Computer Architecture & Real-Time Operating System

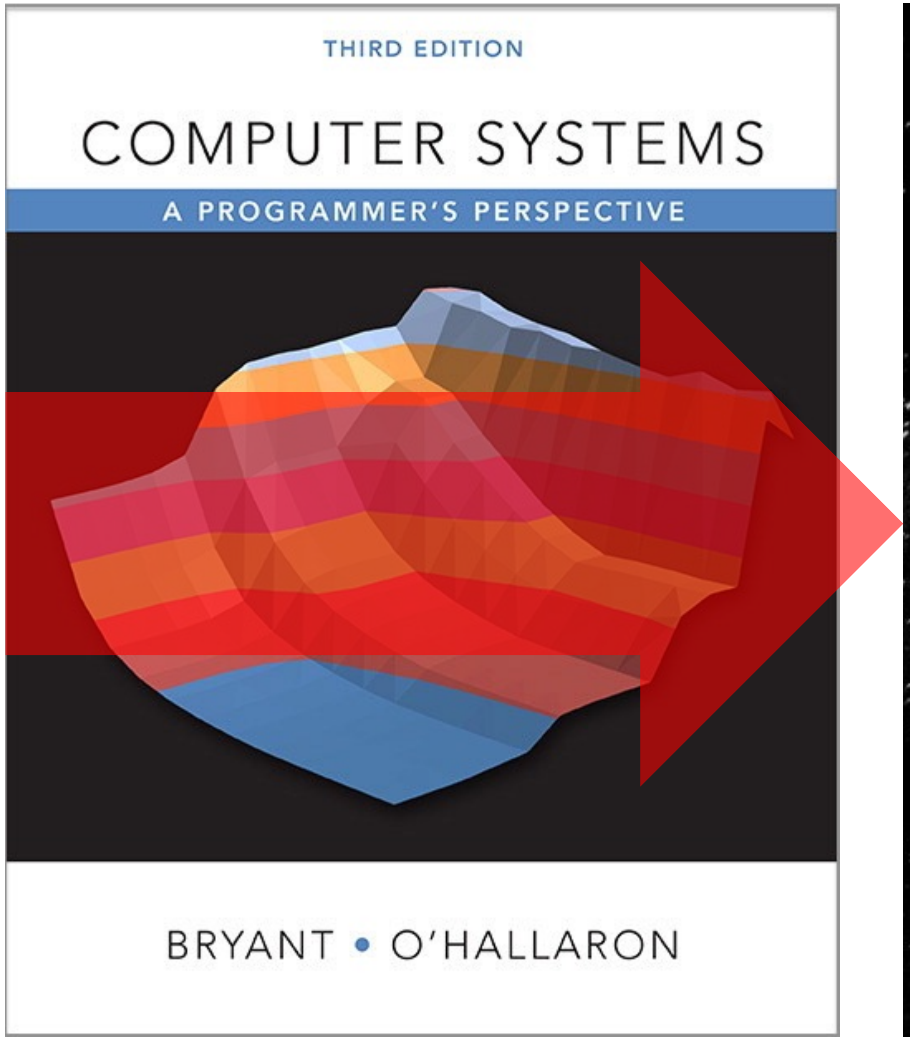
12. Operating System Overview

Prof. Jong-Chan Kim

Dept. Automobile and IT Convergence

KMU 국민대학교
KOOKMIN UNIVERSITY

We are moving on to the next topic (OS)



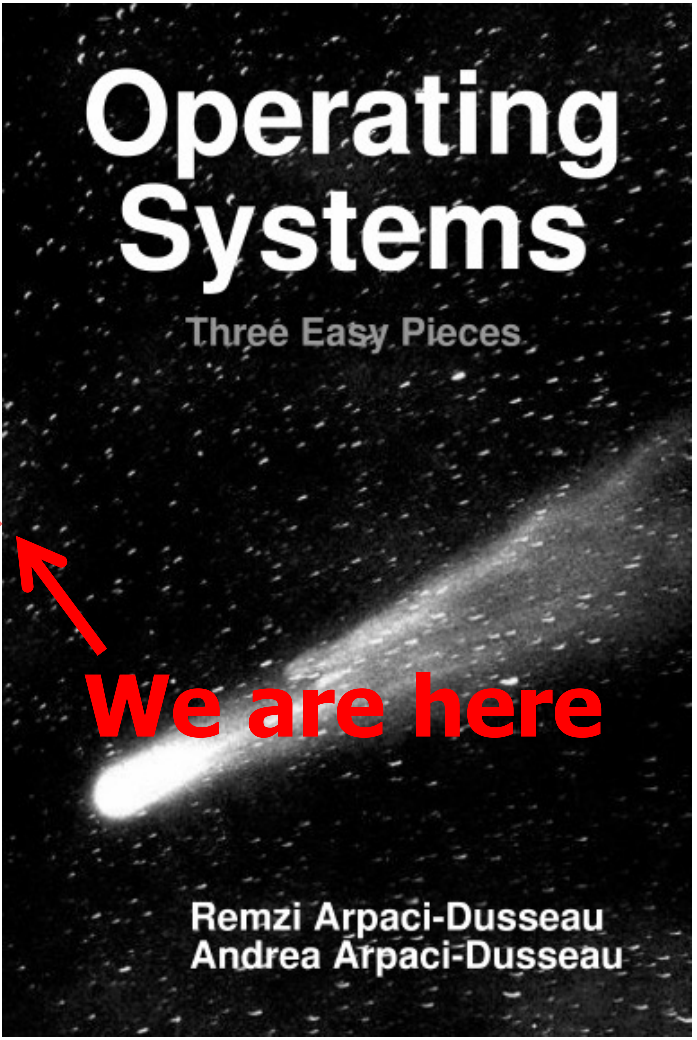
THIRD EDITION

COMPUTER SYSTEMS

A PROGRAMMER'S PERSPECTIVE

BRYANT • O'HALLARON

Computer Architecture Textbook



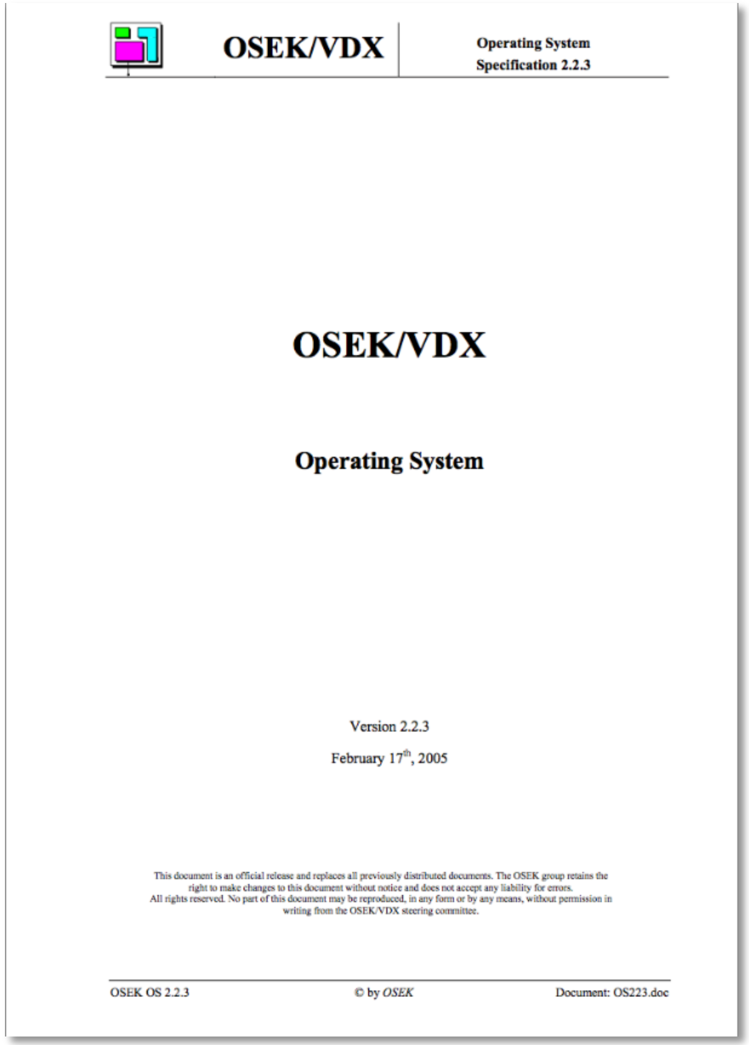
Operating Systems

Three Easy Pieces

Remzi Arpaci-Dusseau
Andrea Arpaci-Dusseau

We are here

OS Textbook



OSEK/VDX | Operating System Specification 2.2.3

OSEK/VDX

Operating System

Version 2.2.3

February 17th, 2005

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OSEK OS 2.2.3 © by *OSEK* Document: OS223.doc

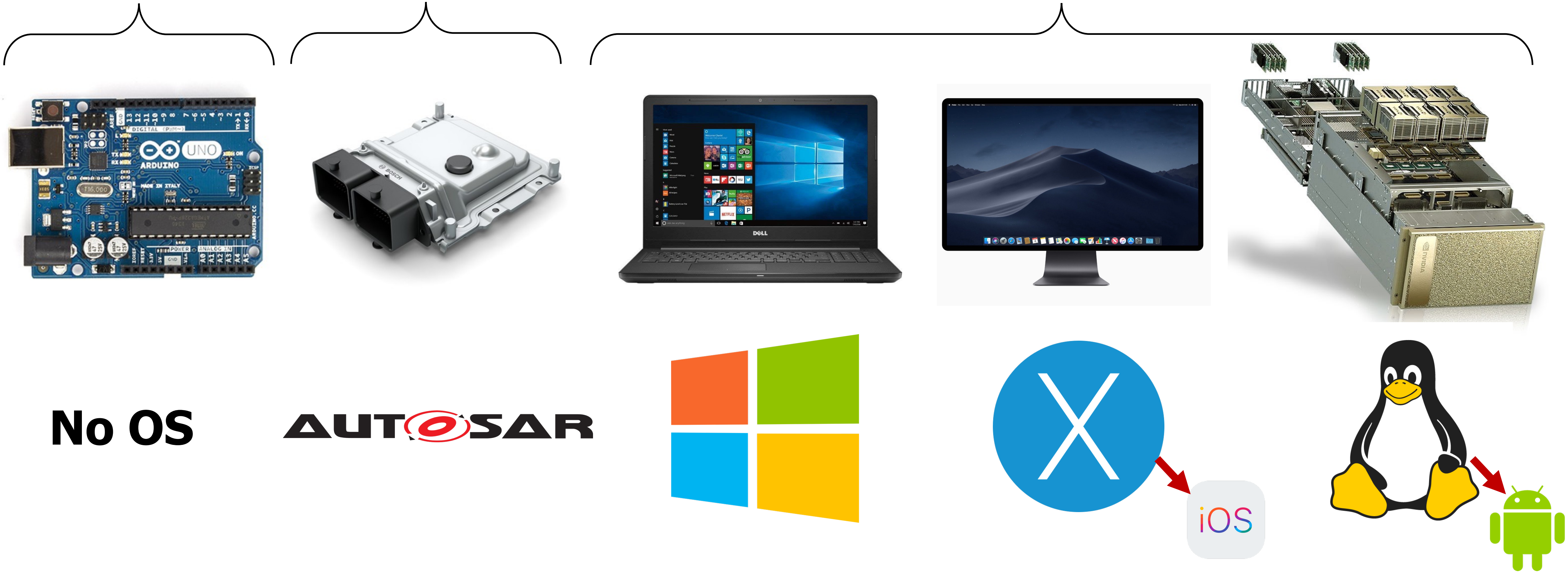
Why OS matters?

- Computers have fundamentally the same hardware architecture
- Different operating systems make the real difference

Firmware

Real-Time OS

General-Purpose OS

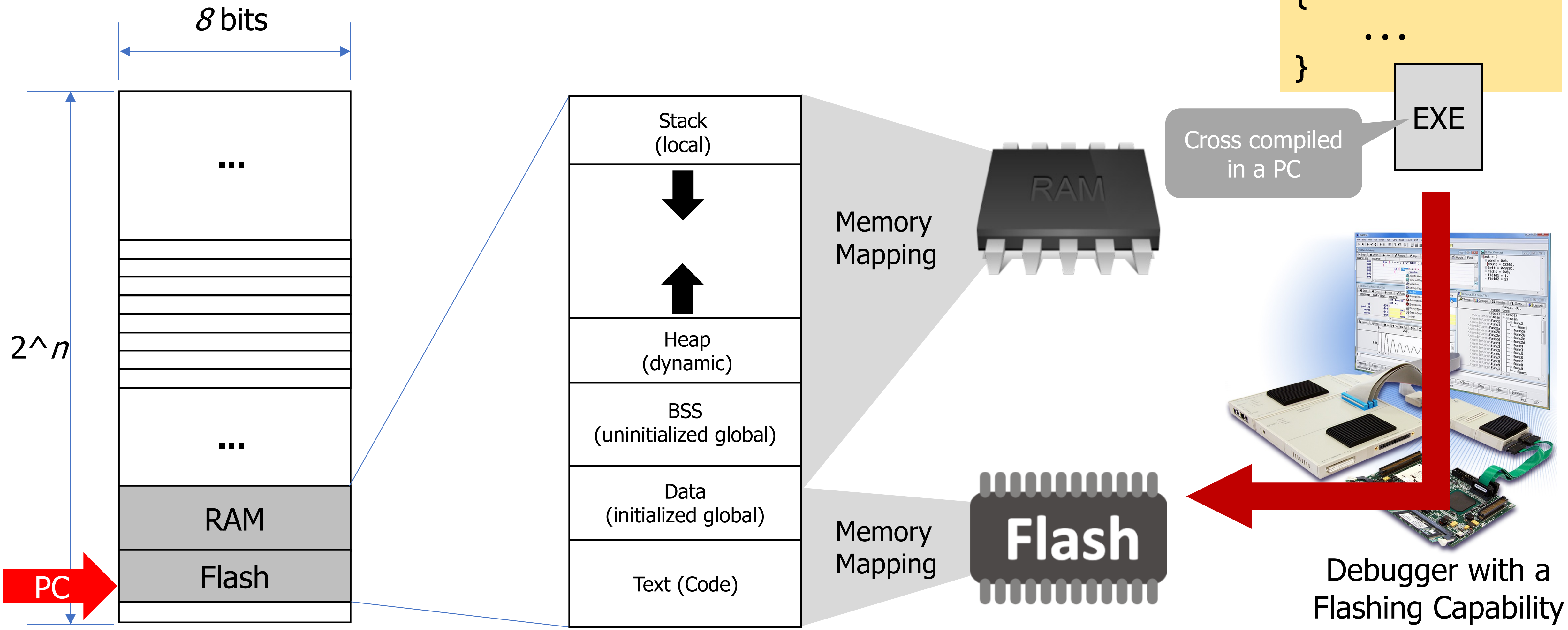


No OS

Firmware-based Systems

- A system with a single application having a single “main” function
- Programs directly executed on flash memory (no loading)

```
int main(void)
{
     ...
}
```



8 bits

2^*n*

...

...

RAM

Flash

PC

Stack
(local)

Heap
(dynamic)

BSS
(uninitialized global)

Data
(initialized global)

Text (Code)

Memory
Mapping

Memory
Mapping

EXE

Cross compiled
in a PC

Debugger with a
Flashing Capability

OS-based Systems

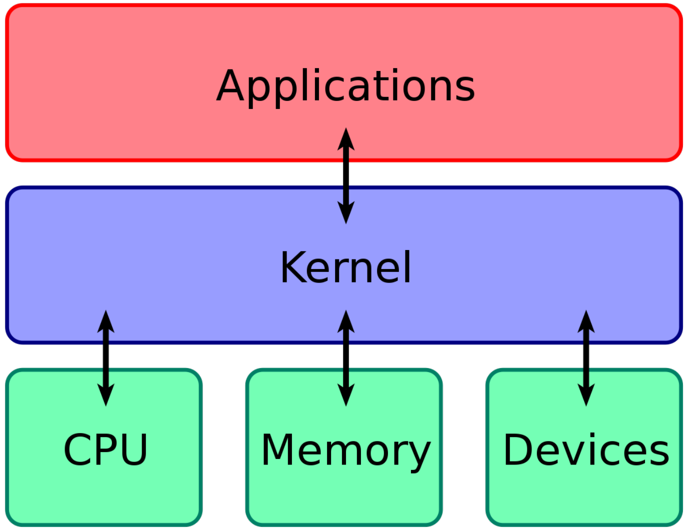
- End User's View
  - Graphical or Command-line User Interface
  - Filesystem and Directory Structure

- Program's View
  - HW Resource Manager
  - Illusion Maker (Dedicated HW for each application)

- Programmer's View
  - Set of Library Functions and System Calls

Inside library files

Directly provided by the OS kernel

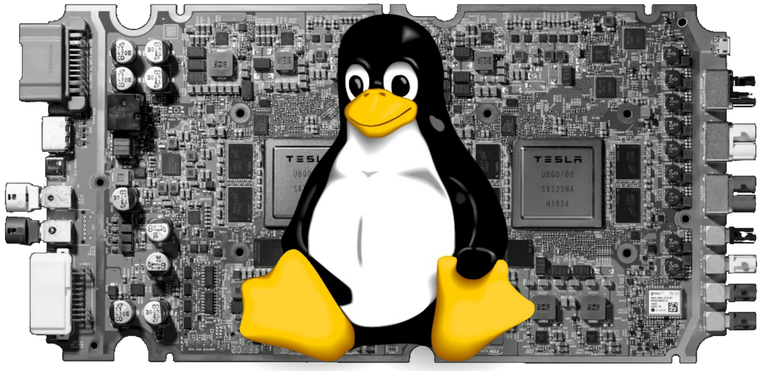


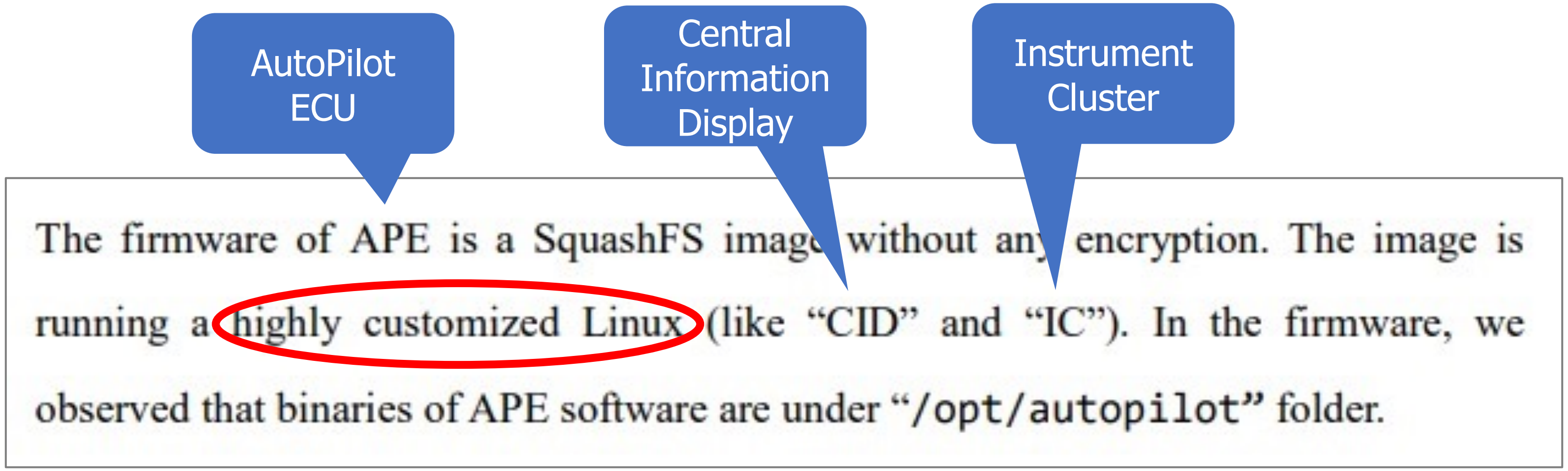
The core component of an OS

Our Focus: Linux Operating System

- The most widely used operating system
- Tesla Autopilot is based on Linux
- Standard OS for developers

Linux Is Not UniX





AutoPilot ECU

Central Information Display

Instrument Cluster

The firmware of APE is a SquashFS image without any encryption. The image is running a highly customized Linux (like "CID" and "IC"). In the firmware, we observed that binaries of APE software are under "`/opt/autopilot`" folder.

Source: Experimental Security Research of Tesla Autopilot (Tencent Keen Security Lab) 2019.3

Birth of UNIX (1969)

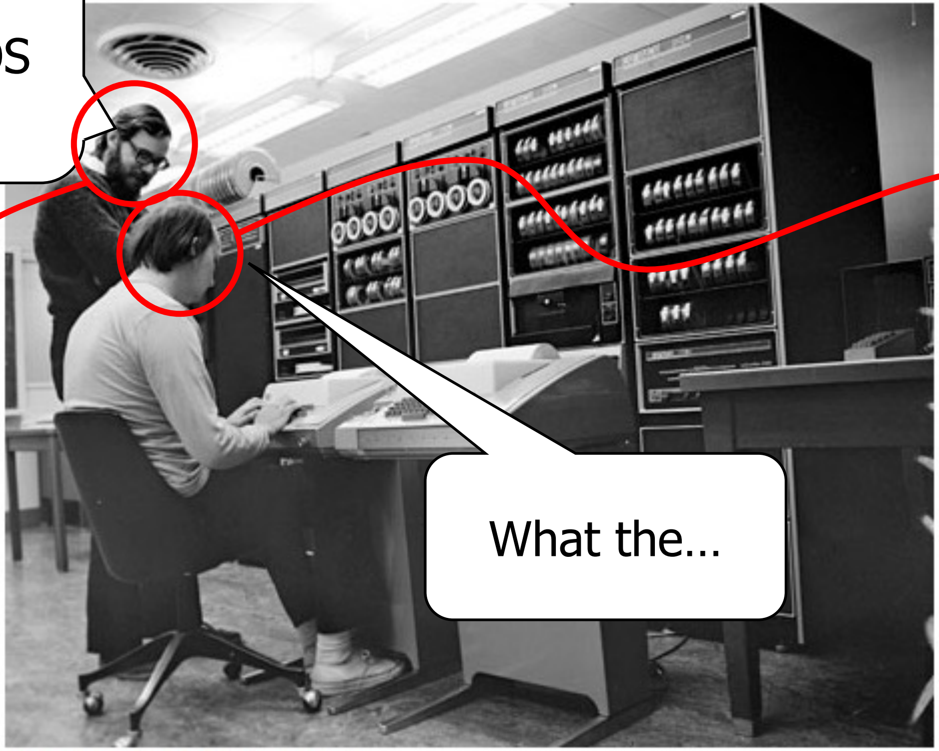


Photo: Alcatel-Lucent

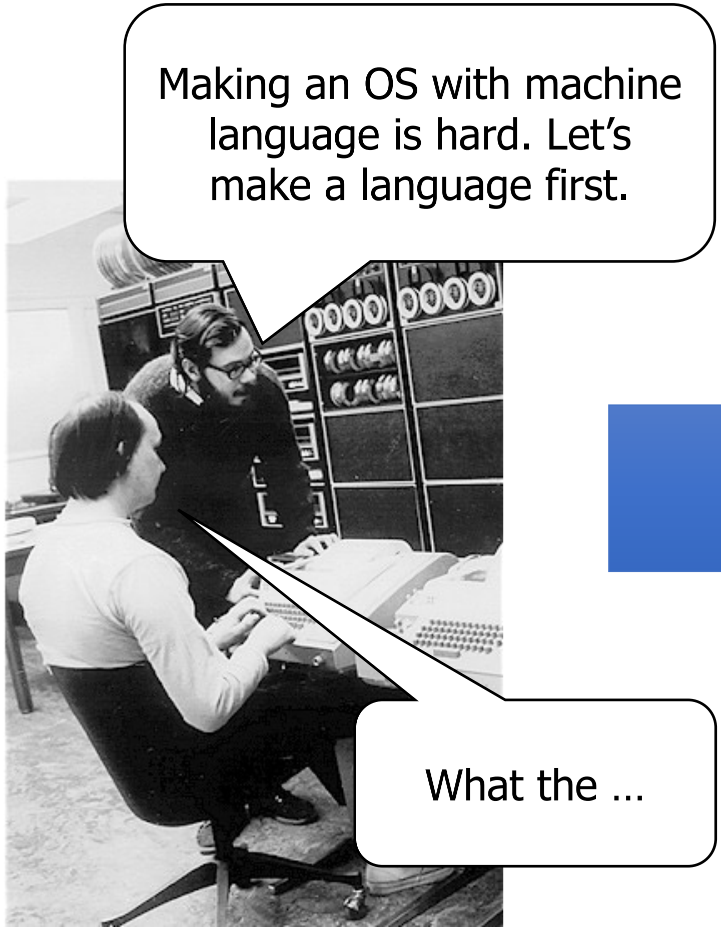
Dennis Ritchie
1941 - 2011

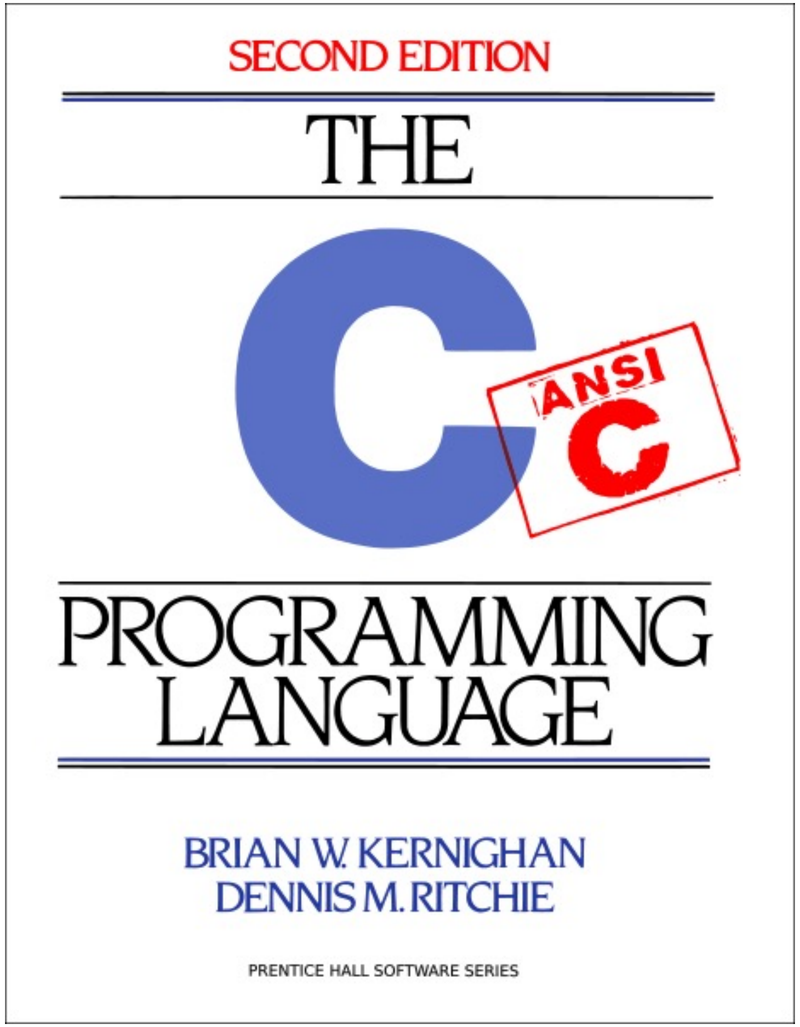
Dennis Ritchie & Ken Thompson
at
AT&T Bell Lab.

Photo: Gabriela Hasbun

Proud father: Ken Thompson poses to show off his brainchild, 40 years after its birth.

Birth of C Programming Language (1972)


Making an OS with machine language is hard. Let's make a language first.
What the …



SECOND EDITION

THE

C

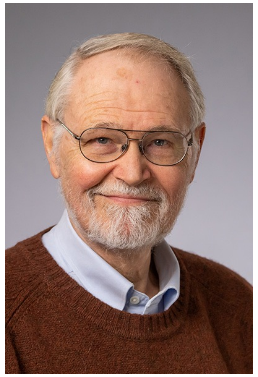
ANSI C

PROGRAMMING LANGUAGE

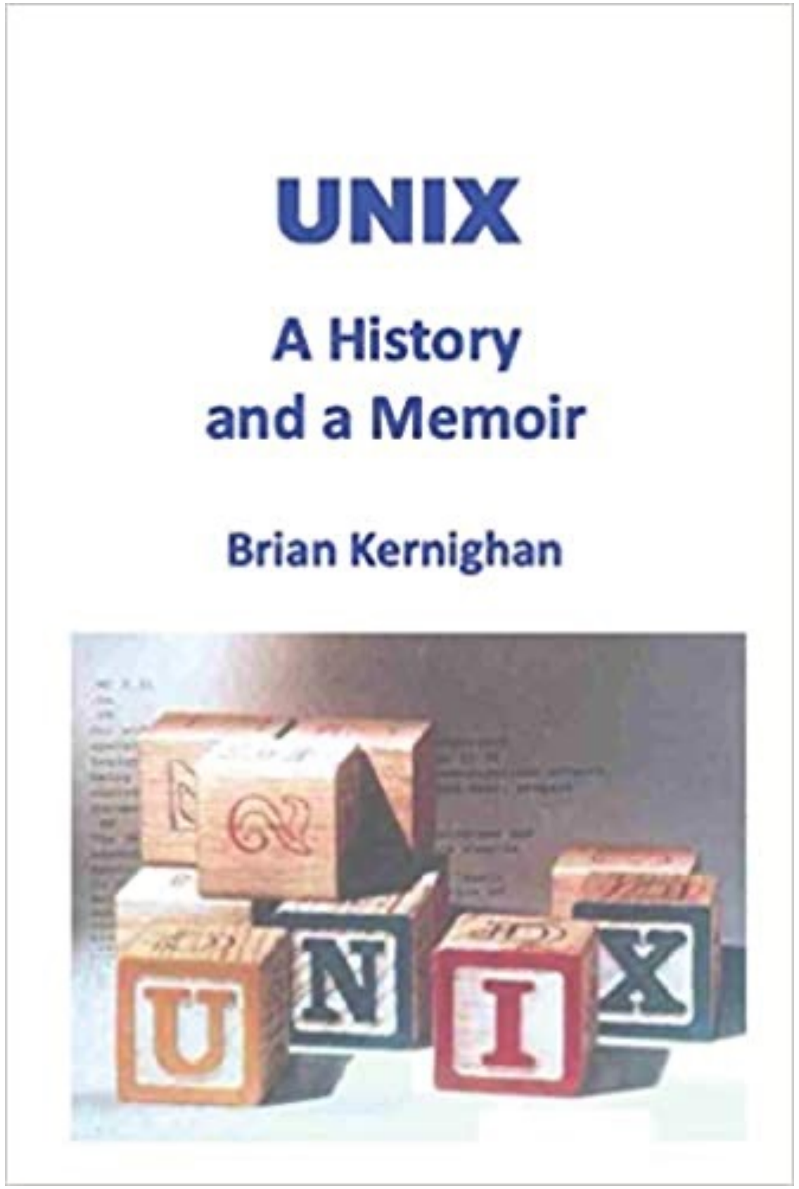
BRIAN W. KERNIGHAN
DENNIS M. RITCHIE

PRENTICE HALL SOFTWARE SERIES

A History



Brian Kernighan

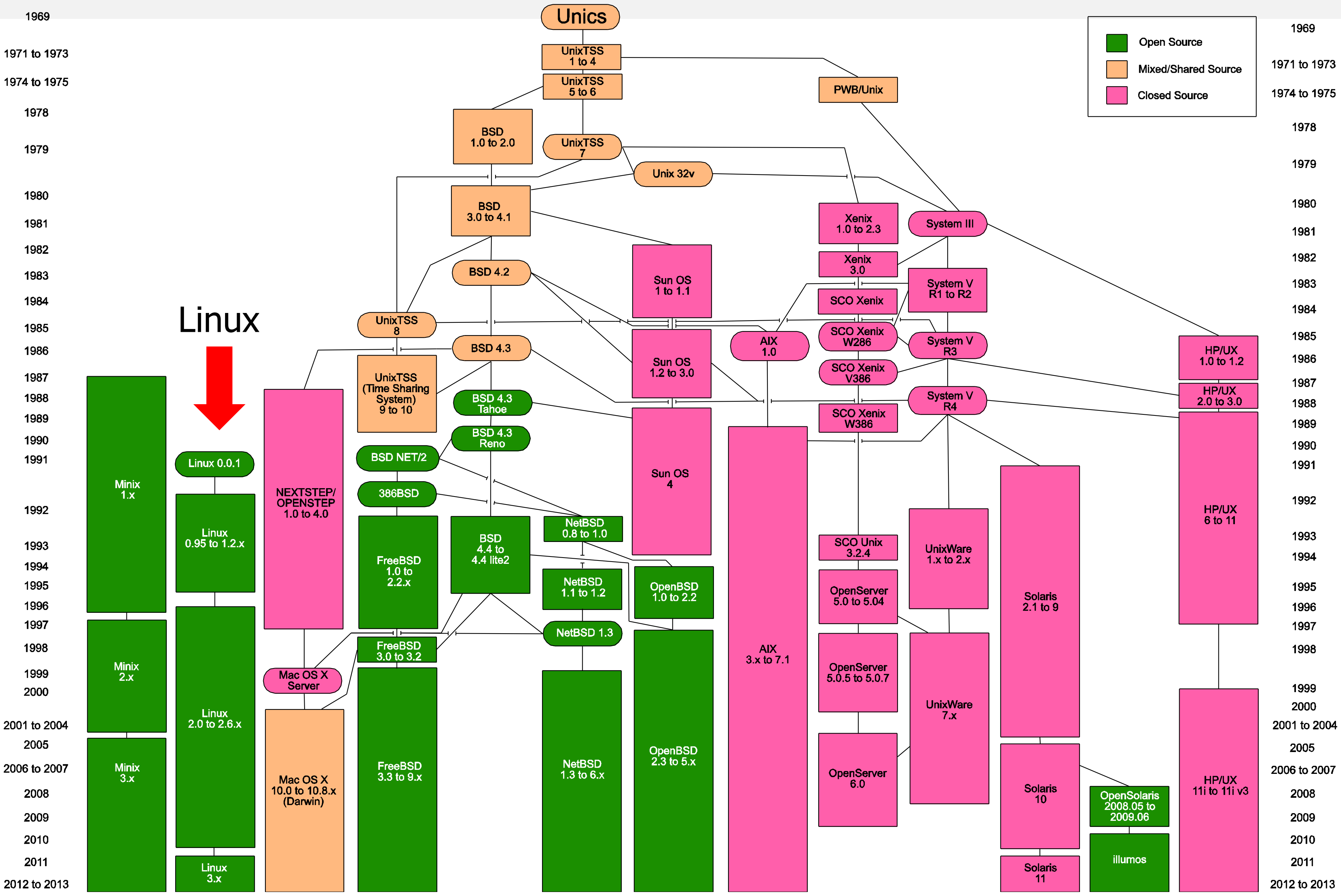


UNIX

A History
and a Memoir

Brian Kernighan

UNIX Family Tree



🟩 Open Source

🟧 Mixed/Shared Source

🟥 Closed Source

Linux

1969
1971 to 1973
1974 to 1975
1978
1979
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1999
2000
2001 to 2004
2005
2006 to 2007
2008
2009
2010
2011
2012 to 2013

Unics
UnixTSS 1 to 4
UnixTSS 5 to 6
PWB/Unix
BSD 1.0 to 2.0
UnixTSS 7
Unix 32v
BSD 3.0 to 4.1
Xenix 1.0 to 2.3
System III
Sun OS 1 to 1.1
Xenix 3.0
BSD 4.2
System V R1 to R2
SCO Xenix
UnixTSS 8
SCO Xenix W286
System V R3
AIX 1.0
HP/UX 1.0 to 1.2
BSD 4.3
Sun OS 1.2 to 3.0
SCO Xenix V386
UnixTSS (Time Sharing System) 9 to 10
HP/UX 2.0 to 3.0
BSD 4.3 Tahoe
System V R4
SCO Xenix W386
BSD 4.3 Reno
Linux 0.0.1
BSD NET/2
Minix 1.x
NEXTSTEP/ OPENSTEP 1.0 to 4.0
Sun OS 4
386BSD
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
Solaris 2.1 to 9
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
Minix 2.x
Mac OS X Server
AIX 3.x to 7.1
OpenServer 5.0.5 to 5.0.7
UnixWare 7.x
Linux 2.0 to 2.6.x
Mac OS X 10.0 to 10.8.x (Darwin)
FreeBSD 3.3 to 9.x
NetBSD 1.3 to 6.x
OpenBSD 2.3 to 5.x
Minix 3.x
OpenServer 6.0
Solaris 10
OpenSolaris 2008.05 to 2009.06
HP/UX 11i to 11i v3
illumos
Linux 3.x
Solaris 11

1969
1971 to 1973
1974 to 1975
1978
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2001 to 2004
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2006 to 2007
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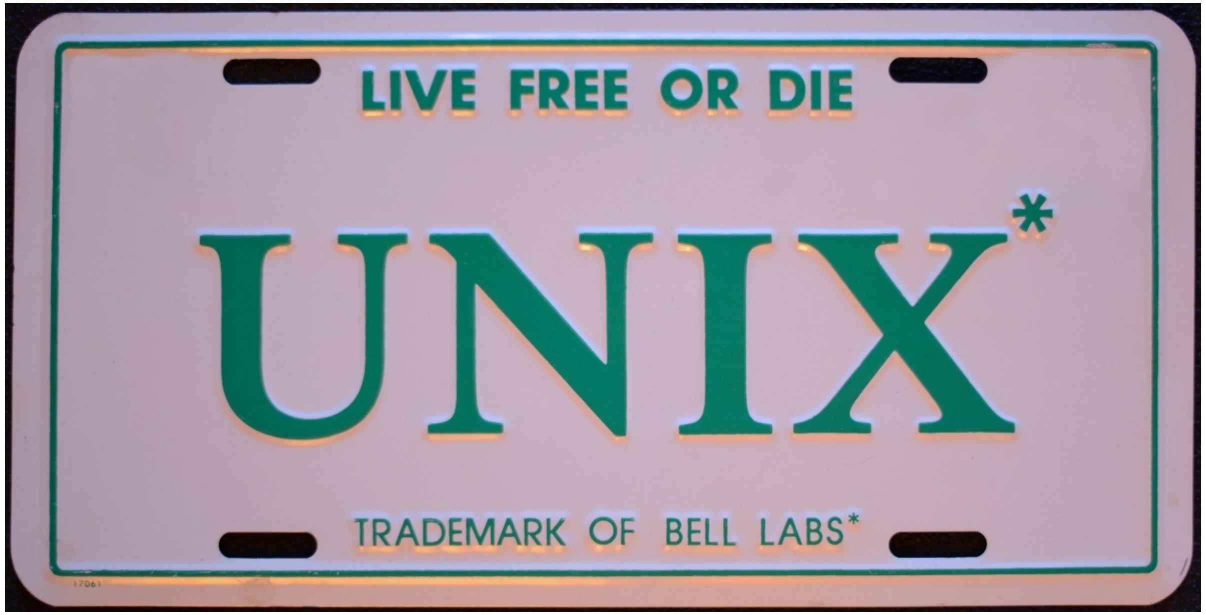
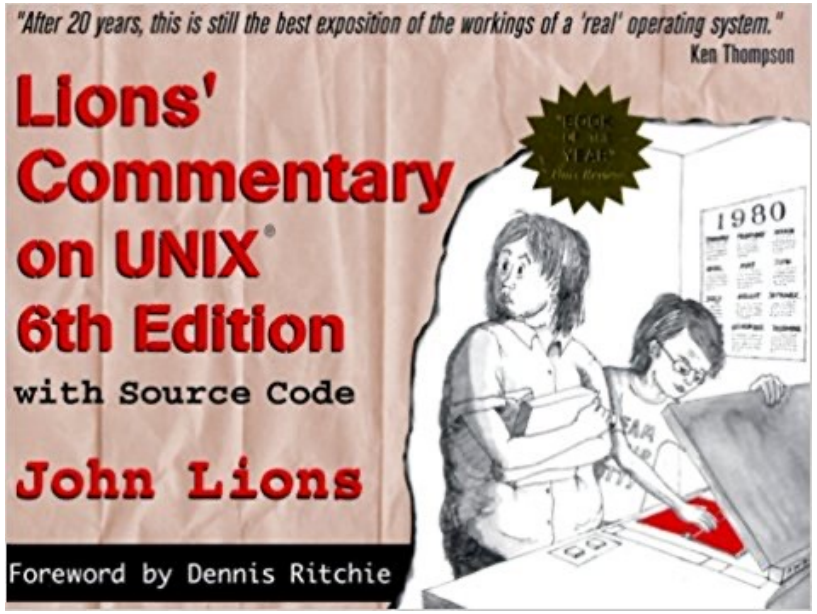
2011
2012 to 2013

https://en.wikipedia.org/wiki/History_of_Unix

UNIX Dark Age

- Unix source code had been open for classroom use until 1979
- From then, AT&T closed it for profit by selling it
- Lion’s book (1976) had been illegally used to study UNIX




"After 20 years, this is still the best exposition of the workings of a 'real' operating system."
Ken Thompson
Lions' Commentary on UNIX® 6th Edition
with Source Code
John Lions
Foreword by Dennis Ritchie
1980

GNU (GNU's Not Unix)

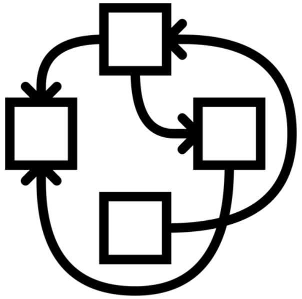
- Launched by Richard Matthew Stallman aka RMS at MIT in 1983
- The goal was to develop a UNIX-compatible free operating system
- GPL (GNU General Public License)
- Famous software packages (e.g., GCC, GDB, Make, GNU C Library, …)
- By the early 1990s, everything except its kernel had been developed

Infectious

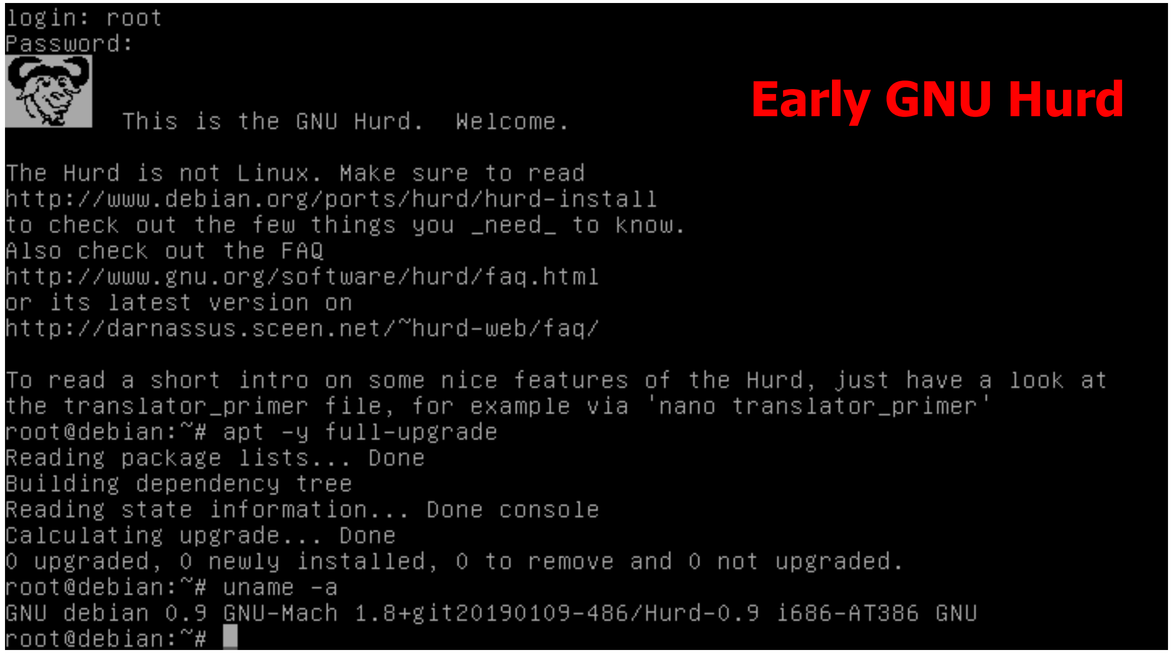
Freedom, not about the price

Richard Stallman
(Source: Wikipedia)

GNU Project



Hurd (Kernel)



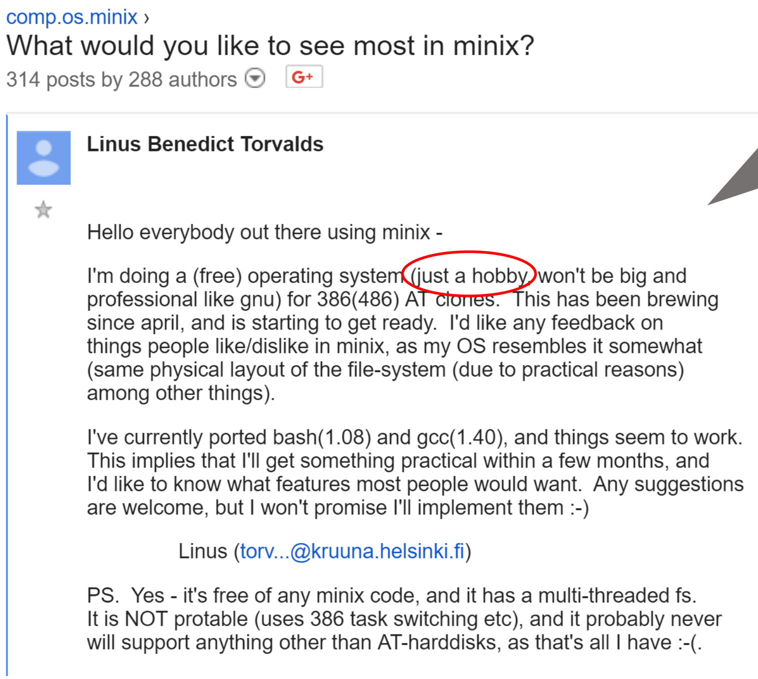
Early GNU Hurd

```
login: root
Password:

        This is the GNU Hurd.  Welcome.

The Hurd is not Linux. Make sure to read
http://www.debian.org/ports/hurd/hurd-install
to check out the few things you _need_ to know.
Also check out the FAQ
http://www.gnu.org/software/hurd/faq.html
or its latest version on
http://darnassus.sceen.net/~hurd-web/faq/

To read a short intro on some nice features of the Hurd, just have a look at
the translator_primer file, for example via 'nano translator_primer'
root@debian:~# apt -y full-upgrade
Reading package lists... Done
Building dependency tree
Reading state information... Done console
Calculating upgrade... Done
0 upgraded, 0 newly installed, 0 to remove and 0 not upgraded.
root@debian:~# uname -a
GNU debian 0.9 GNU-Mach 1.8+git20190109-486/Hurd-0.9 i686-AT386 GNU
root@debian:~# 
```

Birth of Linux Kernel (1991~)

- GPLed UNIX kernel began in 1991 by a Finnish student, Linus Torvalds
- Became much more popular than the GNU Hurd kernel
- Has grown up to 27.8 million lines of code (2020)

Version Number



comp.os.minix ›
What would you like to see most in minix?
314 posts by 288 authors

Linus Benedict Torvalds

Hello everybody out there using minix -

I'm doing a (free) operating system (just a hobby, won't be big and professional like gnu) for 386(486) AT clones. This has been brewing since april, and is starting to get ready. I'd like any feedback on things people like/dislike in minix, as my OS resembles it somewhat (same physical layout of the file-system (due to practical reasons) among other things).

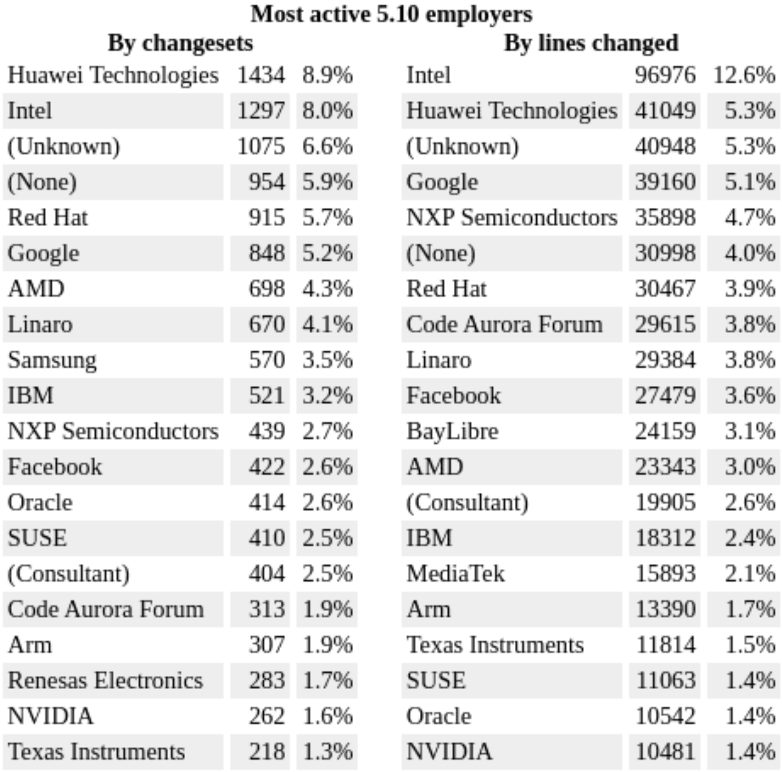
I've currently ported bash(1.08) and gcc(1.40), and things seem to work. This implies that I'll get something practical within a few months, and I'd like to know what features most people would want. Any suggestions are welcome, but I won't promise I'll implement them :-)

Linus (torv...@kruuna.helsinki.fi)

PS. Yes - it's free of any minix code, and it has a multi-threaded fs. It is NOT protable (uses 386 task switching etc), and it probably never will support anything other than AT-harddisks, as that's all I have :-(.

Linus's first email announcing Linux to comp.os.minix

Linus Torvalds (1969 ~)



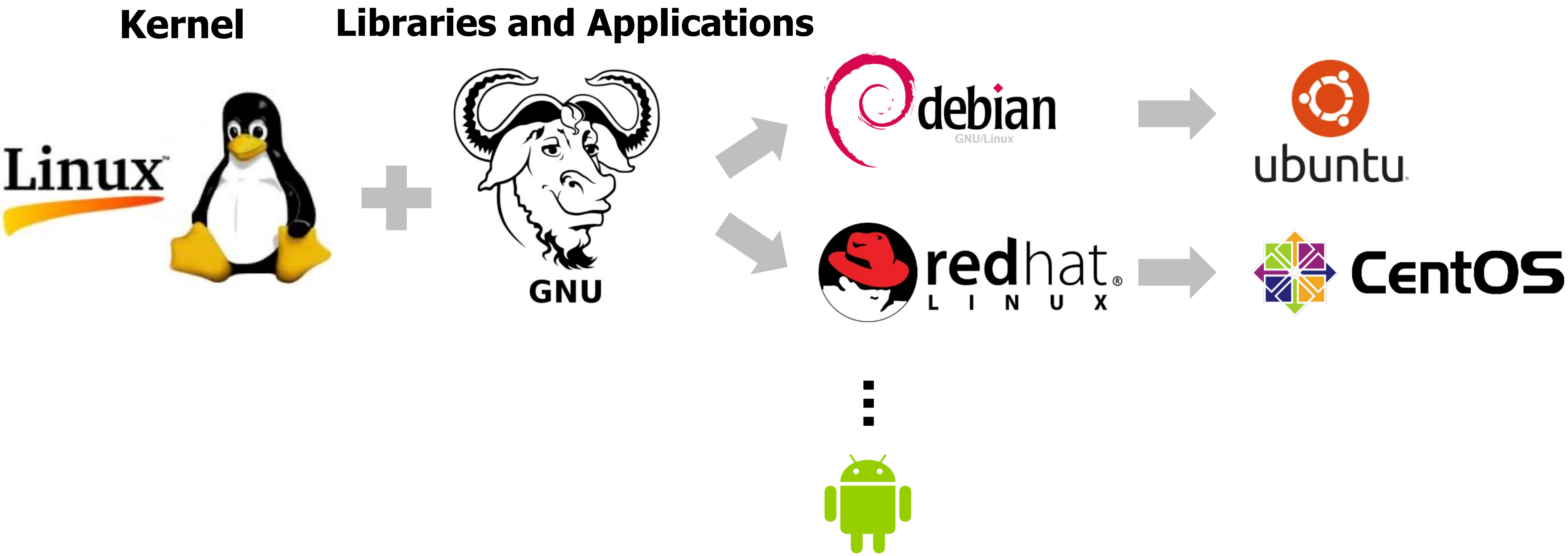
Most active 5.10 employers

By changesets			By lines changed		
Huawei Technologies	1434	8.9%	Intel	96976	12.6%
Intel	1297	8.0%	Huawei Technologies	41049	5.3%
(Unknown)	1075	6.6%	(Unknown)	40948	5.3%
(None)	954	5.9%	Google	39160	5.1%
Red Hat	915	5.7%	NXP Semiconductors	35898	4.7%
Google	848	5.2%	(None)	30998	4.0%
AMD	698	4.3%	Red Hat	30467	3.9%
Linaro	670	4.1%	Code Aurora Forum	29615	3.8%
Samsung	570	3.5%	Linaro	29384	3.8%
IBM	521	3.2%	Facebook	27479	3.6%
NXP Semiconductors	439	2.7%	BayLibre	24159	3.1%
Facebook	422	2.6%	AMD	23343	3.0%
Oracle	414	2.6%	(Consultant)	19905	2.6%
SUSE	410	2.5%	IBM	18312	2.4%
(Consultant)	404	2.5%	MediaTek	15893	2.1%
Code Aurora Forum	313	1.9%	Arm	13390	1.7%
Arm	307	1.9%	Texas Instruments	11814	1.5%
Renesas Electronics	283	1.7%	SUSE	11063	1.4%
NVIDIA	262	1.6%	Oracle	10542	1.4%
Texas Instruments	218	1.3%	NVIDIA	10481	1.4%

Recent Contributions from Big Companies

GNU/Linux Operating Systems

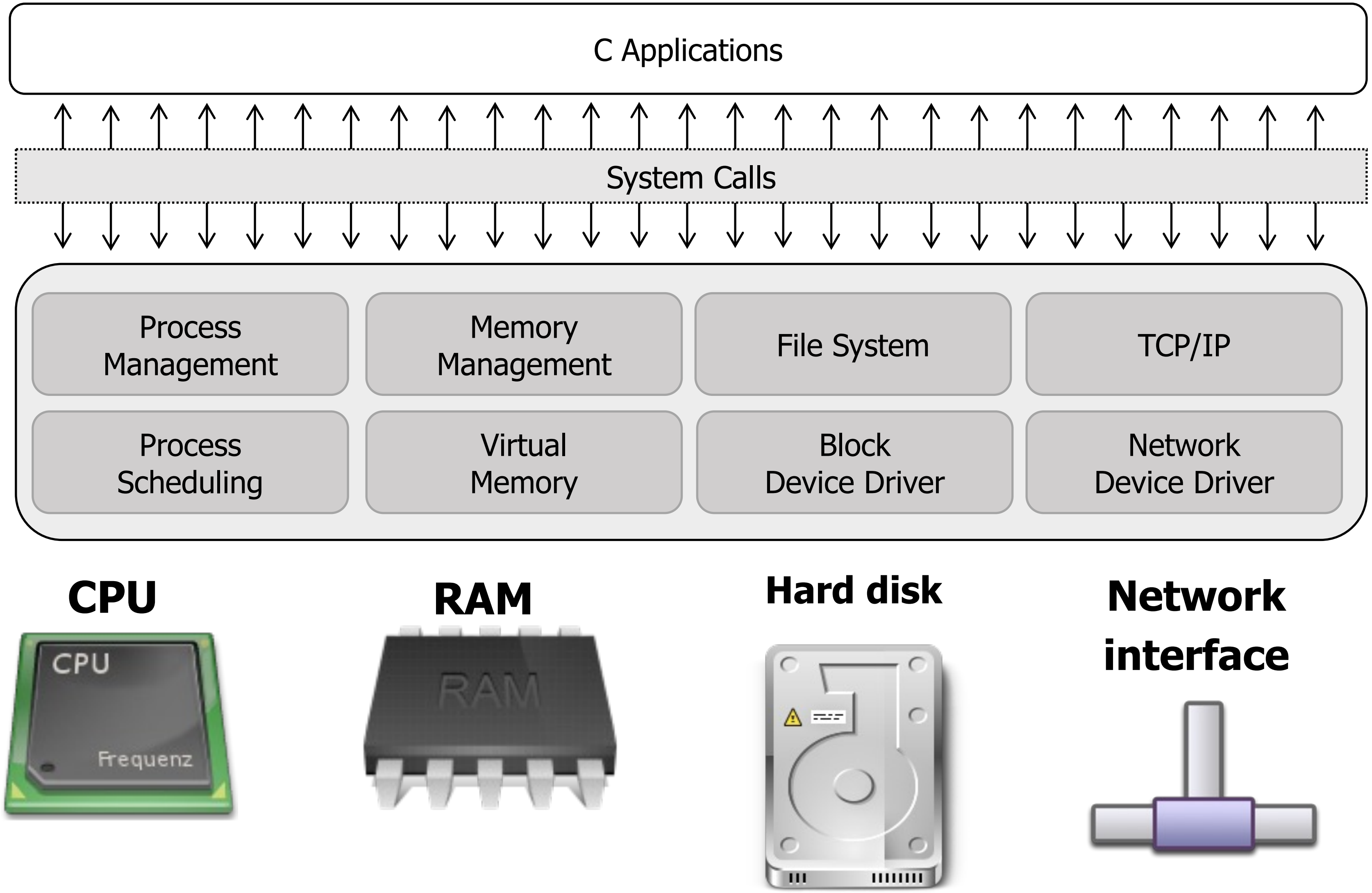
- Many companies and organizations develop their own **GNU/Linux operating system** based on the Linux kernel and the GNU project



Kernel

Libraries and Applications

Operating System Kernel



C Applications

System Calls

Process Management

Memory Management

File System

TCP/IP

Process Scheduling

Virtual Memory

Block Device Driver

Network Device Driver

CPU

RAM

Hard disk

Network interface

Software Layers and Control Flows

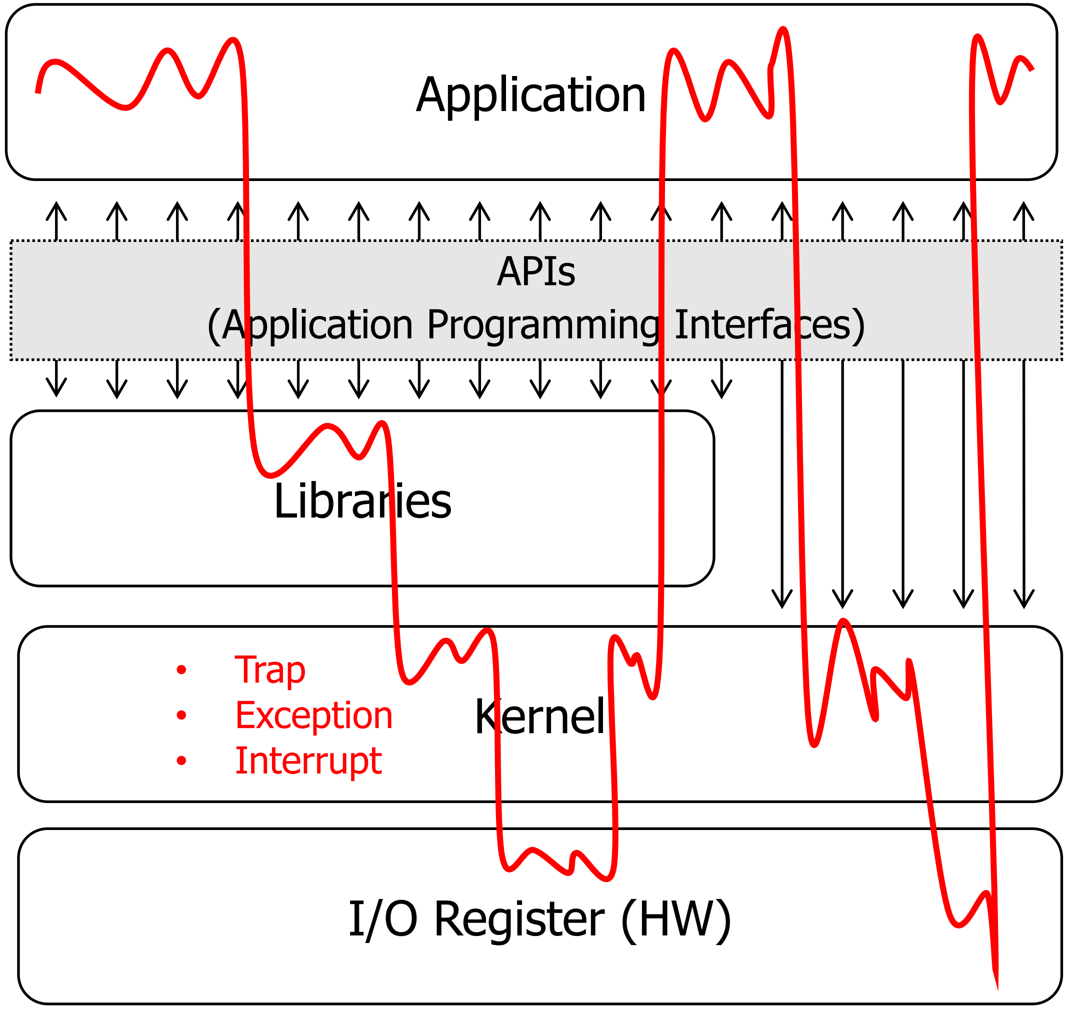
- Limited access to address space
- Cannot access hardware registers directly

User Level

CPU mode changes between user mode and kernel mode (privileged mode)

Kernel Level

- Unlimited access to address space
- Can directly handle hardware registers



Library Function vs System Call

```
#include <stdio.h>

int main(void)
{
    printf("Hello World\n");
    return 0;
}
```

Library function

- Library Functions
  - Serviced in user level
  - May call system calls inside

```
#include <unistd.h>

int main(void)
{
    write(STDOUT_FILENO, "Hello World\n", 12);
    return 0;
}
```

System call

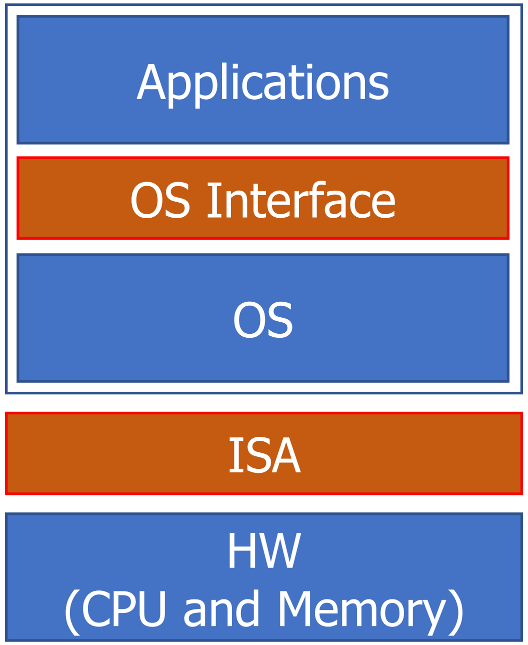
- System Calls
  - Serviced inside the kernel

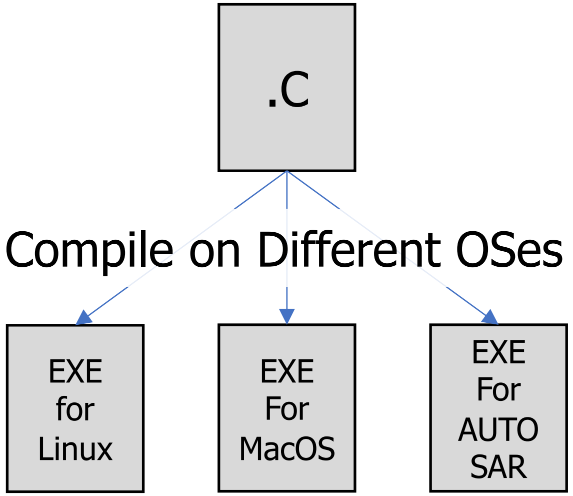
User Mode / Kernel Mode Transition

- Trap (Synchronous)
  - Calling a system call
- Exception (Synchronous)
  - Jump to an exception handler in kernel
  - E.g.) divide by zero
- Interrupt (Asynchronous)
  - Jump to an interrupt handler in kernel
  - E.g.) Hardware interrupt

OS Interfaces

- Standards for library functions and system calls (or APIs)
  - Applications are "portable" across different OSes with the same OS interface
  - Source-level portability, not binary-level portability





Single Source Code for Multiple OSes

POSIX Standards

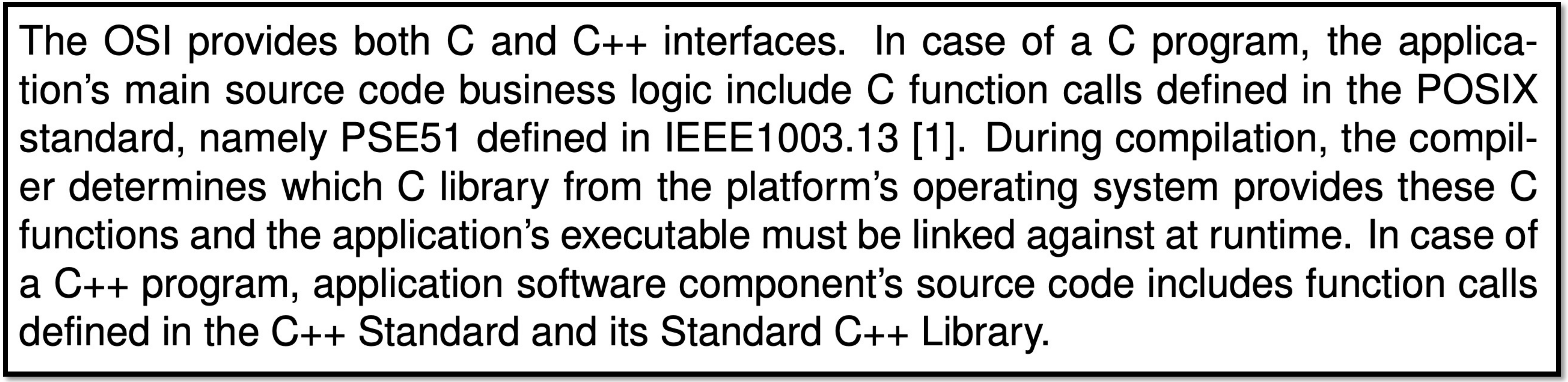
- Portable Operating System Interface (POSIX)
  - The most popular OS interface for UNIX-like OSes

- 1003.1-2017 - IEEE Standard for Information Technology--Portable Operating System Interface (POSIX(TM)) Base Specifications, Issue 7
  - https://ieeexplore.ieee.org/document/8277153
  - Baseline standard

- 1003.13-2003 - IEEE Standard for Information Technology - Standardized Application Environment Profile (AEP) - POSIX(TM) Realtime and Embedded Application Support
  - https://ieeexplore.ieee.org/document/1342418
  - Minimal standard (subsets) for real-time embedded applications

Adaptive AUTOSAR based on POSIX 1003.13

- AUTOSAR Adaptive Platform
  - Platform software standards for autonomous driving systems
  - Based on POSIX 1003.13



The OSI provides both C and C++ interfaces. In case of a C program, the application's main source code business logic include C function calls defined in the POSIX standard, namely PSE51 defined in IEEE1003.13 [1]. During compilation, the compiler determines which C library from the platform's operating system provides these C functions and the application's executable must be linked against at runtime. In case of a C++ program, application software component's source code includes function calls defined in the C++ Standard and its Standard C++ Library.

Specification of Operating System Interface for AUTOSAR Adaptive Platform

Summary

- Firmware vs. OS-based Systems
- History of UNIX and Linux Operating Systems
- The Kernel Concept and System Calls
- User Mode vs. Kernel Mode
- POSIX Standard