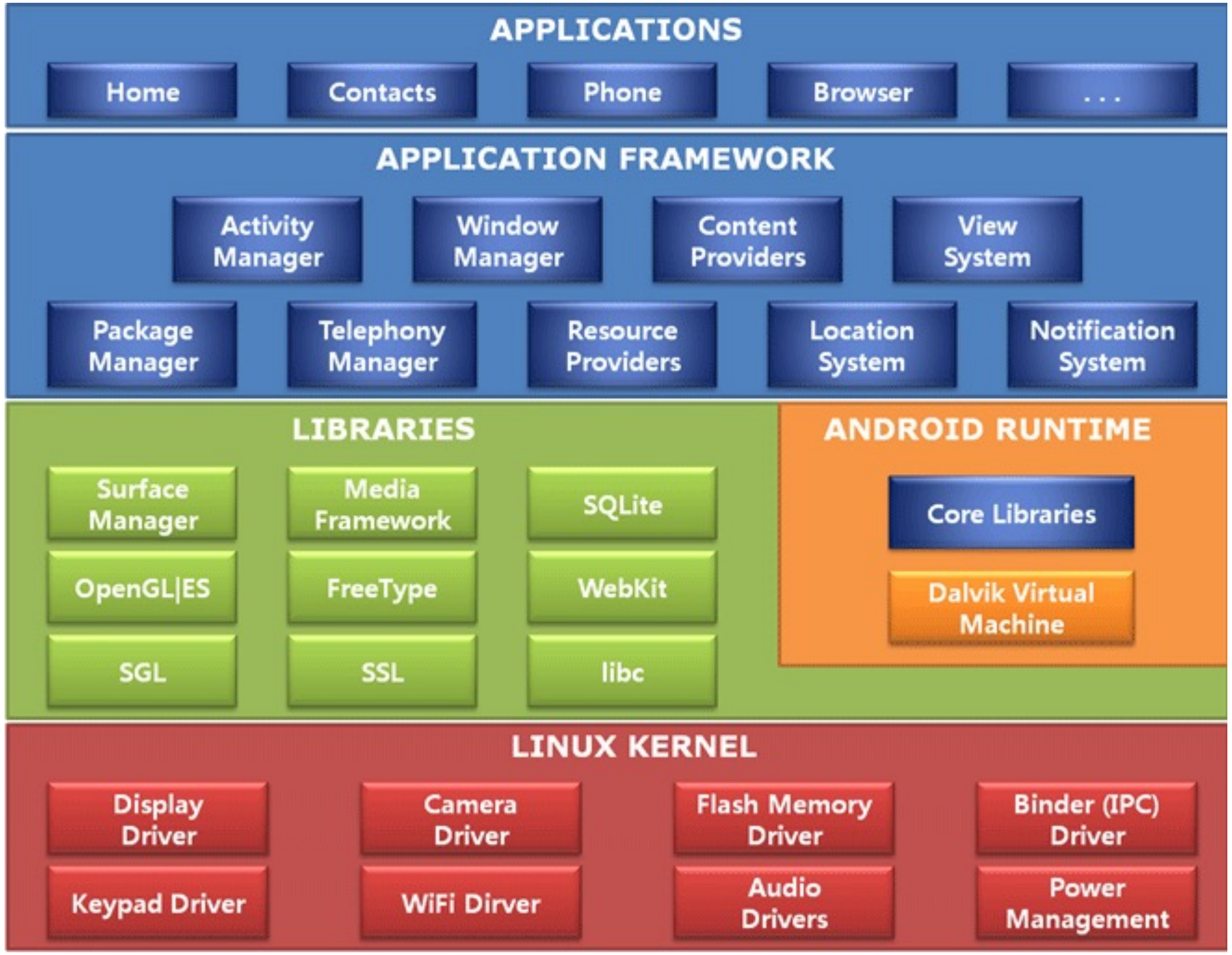
Timeline of Macintosh operating systems



MacOS


GUI ("Aqua")
API
Carbon
QuickTime
BSD
Classic
Cocoa
Java
JRE
JVM
Application services
Quartz
OpenGL
PrintCore
...
Carbon Core
Core services
Core foundation
Core services
non-GUI API...
Core OS ("Darwin")
System utilities
Kernel ("xnu")
File systems
Networking
NKE
POSIX
BSD
I/O Kit
Drivers
Mach
Hardware

Android OS



APPLICATIONS

Home, Contacts, Phone, Browser, . . .

APPLICATION FRAMEWORK

Activity Manager, Window Manager, Content Providers, View System

Package Manager, Telephony Manager, Resource Providers, Location System, Notification System

LIBRARIES

Surface Manager, Media Framework, SQLite

OpenGL|ES, FreeType, WebKit

SGL, SSL, libc

ANDROID RUNTIME

Core Libraries

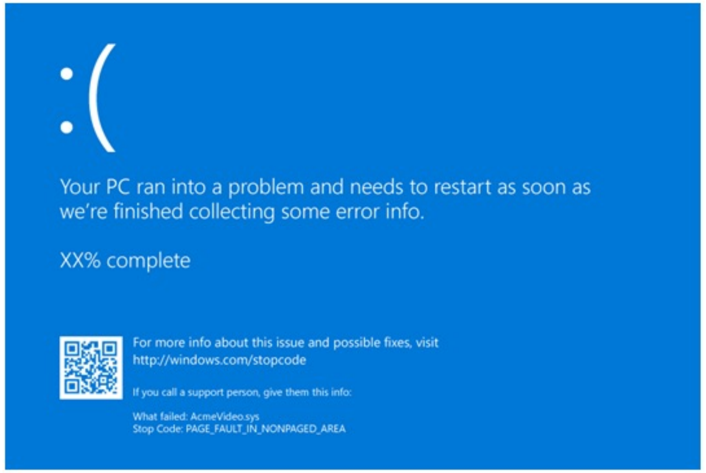
Dalvik Virtual Machine

LINUX KERNEL

Display Driver, Camera Driver, Flash Memory Driver, Binder (IPC) Driver

Keypad Driver, WiFi Dirver, Audio Drivers, Power Management

The Show Stopper



:(

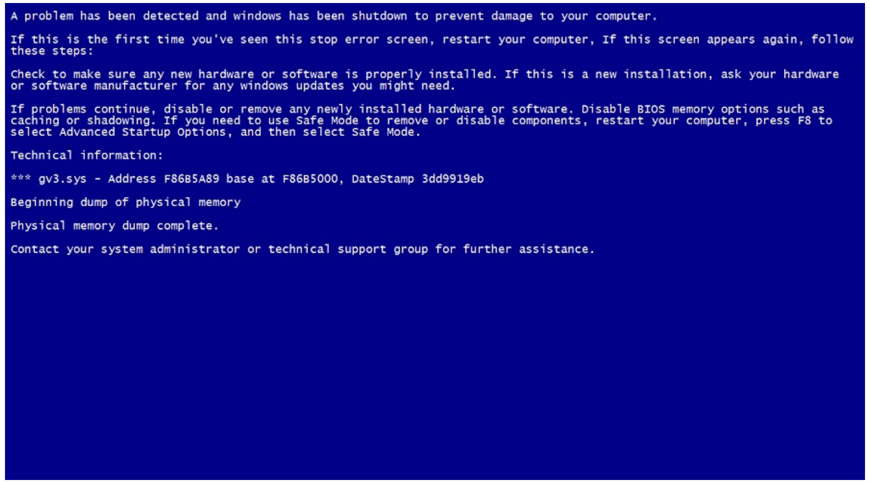
Your PC ran into a problem and needs to restart as soon as we're finished collecting some error info.

XX% complete

For more info about this issue and possible fixes, visit http://windows.com/stopcode

If you call a support person, give them this info:

What failed: AcmeVideo.sys
Stop Code: PAGE_FAULT_IN_NONPAGED_AREA



```
A problem has been detected and windows has been shutdown to prevent damage to your computer.

If this is the first time you've seen this stop error screen, restart your computer, If this screen appears again, follow
these steps:

Check to make sure any new hardware or software is properly installed. If this is a new installation, ask your hardware
or software manufacturer for any windows updates you might need.

If problems continue, disable or remove any newly installed hardware or software. Disable BIOS memory options such as
caching or shadowing. If you need to use Safe Mode to remove or disable components, restart your computer, press F8 to
select Advanced Startup Options, and then select Safe Mode.

Technical information:

*** gv3.sys - Address F86B5A89 base at F86B5000, DateStamp 3dd9919eb

Beginning dump of physical memory

Physical memory dump complete.

Contact your system administrator or technical support group for further assistance.
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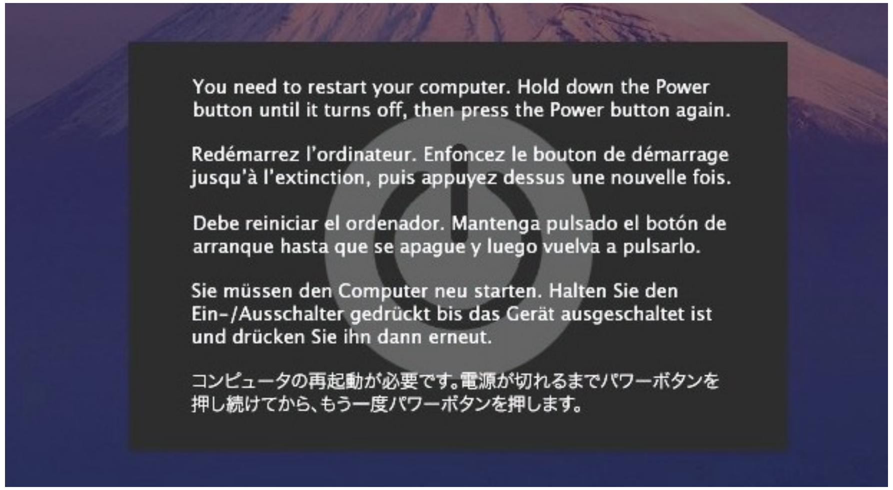


You need to restart your computer. Hold down the Power button until it turns off, then press the Power button again.

Redémarrez l'ordinateur. Enfoncez le bouton de démarrage jusqu'à l'extinction, puis appuyez dessus une nouvelle fois.

Debe reiniciar el ordenador. Mantenga pulsado el botón de arranque hasta que se apague y luego vuelva a pulsarlo.

Sie müssen den Computer neu starten. Halten Sie den Ein-/Ausschalter gedrückt bis das Gerät ausgeschaltet ist und drücken Sie ihn dann erneut.

コンピュータの再起動が必要です。電源が切れるまでパワーボタンを押し続けてから、もう一度パワーボタンを押します。

Characteristics of OSes

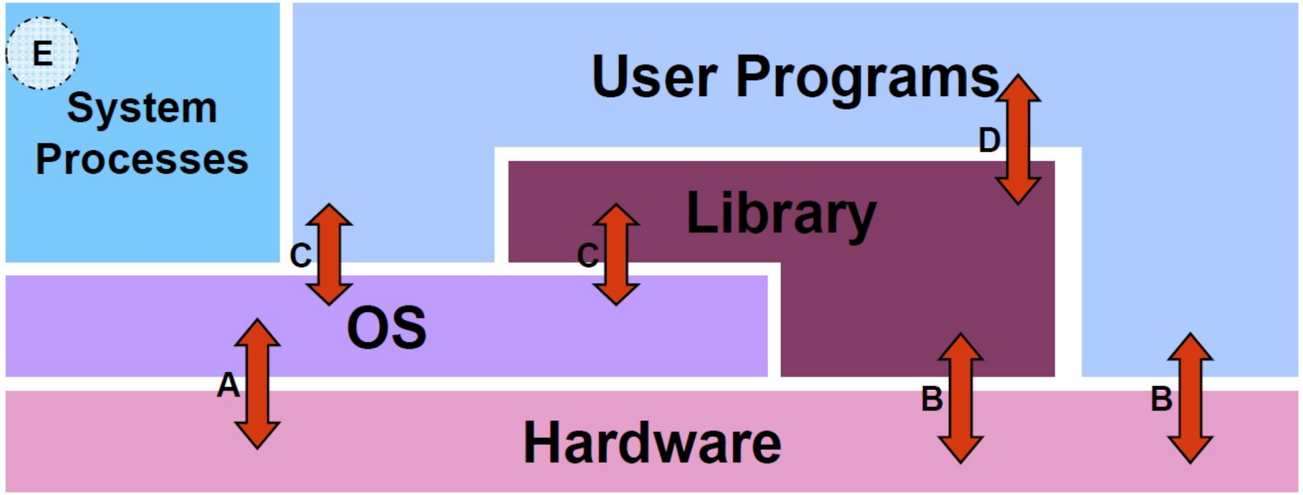
Types of OS

- Batch
    - Data centers
- Interactive
    - PCs
    - Mobile devices
- Real-time
    - Embedded systems
    - Robots
- Hybrid

Structures of OS

- Monolithic
- Microkernel
- Network OS
- Distributed OS
- Exokernels

A Generic OS

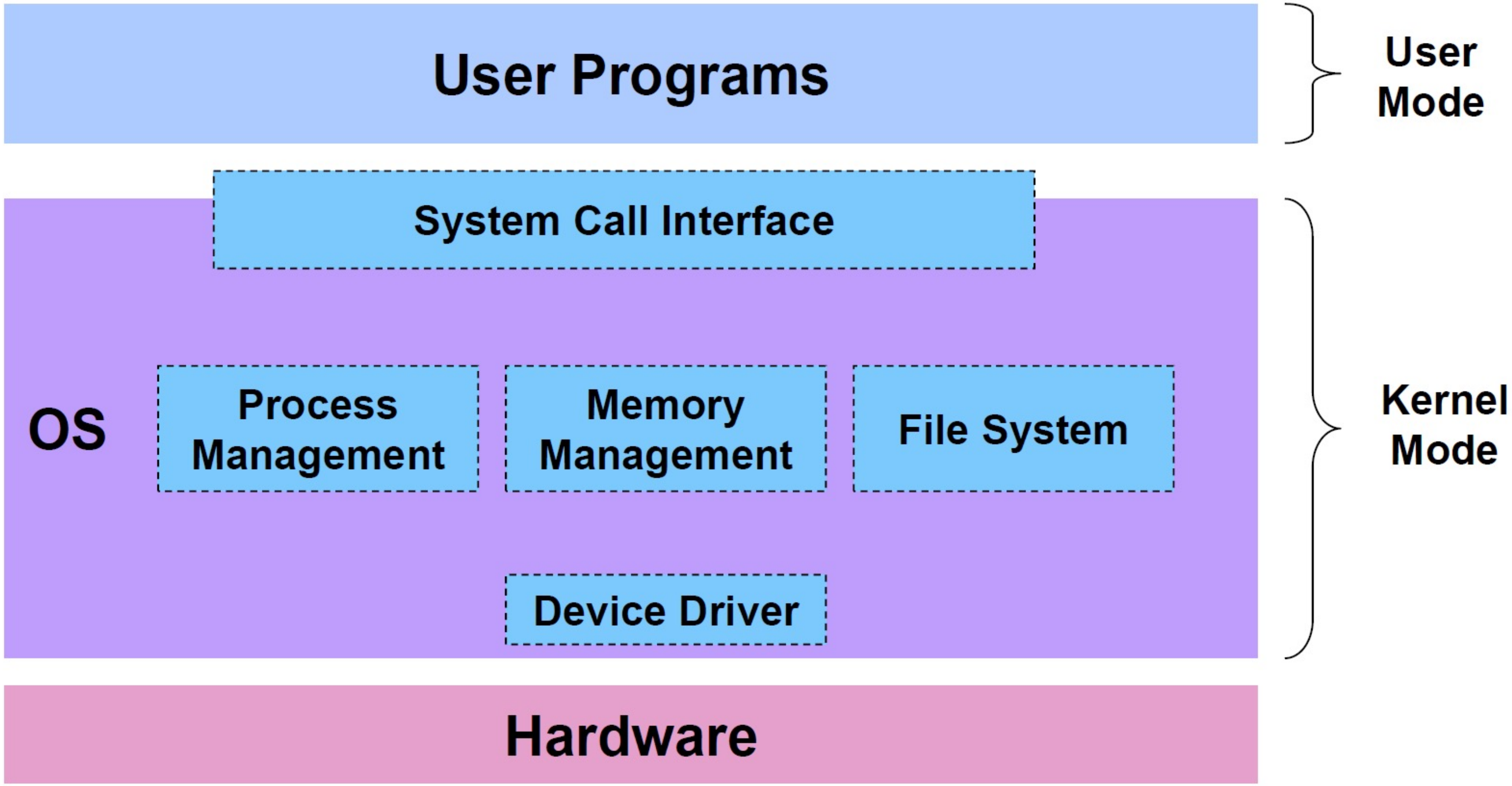


- **A**: OS executing machine instructions
- **B**: normal machine instructions executed (program/library code)
- **C**: calling OS using ***system call interface***
- **D**: user program calls library code
- **E**: system processes
  - Provide high level services, usually part of OS

Monolithic Design

- Usually a single large process
- Runs in a single address space – the kernel space
- Often a single binary file loaded at boot time
  - With other processes and files such as drivers assisting

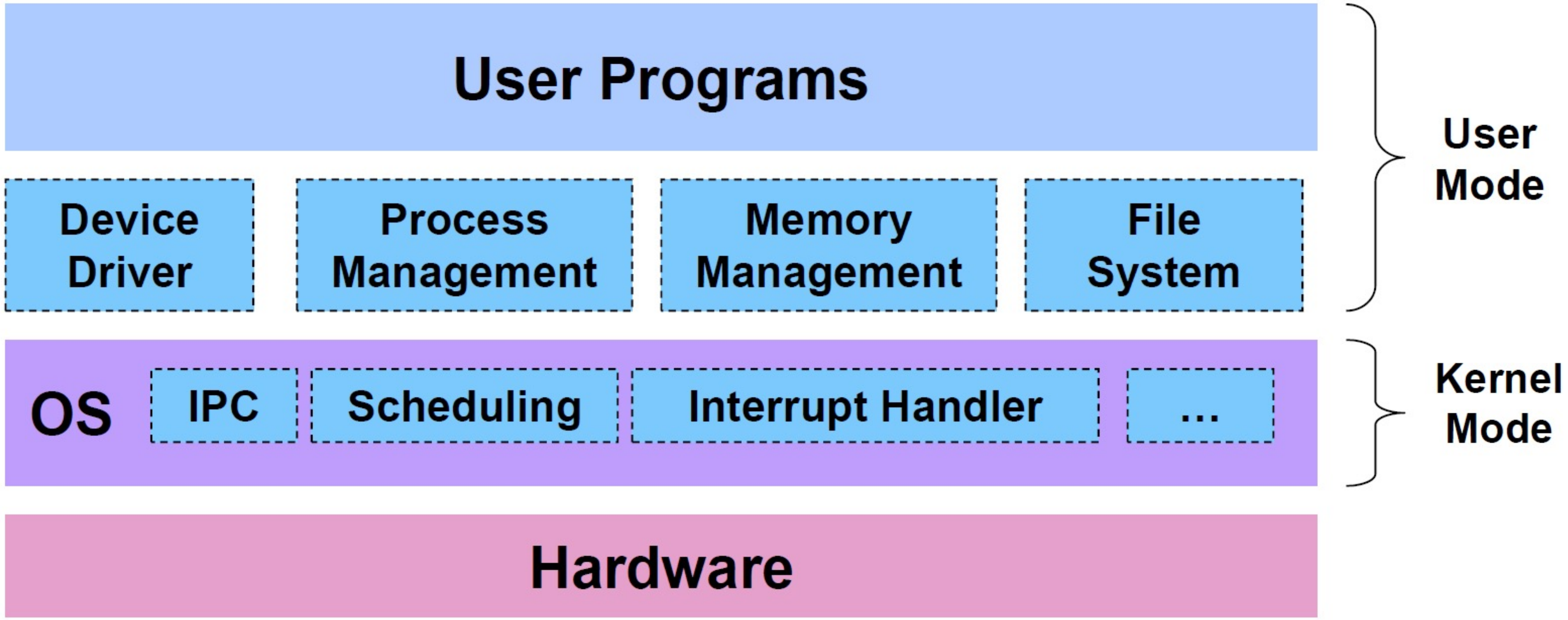
Monolithic Design



Microkernel

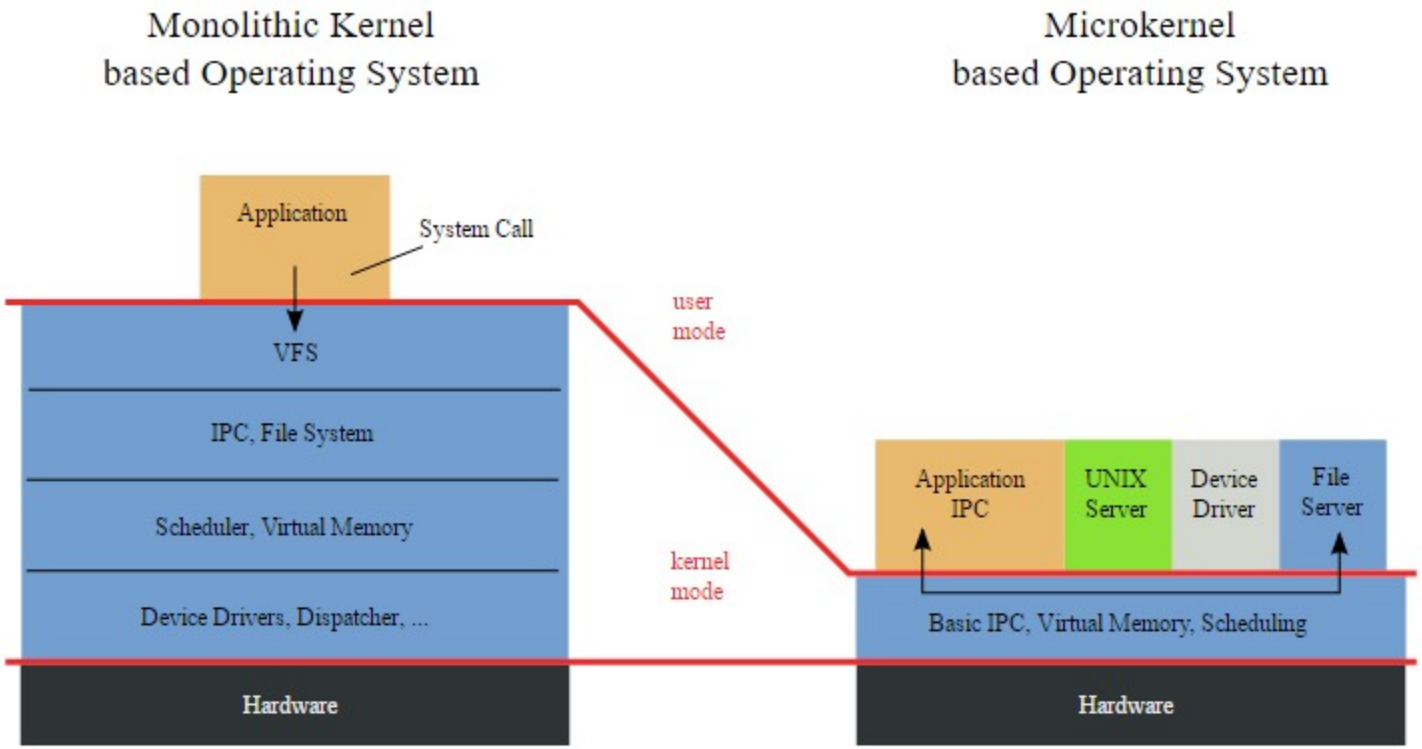
- Small kernel supporting minimal essential services
    - IPC, virtual memory, processing scheduling, interrupt handling, protection
- All other services handled by separate user level server processes
- Applications request for services from the server processes

Microkernel Design



Example: MINIX 3 – kernel only 12,000 lines

Microkernel – using IPC



Microkernel pros and cons

- Security advantage
  - Principle of Least Privilege
    - “only enough privilege to do what is required – and no more”
    - A problem bugging Windows

- Performance disadvantage
  - IPC requires 2 OS kernel crossing and process scheduling

Exokernels

- Squeeze kernel even further by removing more of its management duties

- Give applications direct access to hardware via libraries

- Experimental