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
• 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

46+ years ago!
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
• 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

OS

Apps

Ethernet Wi-Fi Disk USB etc.

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The End