UNIVERSITY OF BIRMINGHAM

Computer Systems
Elements of an Operating System

Lecture Objective / Overview

In this lecture, we shall see:

- What happens when your computer starts
- The role of memory in a computer system
- How an OS manages multitasking

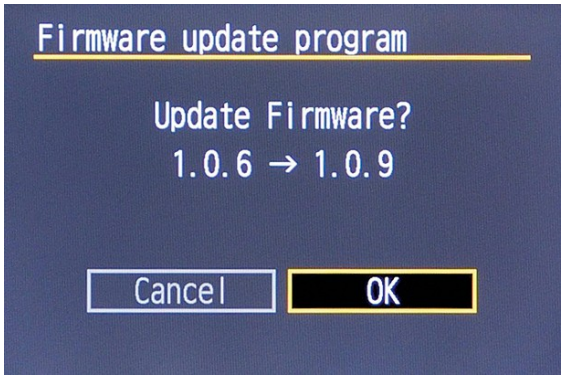
Starting your Computer …

- A small bootstrap program is loaded when your computer is started or rebooted
  - Based on the saying "to pull oneself up by one's bootstraps"
  - A seemingly impossible task
  - A self-sustaining process that proceeds without external help
- First coined in 1953 by Computer Scientist Werner Buchholz when talking about the "self-loading procedure" of the IBM Type 701 Computer

https://ieeexplore.ieee.org/document/4051191

Starting your Computer …

- Stored in Read-Only Memory (ROM) or Electrically Erasable Programmable Read-Only Memory (EEPROM).
  - Why? Can not be easily infected by a virus
- Known as firmware
- Initializes all aspects of the system:
  - CPU registers
  - Device controllers
  - Memory contents
- Loads the operating system kernel into memory



Once the Firmware is loaded …

- Some services are provided outside of the kernel
  - These are loaded at boot time to become system processes or system daemons
  - These run the entire time the kernel is running
- On UNIX, the first system process is "init"
- Once this is all loaded, the operating systems sits and waits for events to occur…

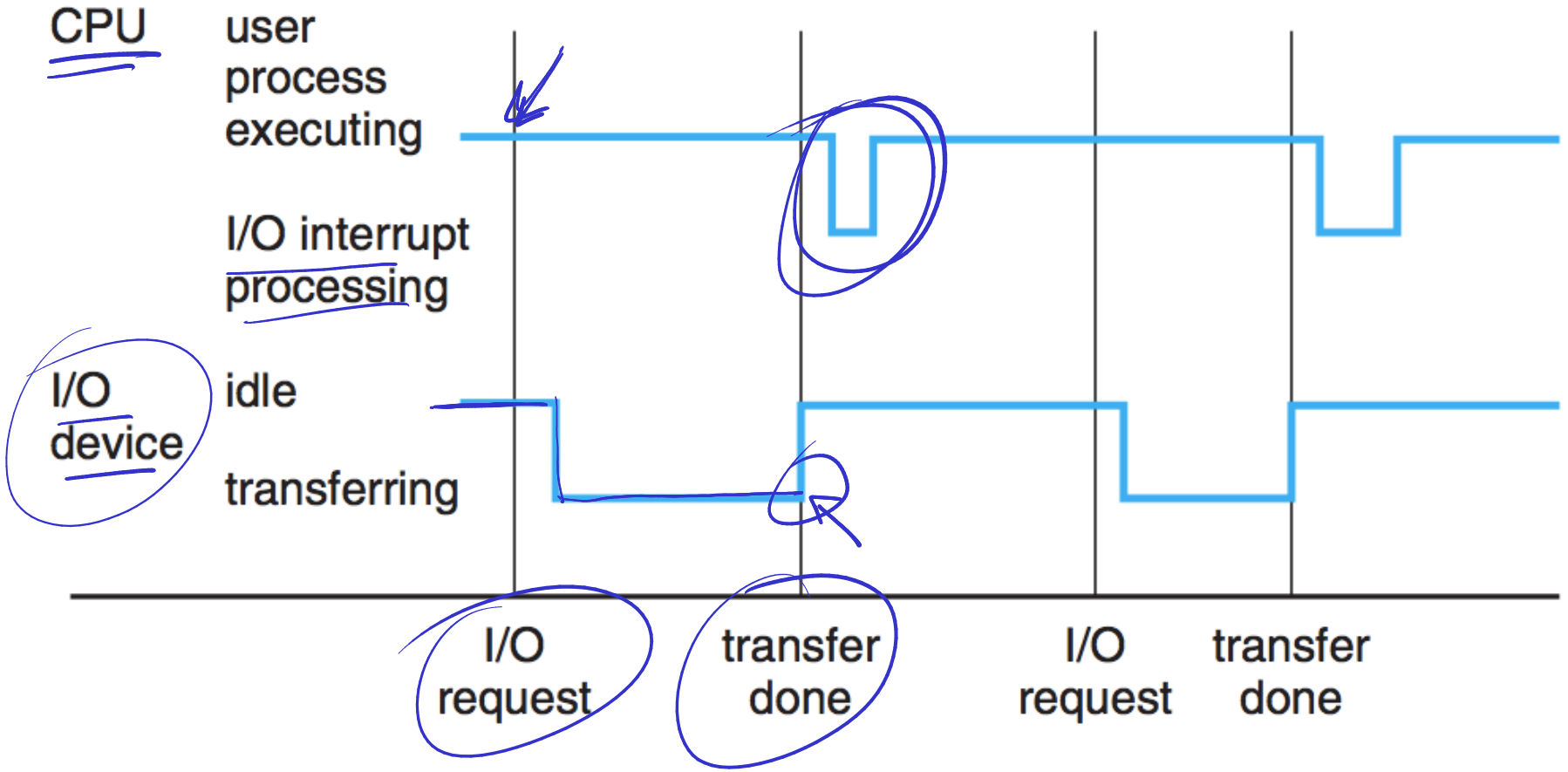
Something happens …

- **Examples:** A user clicks a mouse or a program tries to access a file
- These events are called **interrupts**
  - Can be triggered by hardware or software.
- Hardware may trigger an interrupt at any time by sending a signal to the CPU
- Software triggers an interrupt by executing a special operation
  - A **system call**

How does the CPU react?

- Stops what it is doing
- Immediately transfers execution to a fixed location
- This usually contains the starting address where the service routine for the interrupt is located
- The interrupt service routine executes
- On completion, the CPU resumes interrupted computation

Interrupt Timeline



Memory

- An array of bytes, where each byte is addressable
- Read-only Memory (ROM)
- Electrically Erasable Programmable ROM (EEPROM)
- ROM cannot be modified
  - Suitable for bootstrap programs and game cartridges(!)
- EEPROM can only be changed infrequently
  - Most smartphones store factory-bundled programs on EEPROM
- CPU needs memory that it can read and write to
  - Random-Access Memory (RAM)
  - Implemented in a semiconductor technology called Dynamic RAM (DRAM)

Register / Cache Memory

- Registers are another type of memory
- Main memory goes away when machine is switched off
- Secondary storage: magnetic disks, optical disks, tapes.
- **Cache Memory:**
  - Data that has been used a lot is cached into a faster storage system
  - If CPU is looking for information, cache is first checked.

Multi-tasking in the CPU

- Eventually the first job finishes waiting and gets the CPU back.
- Time-sharing:
  - CPU executes multiple jobs by switching between them
  - Switches occur so frequently that the users can interact with each program while it is running
  - The KDF9 could handle up to 4 completely independent programs at once!

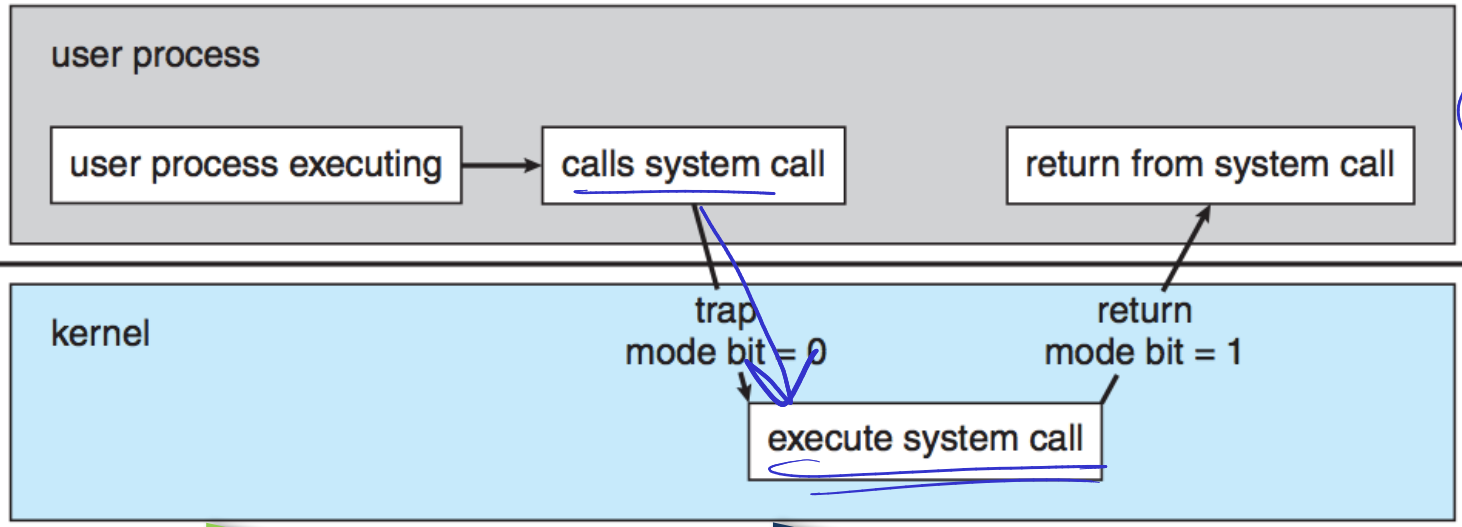
Time Sharing

- Time **sharing**: Several jobs are kept simultaneously in memory
- CPU **Scheduling**: Process of deciding which job is brought to memory to be executed when space is an issue
- Reasonable response time is of utmost importance:
  - Processes are **swapped** in and out of main memory to the disk
  - **Virtual memory** is used. This technique allows the execution of a process that is not completely in memory!

Time Sharing

- Virtual memory scheme enables users to run programs that are larger than actual **physical memory**
- It abstracts main memory into a large, uniform array of storage, separating **logical memory** as viewed by the user from physical memory
- This frees programmers from concern over memory-storage limitations!

Dual Mode



User Mode

- user program executes in user mode
- certain areas of memory are protected from user access
- certain instructions may not be executed

Kernel Mode

- monitor executes in kernel mode
- privileged instructions may be executed
- protected areas of memory may be accessed

Why do we need Dual Mode?

- MS-DOS: Intel 8088 architecture which has no mode bit
- User program can therefore wipe out the whole OS
- Programs are able to write to a device
- In dual mode: Hardware detect errors that violate modes and handle them with the help of OS

Why do we need Dual Mode?

- Stops user program attempting to execute an illegal instruction or to access memory of other users
- When detected:
  - OS must terminate the program
  - OS gives error message
  - Produces memory dumps by writing to a file. This can be checked by a user (if you're brave!)

System Calls

- System calls are the mechanism through which services of the operating systems are sought.
- What language?
  - Typically C and C++
  - Sometimes assembly language
  - System call for reading data from one file and writing to another file:

$ cp file1 file2

System Calls

- **Open** file1
  - Possible error (print, abort)
- **Create** file2 (if exists, rewrite/rename)
- Start **read** and **write** (errors: diskspace, memory stick unplugged)
  - Read/write **complete**
- **Close** files
- **Are these accessed directly?** No - via API

System Calls : API Wrapper

- Application Programming Interface (API)
- Specifies a set of functions that are available to an application programmer
  - Includes the parameters passed to each function
  - Also includes the return values that the programmer can expect
- Programmer accesses API via a library of code provided by the OS
- **Example:** Windows API for Windows systems
  - **CreateProcess()** invokes the NTCreateProcess() system call in the Windows kernel. This return value 0 or 1, if error thrown.

System Calls : API Wrapper

- **POSIX API** for POSIX-based systems (UNIX, Linux & macOS)
  - Programmer accesses an API via a library of code provided by the OS
- Example: read()
- Input:
  - int fd: file descriptor to be read
  - void *buf: pointer into buffer to be read into
  - size_t count: maximum number of bytes to read
- Output:
  - number of bytes read, if successful
  - -1 if failed

System Calls : API Wrapper

Example:

- Java API for programs that run on the Java virtual machine
- getParentFile()
- invoked on a file object
- Output**:**
  - Returns the abstract pathname of this file's parent, or null if this pathname does not name a parent directory.
  - JVM uses the OS system calls.

Why use an API?

- Why not invoke system calls directly?
  - Program portability: program can compile and run on any system that supports the API
  - System calls can often be more detailed and difficult to work with
  - Give access to high level objects (Java API)
- For example, think of interfaces in Java
- Using system calls is like implementing an interface

The Effect of a System Call

- The caller only needs to know the signature!
- Method call and parameters are passed into registers
- Values saved in memory
  - In a table or stacks
  - Addresses in registers
- Stack is preferred, as no limit to number of parameters

Summary

What elements of the OS have we looked at?

- The Role of Memory
- Multitasking / Time Sharing
- System calls
- APIs

References / Links

- Chapter # 1: **Operating System Concepts** (9th edition) by Silberschatz, Galvin & Gagne