Operating Systems Design

01. Introduction

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In the beginning…

There were no operating systems

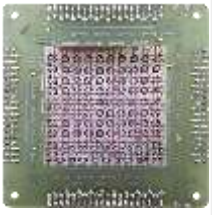
"Preparing ENIAC for a series of runs was an incredibly involved process. First, detailed instructions had to be written defining the problem and a procedure for solving it. These instructions were programmed by adjusting switches manually and inserting thousands of cables into as many as forty large plug boards. A team of five operators might work several days on the external wiring and many more days searching for errors and correcting them."

— *Breakthrough to the Computer Age, Harry Wulforst, Charles Scribner's & Sons Pub., 1982*

Programming the ENIAC

Ferrite Core Memory

- Fast, random-access memory
  - Non-volatile
  - Write-after-read to preserve bit
- First used in MIT's Whirlwind-1
  - 1953
  - 32×32×16 bits
- Used through ~1980



Late 1940s – 1950s

- Stored program concept: reload a program
- Reusable code ("subroutines")
- IBM SHARE (Society to Help Alleviate Redundant Effort)
- The OS emerges
  - I/O Control System (IOCS): Common I/O routines for device access
    - Precursor to *device drivers*
  - Batch systems (1956)
    - "Control cards" after a deck of punched cards to terminate one job and prepare for the next
      - Programmatic transition to reduce overhead of starting new jobs
    - Branch to a location in the OS that would cause the next program to get loaded and run
    - Job control languages to define resource needs

The Interrupt

- 1951 – UNIVAC I: exception handling
  - Transfer control on arithmetic overflow
- 1956 – UNIVAC 1103A
  - Hardware interrupt support
  - Interrupt writes PC to memory location & transfers control to an Interrupt Service Routine

1960s

- Goal: improve throughput
  - Use every possible second of CPU time
- Multiprogramming
  - Keep several programs in memory at once; switch between them
  - Works because of the speed mismatch between I/O and CPU
- 1961: Time sharing: preemption
  - CTSS (Compatible Time-Sharing System): Process scheduling
- 1962: the System Call (Atlas I Computer, Manchester)
  - Privileged & unprivileged modes

1960s

- Interactive access
- User accounts and passwords
- Direct storage access (file systems)
- Transaction processing systems (SABRE)
  - IBM & American Airlines

1960s

- 1961: DEC PDP-1 – first minicomputer ($125,000+)
- 1964: IBM System/360
  - PCP/360: sequential jobs (batch)
  - MFT: Multiple job system, fixed number of tasks
  - MVT: Multiple jobs, variable number of tasks (direct memory)
  - Direct Address Translation (precursor of virtual memory & the Memory Management Unit)
  - *Channels*: specialized processors for transferring data between main memory and an I/O device (*precursor of DMA*)

December 9, 1968: The Mother of All Demos

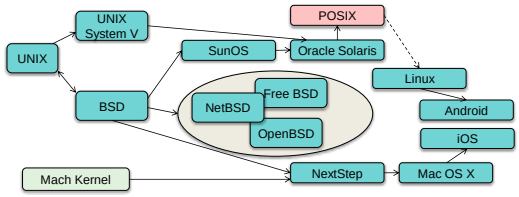
- Douglas Engelbart
  Stanford Research Institute (SRI), Augmentation Research Center
- Presented at Fall Joint Computer Conference
- Introduced
  - Computer mouse
  - Windows
  - Video conferencing
  - WYSIWYG word processing (with cut & copy) & embedded objects
  - Collaborative editing
  - Version control
  - Hypertext

1964-1970: Multics

- Memory mirrored onto the disk and available via the file system
- Dynamic linking for code & data segments
- Interprocess communication via shared segments
- Multiprocessor support
- On-line reconfiguration of system HW without downtime
- Hierarchical security model using protection rings
- Hierarchical file system with arbitrary file names
- Symbolic links
- Command processor not part of the operating system
- Written in a high-level language
  - EPL, a subset of PL/1 with extensions
- I/O redirection to files and programs ("pipes")

Late 1960s – 1970s

- 1970s: UNIX
  - Portable operating system
  - Written in an efficient high level language (C)
  - The UNIX programming environment: shell, pipes, "tools"



1972: Virtual Machines

- 1972: Virtual Machines (VM/370)
  - Run multiple operating systems on one machine
  - Each "machine" presents the same System/370 architecture
  - Hypervisor
    - Control program that runs on the physical hardware and creates the virtual machines
    - Intercepts & interprets all I/O operations and privileged instructions
    - Partitions memory

1973: Xerox Alto

- A *personal* computer (dedicated to one user)
  - Desktop UI metaphor and a mouse
  - Inspired by Douglas Englebart's On-Line System
- Specs
  - TI bit-slice processor
  - 128-512 KB RAM
  - 2.5MB removable hard disk
  - Ethernet
  - B&W CRT
  - 3-button mouse
  - Small fridge-sized cabinet
- Inspired the Mac & Microsoft Windows

1971 - 1975

- Microprocessors emerge
  - Intel 4004 → 8008 → 8080
  - Zilog Z-80, MOS Technology 6502, Motorola 6800, 6809
  - CP/M: dominant OS for 8080 family of machines
    - CCP: command interpreter
    - BDOS: file operations, printing, and console I/O
    - BIOS: character I/O, disk sector read/write

Initial cost
8080: $360
6502: $25

Late 1970s: Home PCs

- 1975: Early PCs – targeted at hobbyists
  - Connect your own teletype or use a front panel
  - Build it from a kit
  - Write your own OS drivers

- 1977: Ready-to-use personal computers
  - Apple II
  - Commodore PET
  - Radio Shack TRS-80 Model I
  - Followed by:
    - Atari 400, Atari 800, TI-99/4A, Commodore Vic 20, Commodore 64, …

1980s

- 1981: IBM PC
  - Open architecture; Microsoft OS
  - Only proprietary component was the BIOS
- 1982: BIOS was reverse engineered
  - PC clones (Compaq, Columbia, Dell, HP, …)

- 1984: Apple Macintosh

1980s

- Client-server networking
  - Personal workstations
  - Network file systems
- 1985: Intel 80386
  - Virtual memory with paging
  - Virtual 8086 mode for multiple legacy programs

1990s

- 1990: Windows 3.0
  - Takes advantage of virtual memory provided by 80386
- 1993: Window NT
  - New OS built from scratch
- Open Source Operating Systems
  - Linux, FreeBSD, NetBSD, OpenBSD
- 1995: Windows 95
  - Built-in Internet support (networking usually via modem)

1990s

- PCI bus: Plug & Play hardware
  - Adding hardware becomes easy
- Laptops become mainstream: *power usage is important*
- 1993: NCSA Mosaic – the web browser
- Network PC, thin clients
  - Failed … but resurrected with the Google Chromebook

2000s

- PC-based machine virtualization
  - Virtualization support added by Intel & AMD (2006)
  - Virtual machine migration
- Cloud computing, on-demand data centers
- Security
  - Hardware authentication, Storage encryption, digital rights management: Trusted Platform Module
  - Personal firewalls
  - Address space layout randomization

Multi-core Architectures

- 2005: Intel Introduces dual core Pentium D
  - 90nm process – Pentium Extreme Edition
  - 230 million transistors
  - 2 MB L2 cache
- Late 2014: Intel Haswell-E i7-5960X
  - 8 Cores
  - Hyperthreading
  - 2.6 Billion 22nm tri-gate 3-D transistors
  - 2133 MHz DDR4 memory interface
  - 20 MB L3 cache (shared across cores)

2000s

- Focus on mobility
  - Tablets
    - 1991 AT&T EO Personal Communicator
    - 1999: Microsoft Tablet PC
    - 2010: Apple iPad
  - PDAs → smartphones
    - iOS, Android, BlackBerry OS, Windows Mobile
- Increased focus on embedded systems
  - Machine-to-machine (M2M), Internet of Things, Arduino, …
- Cloud computing
  - Large scale data centers, reconfigurable virtual machines

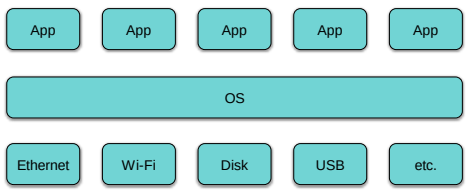
The Operating System

What is an operating system?

- The first program
- A program that lets you run other programs
- A program that provides controlled access to resources:
  - CPU
  - Memory
  - Display, keyboard, mouse
  - Persistent storage
  - Network

  This includes: naming, sharing, protection, communication

The Operating System



The End