OS: An Overview

Operating Systems

Credits: Slides are from Henri Casanova@Hawaii.

Why are we Studying this?

- ~~After all, you probably will not develop an OS~~
  - Unless you land a super interesting job :)
- Important to understand what you use
  - Understanding how the OS works helps you develop (better) apps, understand what you can and cannot do, understand performance, understand why some OS may be better/worse than some other in some situations
- Pervasive abstractions
  - OS concepts are fundamental and re-usable when implementing apps that are not operating systems
- Complex software systems
  - Many of you will participate in complex software systems
  - OSs are among the most interesting such systems and lessons from OSes (and their evolutions) can be applied in many other contexts

Studying OS Today

- Thanks to the open-source movement we have access to a lot of OS code
- Before OSes were even **more** mysterious
  - We can now look at “old” commercial OSes, which often reveals that they were pretty cool (or pretty scary)
- In fact, it’s become possible for any student to create an OS after reading other OS code
  - Or to contribute to an existing OS
- And thanks to virtualization technology, one can play with and run OSes easily
  - Without compromising one’s computer
  - But we won’t so that because we’re not doing any C

This Set of Lecture Notes

- This set of lecture notes is a 10,000 ft overview of the OS
- Many details will be explained throughout the semester
- Some terms are used, which you may not be familiar with, and that will all be explained later
- Some simplifying assumptions are made
  - If you know better, then bear with us until a further lecture

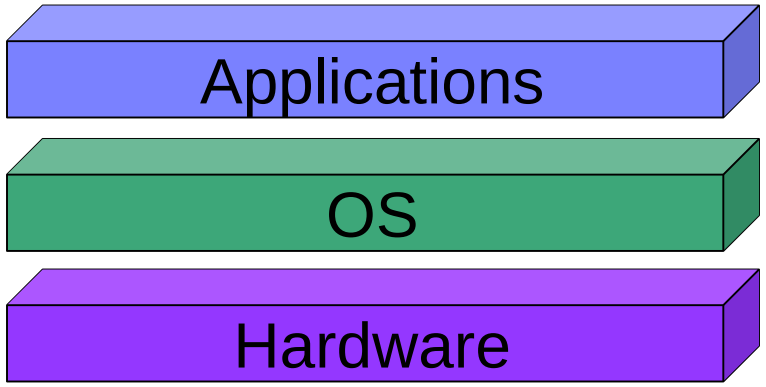
What is an OS?

- What do you think the answer is?

  (there are many possible answers)

What is an OS?

- One answer: software layer between the applications and the hardware because the hardware would be too difficult for users to use



- Or: it's "all the code you didn't have to write" when you wrote your application
  - Not quite right as there are tons of non-OS libraries that you didn't write as well

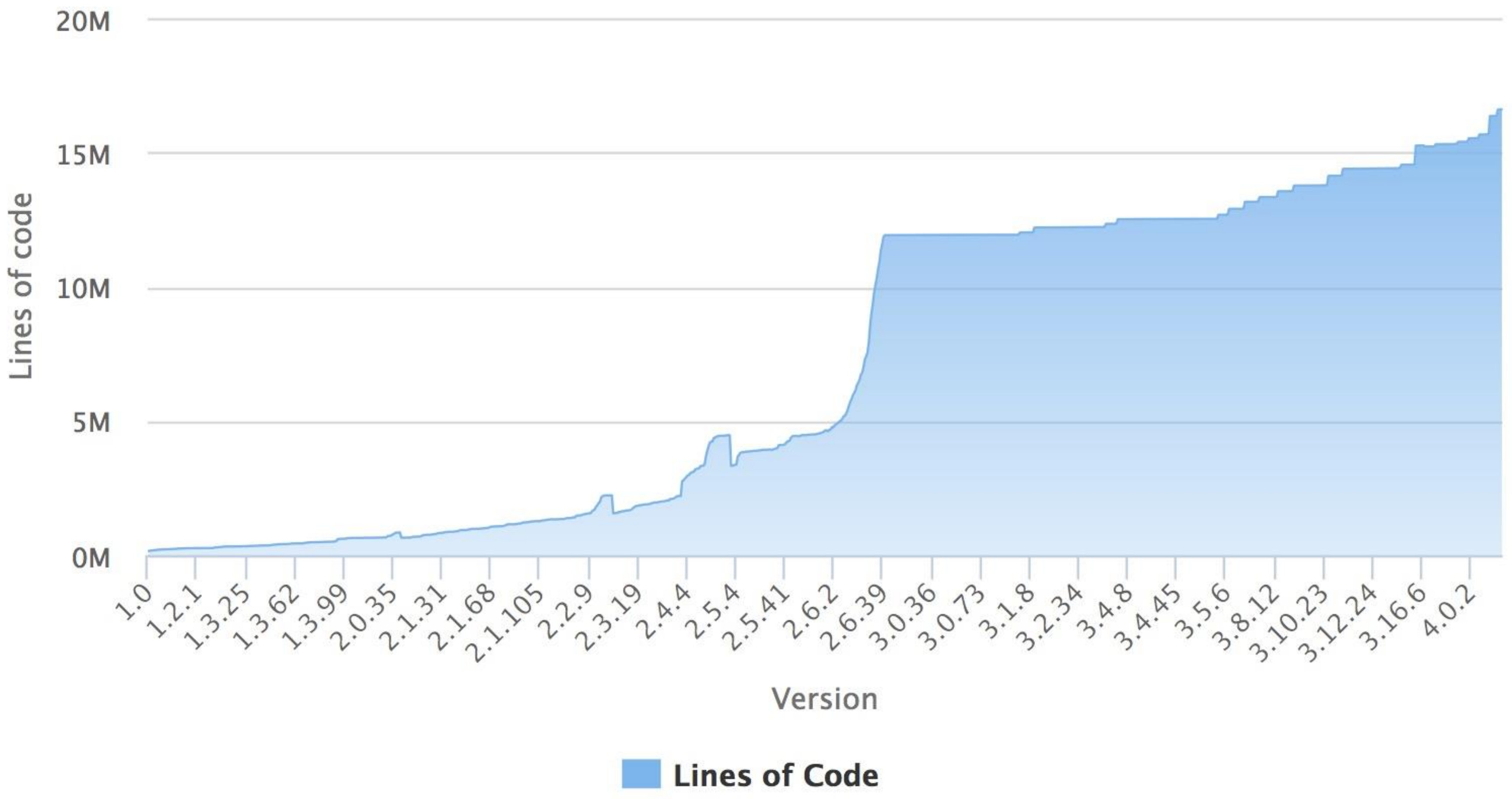
What is an OS?

- It’s a resource abstractor and a resource allocator
  - The OS defines a set of logical resources that correspond to hardware resources, and a set of well-defined operations on logical resources
    - e.g., physical resources: CPU, Disks, RAM
    - e.g., logical resources: processes, files, arrays
  - The OS decides who (which running program) gets what resource (share) and when
- Popular yet very wrong definition: It’s the one program (in fact, its “kernel” component) that runs at all times
  - It’s a misleading view of the kernel (which is not a running program at all)

How big is an OS?

- The question “What is part of the OS and what isn’t?” is a difficult one
  - What about the windowing system? “system” programs?
  - The 1998 lawsuit against Microsoft putting “too much” in what they called the Operating System (see the book p. 6)
- But here are a few SLOC (Source Line of Code) numbers
  - Windows NT (1993): 6 Million
  - Windows XP: ~50 Million
  - Windows Vista: ~XP + 10
  - Max OS X 10.4: ~86 Million
  - Ubuntu distribution: > 230 Million
    - But tons of things are not part of the OS
    - Kernel 2.6.29: 11 Million
- No matter: OSes are BIG

Linux Kernel Lines of Code



- https://www.linuxcounter.net/statistics/kernel

How does one start an OS?

- When a computer boots, it needs to run a first program: the bootstrap program
  - Stored in Read Only Memory (ROM)
  - Called the “firmware” or bootloader
- The bootstrap program initializes the computer
  - Register content, device controller contents, etc.
- It then locates and loads the OS kernel into memory
- The kernel starts the first process (called “init” on Linux, “launchd” on Mac OS X).. let's see it...
- And then, nothing happens until an event occurs
  - more on events in a few slides

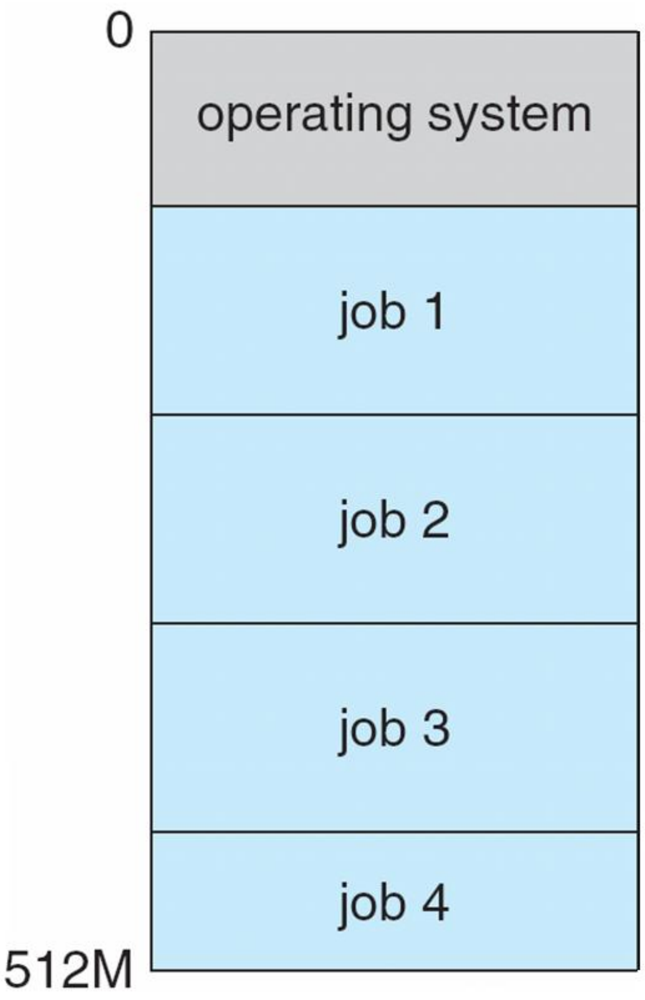
Multi-Programming

- Multi-Programming: Modern OSes allow multiple “jobs” (running programs) to reside in memory simultaneously
  - The OS picks and begins to execute one of the jobs in memory
  - When the job has to wait for “something”, then the OS picks another job to run
  - This is called a context-switch, and improves productivity
- We are used to this now, but it wasn’t always so
  - Single-user mode
    - Terrible productivity (while you “think”, nobody else is using the machine)
  - Batch processing (jobs in a queue)
    - Low productivity (CPU idle during I/O operations)

Time-Sharing

- Time-Sharing: Multi-programming with rapid context-switching
- Jobs cannot run for “too long”
- Allows for interactivity
  - Response time very short
  - Each job has the illusion that it is alone on the system
- In modern OSes, jobs are called processes
  - A process is a running program
- There are many processes, some of which are (partly) in memory concurrently
  - Let's run the “ps aux” command on my laptop

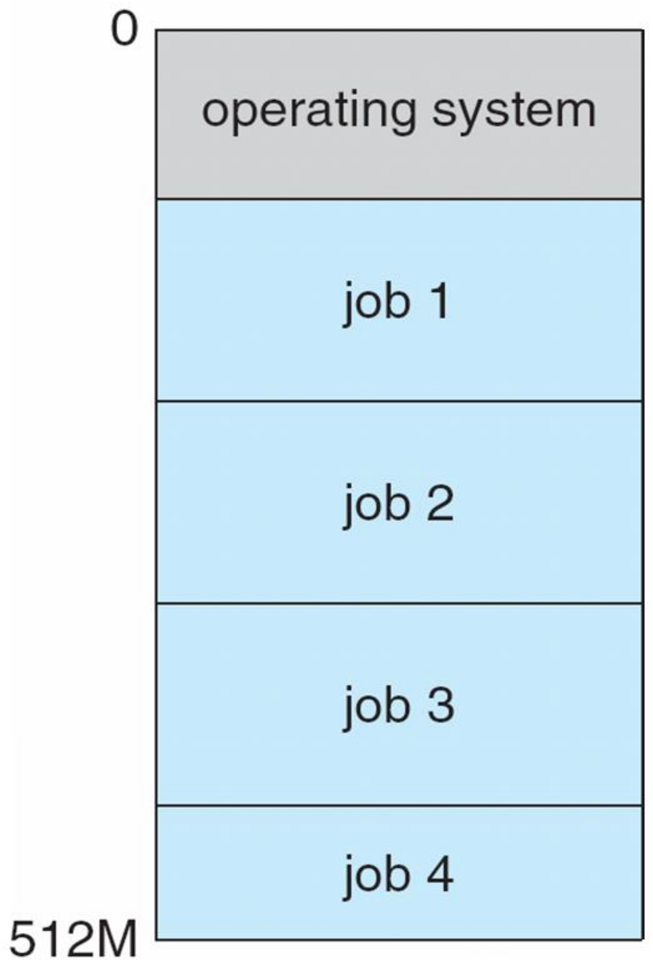
The Running OS



- The code of the operating system resides in memory at a specified address, as loaded by the bootstrap program
- At times, some of this code can be executed by a process
  - Branch to some OS code segment
  - Return to the program's code later
- Each process is loaded in a subset of the memory
  - Code + data
- Memory protection among processes is ensured by the OS
  - A process cannot step on another process' toes

Running the OS Code?

- The kernel is NOT a running job
- It's code (i.e., a data and a text segment) that resides in memory and is ready to be executed at any moment
  - When some event occurs
- It can be executed on behalf of a job whenever requested
- It can do special/dangerous things
  - having to do with hardware



A Note on Kernel Size

- In the previous figure you see that the kernel uses some space in the physical memory
- As a kernel designer you want to be careful to not use too much memory!
  - Hence the fight about whether new features are truly necessary in the kernel
  - Hence the need to write lean/mean code
  - lean → nothing more; mean → single-minded
- Furthermore, there is no memory protection within the kernel
  - The kernel's the one saying to a process "segmentation fault"
  - Nobody's watching over the kernel
- So one must be extremely careful when developing kernels
- Hence the reason why Kernel "hacking" is highly respected

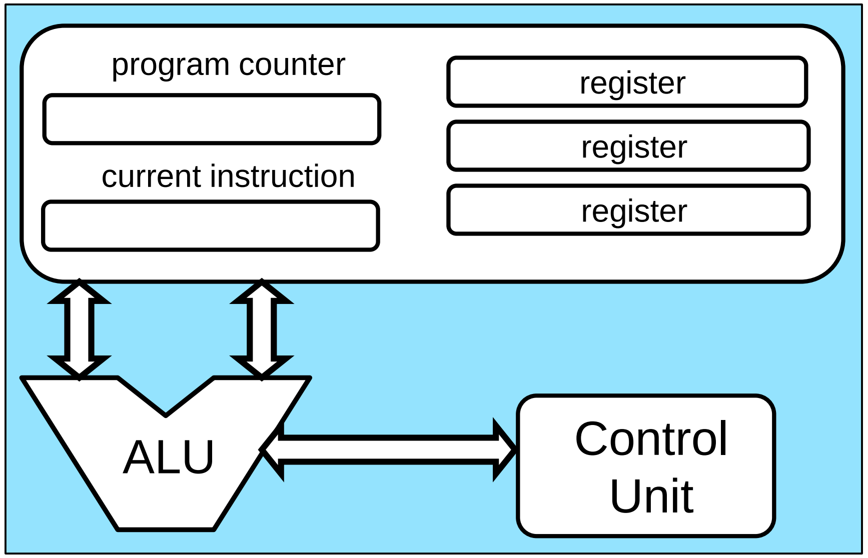
Protected Instructions

- A subset of instructions of every CPU is restricted in usage: only the OS can execute them
  - Known as protected (or privileged) instructions
- For instance, only the OS can:
  - Directly access I/O devices (printer, disk, etc.)
    - Fairness, security
  - Manipulate memory management state
    - Fairness, security
  - Manipulate protected control registers
    - Kernel mode, interrupt level (more on all this later)
  - Execute the halt instruction that shuts down the processor
- The CPU needs to know whether it can execute a protected instruction or not...

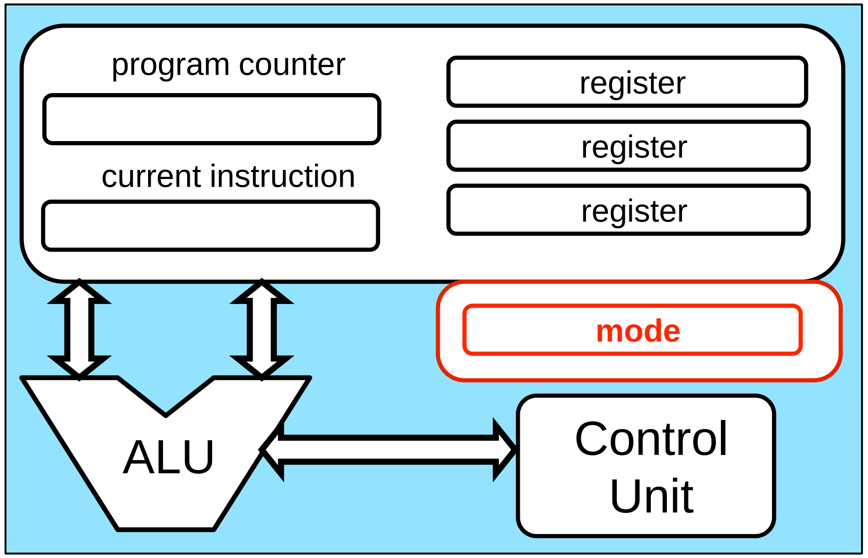
User vs. Kernel Mode

- All modern processors support (at least) two modes of execution:
  - User mode: In this mode protected instructions cannot be executed
  - Kernel mode: In this mode all instructions can be executed
- User code executes in user mode
- OS code executes in kernel mode
- The mode is indicated by a status bit in a protected control register
  - The CPU checks this bit before executing a protected instruction
- Setting the mode bit is, of course, a protected instruction

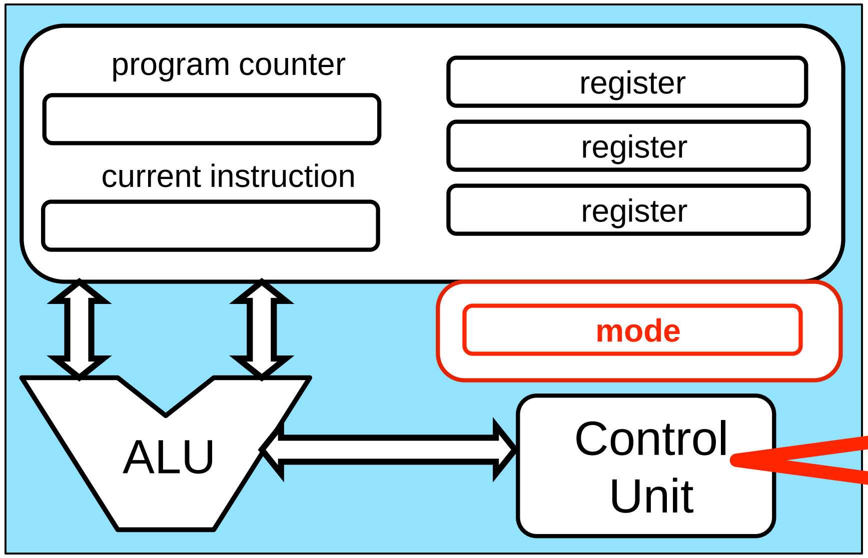
User vs. Kernel Mode



User vs. Kernel Mode



User vs. Kernel Mode



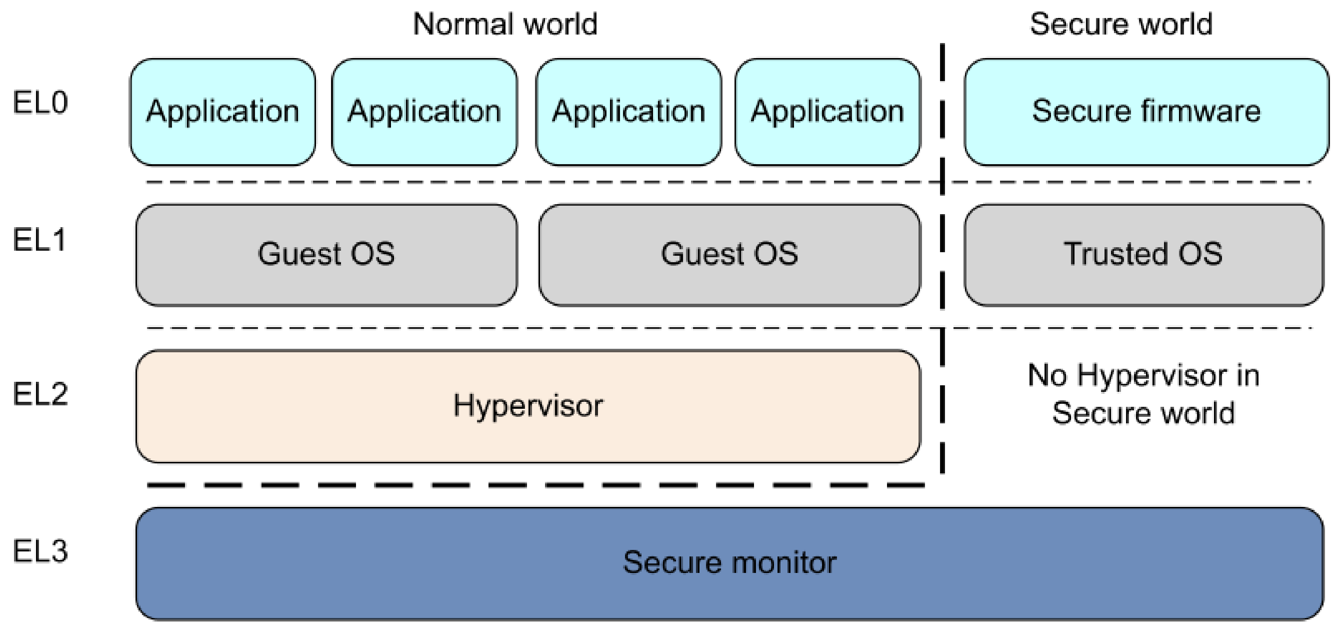
- Decode instruction
- Determine if instruction is privileged or not
  - Based on the instruction code (e.g., the binary code for all privileged instructions could start with ’00’)
- If instruction is privileged and mode == user, then abort!
  - Raise a “trap”

User vs. Kernel Mode

- There can be multiple modes
  - e.g., multiple levels in CPU
- MS-DOS had only one mode, because it was written for the Intel 8088, which had no mode bit
  - A user program could wipe out the whole system due to a bug (or a malicious user)
  - Multiple user programs could write to the same device concurrently, leading to incoherent behavior

User vs. Kernel Mode

- There can be multiple modes
  - e.g., multiple levels in ARM64



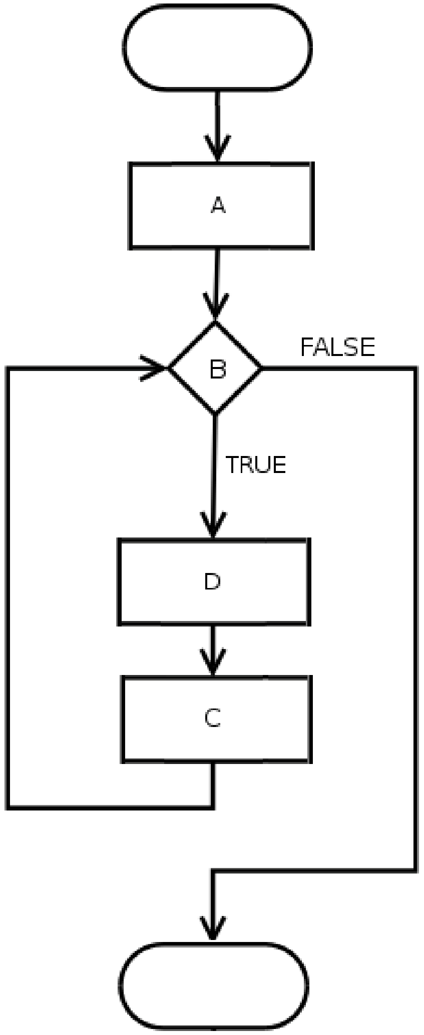
OS Events

- An event is an “unusual” change in control flow
  - A usual change is some “branch” instruction within a user program for instance
- An event stops execution, changes mode, and changes context
  - i.e., it starts running kernel code
- The kernel defines a handler for each event type
  - i.e., a piece of code executed in kernel mode
- Once the system is booted, all entries to the kernel occur as the result of an event
  - The OS can be seen as a huge event handler

Control flow

In computer science, control flow (or flow of control) is the order in which individual statements, instructions or function calls of an program are executed.

for(A;B;C)
  D;



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

A flow chart showing control flow.

10K-foot View of Kernel Code

```
void processEvent(event) {
        switch (event.type) {
        case NETWORK_COMMUNICATION:
                NetworkManager.handleEvent(event);
                break;

        case SEGMENTATION_FAULT:
        case INVALID_MODE:
                ProcessManager.handleEvent(event);
                break;
                ...
        }
        return;
}
```

OS Events

- There are two kinds of events: interrupts and traps (or exceptions)
  - The two terms are often confused (even in the textbook)
  - The term fault often refers to unexpected events
- **Interrupts are caused by external events**
  - Hardware-generated
  - e.g., some device controller says “something happened”
- **Traps are caused by executing instructions**
  - Software-generated interrupts
  - e.g., the CPU tried to execute a privileged instruction but it’s not in kernel mode
  - e.g., a division by zero

OS Events

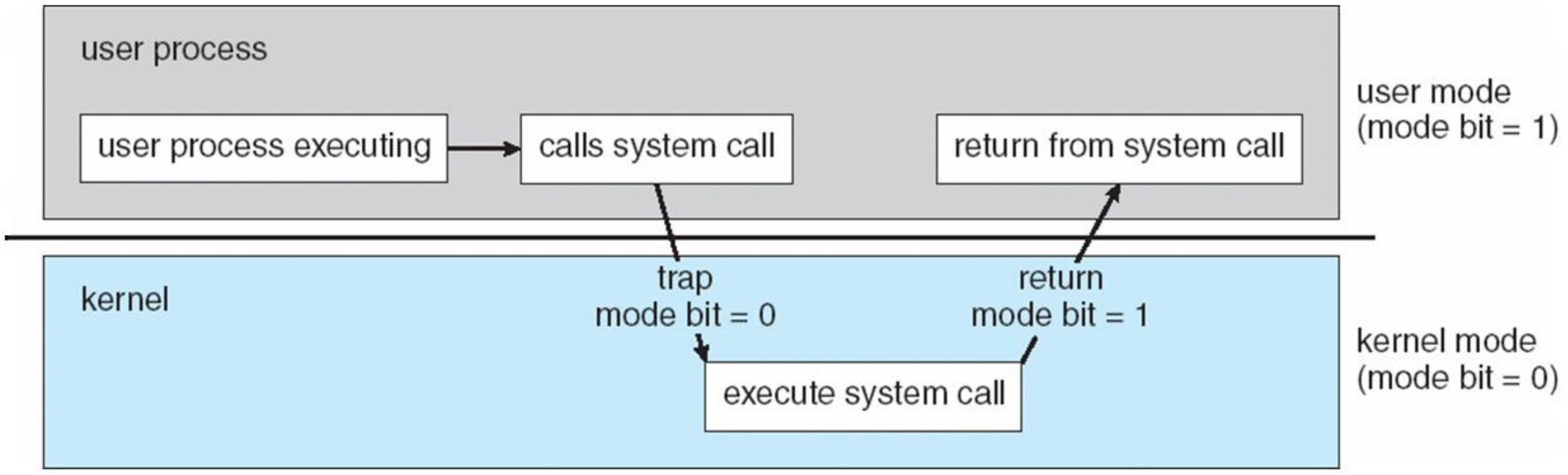
- When the CPU is interrupted, it stops what it is doing and immediately transfers execution to a fixed location in the kernel code
  - the “processEvent()” method in my mock-up kernel code a couple slides ago
- Could result in:
  - Some work being done by the kernel
  - A user process being terminated (e.g., segmentation fault)
- What about “faults” in the kernel?
  - Say dereferencing of a NULL pointer, or a divide by zero
  - This is a fatal fault
  - UNIX Panic, Windows blue screen of death
    - Kernel is halted, state dumped to a core file, machine is locked up

System Calls

- When a user program needs to do something privileged, it calls a system call
  - e.g., to create a process, write to disk, read from the network card
- A system call is a special kind of trap
- Every Instruction Set Architecture (ISA) provides a system call instruction that
  - Causes a trap, which maps to a kernel handler
  - Passes a parameter determining which system call to place (a number)
  - Saves caller state (PC, regs, mode) so it can be restored later
- On the x86 architecture the instruction is called int

```
mov     eax, 12
int                 // places system call #12
```

System Calls



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                break;

        case SYSTEM_CALL:
                SystemCallManager.execute(event);
                break;
                ...
        }
        return;
}
```

Timers

- The OS must keep control of the CPU
  - OS must have a concept of “time”
  - Programs cannot gain an unfair share of the computer
- One way in which the OS (or kernel) retrieves control is when an interrupt occurs
- To make sure that an interrupt will occur reasonably soon, we can use a timer
- The timer interrupts the computer regularly
  - For example, every 1ms-1s
  - The OS always makes sure the timer is set before turning over control to user code
- Modifying the timer is done via privileged instructions

10K-foot View of Kernel Code

```
void processEvent(event) {
        Timer.set(1000);  // Will generate an event in 1000 time units
        switch (event.type) {
        case NETWORK_COMMUNICATION:
                NetworkManager.handleEvent(event);
                break;

        case SEGMENTATION_FAULT:
        case INVALID_MODE:
                ProcessManager.handleEvent(event);
                break;

        case SYSTEM_CALL:
                SystemCallManager.execute(event);
                break;

        case TIMER:
                Timer.handleEvent(event);
                break;
        …
        }
        return;
}
```

Main OS Services

- Process Management
- Memory Management
- Storage Management
- I/O Management
- Protection and Security

Process Management

- A process is a program in execution
  - Program: *passive entity*
  - Process: *active entity*

- The OS is responsible for :
  - Creating and deleting processes
  - Suspending and resuming processes
  - Providing mechanisms for process synchronization
  - Providing mechanisms for process communication
  - Providing mechanisms for deadlock handling

Memory Management

- Memory management determines what is in memory when
    - The kernel is ALWAYS in memory
- The OS is responsible for:
    - Keeping track of which parts of memory are currently being used and by which process
    - Deciding which processes (or parts thereof) and data to move into and out of memory
    - Allocating and deallocating memory space as needed
- The OS is not responsible for memory caching, cache coherency, etc.
    - These are managed by the hardware

Storage Management

- The OS provides a uniform, logical view of information storage
  - It abstracts physical properties to logical storage unit (e.g., as a “file”)
- The OS operates File-System management
  - Creating and deleting files and directories
  - Manipulating files and directories
  - Mapping files onto secondary storage
  - Backup files onto stable (non-volatile) storage media
  - Free-space management
  - Storage allocation
  - Disk scheduling

I/O Management

- The OS hides peculiarities of hardware devices from the user
- The OS is responsible for
  - Memory management of I/O including buffering (storing data temporarily while it is being transferred), spooling (the overlapping of output of one job with input of other jobs), etc.
  - General device-driver interface
    - So that multiple devices can be used with the same kernel as long as they offer some standard interface
  - Drivers for specific hardware devices

Protection and Security

- **Protection:** mechanisms for controlling access of processes to resources defined by the OS
- **Security:** defense of the system against internal and external attacks, for example, due to bugs
    - including denial-of-service, worms, viruses, identity theft, theft of service
- The OS provides:
    - Memory protection, device protection
    - User IDs associated to processes and files
    - Group IDs for sets of users
    - Definition of privilege levels

Privileged Instructions

- In class discussion: which of these instructions should be privileged, and why?
  - Set value of the system timer
  - Read the clock
  - Clear memory
  - Issue a system call instruction
  - Turn off interrupts
  - Modify entries in device-status table
  - Access I/O device

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Sections 1.10 and 1.11

- Operating System Concepts (10th Edition)
- The textbook has sections on “Computing environments” and “Free and Open-Source Operating Systems”
  - Make sure you read them!
  - They talk about a number of topics that are part of the general culture that you should have, in case you don’t have it already

Conclusion

- This set of slides gave a grand tour of what an OS is and what it does
- We have purposely left many elements not fully explained... they will be elucidated throughout the semester

- Reading assignment: Chapter 1
- HW1 is out – due in 1 week