Operating Systems

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12 lectures for CST IA

Course Aims

- This course aims to:
  - explain the structure and functions of an operating system,
  - illustrate key operating system aspects by concrete example, and
  - prepare you for future courses. . .
- At the end of the course you should be able to:
  - compare and contrast CPU scheduling algorithms
  - explain the following: process, address space, file.
  - distinguish paged and segmented virtual memory.
  - discuss the relative merits of Unix and NT. . .

Course Outline

- Introduction to Operating Systems.
- Processes & Scheduling.
- Memory Management.
- I/O & Device Management.
- Protection.
- Filing Systems.
- Case Study: Unix.
- Case Study: Windows NT.

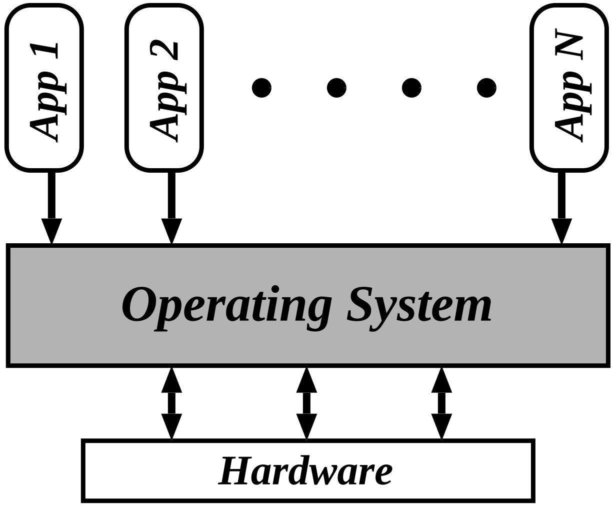
Recommended Reading

- *Concurrent Systems* or *Operating Systems*
  Bacon J [and Harris T], Addison Wesley 1997 [2003]
- *Operating Systems Concepts (5th Ed.)*
  Silberschatz A, Peterson J and Galvin P, Addison Wesley 1998.
- *The Design and Implementation of the 4.3BSD UNIX Operating System*
  Leffler S J, Addison Wesley 1989
- *Inside Windows 2000 (3rd Ed)* or *Windows Internals (4th Ed)*
  Solomon D and Russinovich M, Microsoft Press 2000 [2005]

What is an Operating System?

- A program which controls the execution of all other programs (applications).
- Acts as an intermediary between the user(s) and the computer.
- Objectives:
  - convenience,
  - efficiency,
  - extensibility.
- Similar to a government. . .

An Abstract View



- The Operating System (OS):
  - controls all execution.
  - multiplexes resources between applications.
  - abstracts away from complexity.
- Typically also have some *libraries* and some *tools* provided with OS.
- Are these part of the OS? Is IE a tool?
  - no-one can agree. . .
- For us, the OS $\approx$ the *kernel*.

In The Beginning. . .

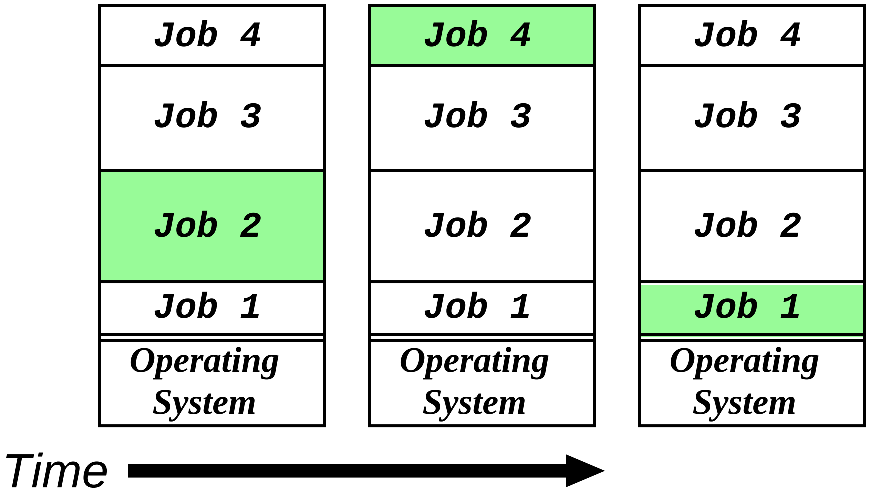
- 1949: First stored-program machine (EDSAC)
- to $\sim$ 1955: "Open Shop".
  - large machines with vacuum tubes.
  - I/O by paper tape / punch cards.
  - user = programmer = operator.
- To reduce cost, hire an $operator$:
  - programmers write programs and submit tape/cards to operator.
  - operator feeds cards, collects output from printer.
- Management like it.
- Programmers hate it.
- Operators hate it.

$\Rightarrow$ need something better.

Batch Systems

- Introduction of tape drives allow *batching* of jobs:
  - programmers put jobs on cards as before.
  - all cards read onto a tape.
  - operator carries input tape to computer.
  - results written to output tape.
  - output tape taken to printer.
- Computer now has a *resident monitor*:
  - initially control is in monitor.
  - monitor reads job and transfer control.
  - at end of job, control transfers back to monitor.
- Even better: *spooling systems*.
  - use interrupt driven I/O.
  - use magnetic disk to cache input tape.
  - fire operator.
- Monitor now *schedules* jobs. . .

Multi-Programming

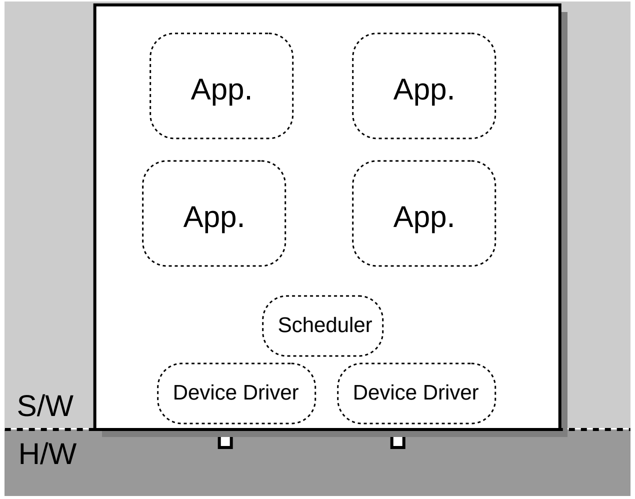


- Use memory to cache jobs from disk $\Rightarrow$ more than one job active simultaneously.
- Two stage scheduling:
  1. select jobs to load: *job scheduling*.
  2. select resident job to run: *CPU scheduling*.
- Users want more interaction $\Rightarrow$ *time-sharing*:
- e.g. CTSS, TSO, Unix, VMS, Windows NT...

Today and Tomorrow

- Single user systems: cheap and cheerful.
  - personal computers.
  - no other users $\Rightarrow$ ignore protection.
  - e.g. DOS, Windows, Win 95/98, . . .
- RT Systems: power is nothing without control.
  - hard-real time: nuclear reactor safety monitor.
  - soft-real time: mp3 player.
- Parallel Processing: the need for speed.
  - SMP: 2–8 processors in a box.
  - MIMD: super-computing.
- Distributed computing: global processing?
  - Java: the network is the computer.
  - Clustering: the network is the bus.
  - CORBA: the computer is the network.
  - .NET: the network is an enabling framework. . .

Monolithic Operating Systems



- Oldest kind of OS structure ("modern" examples are DOS, original MacOS)
- Problem: applications can e.g.
  - trash OS software.
  - trash another application.
  - hoard CPU time.
  - abuse I/O devices.
  - etc. . .
- No good for fault containment (or multi-user).
- Need a better solution. . .

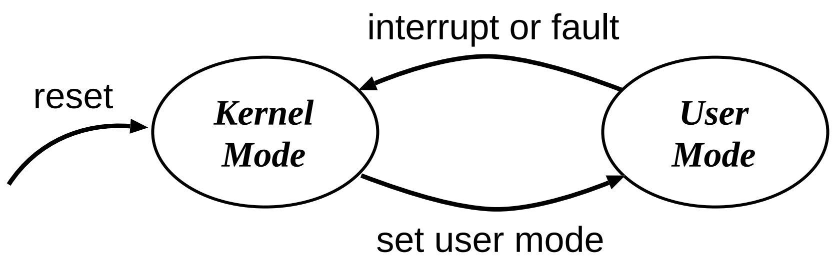
Dual-Mode Operation

- Want to stop buggy (or malicious) program from doing bad things.

⇒ provide $hardware$ support to distinguish between (at least) two different modes of operation:

1. *User Mode* : when executing on behalf of a user (i.e. application programs).
2. *Kernel Mode* : when executing on behalf of the operating system.

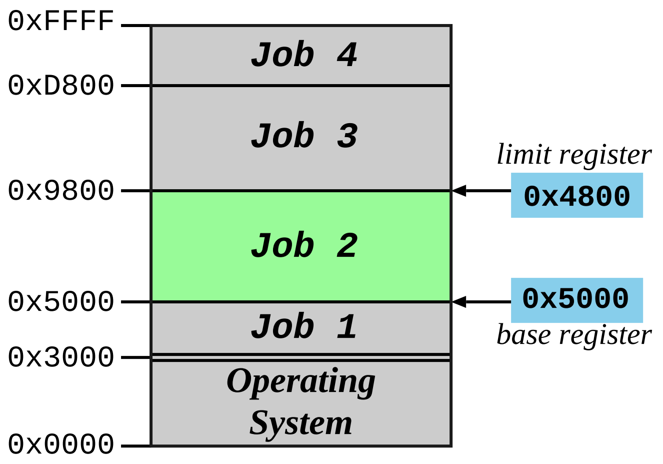
- Hardware contains a mode-bit, e.g. 0 means kernel, 1 means user.



- Make certain machine instructions only possible in kernel mode. . .

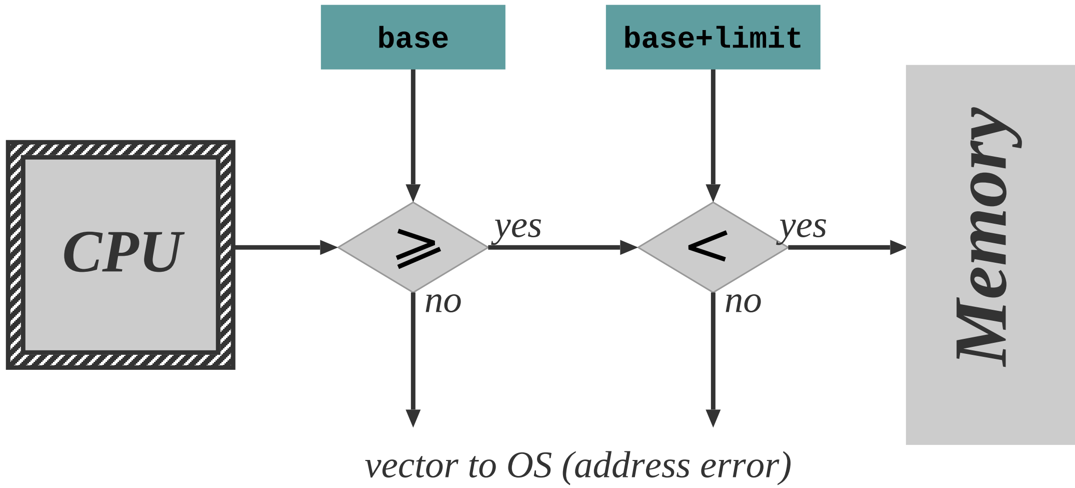
Protecting I/O & Memory

- First try: make I/O instructions privileged.
  - applications can't mask interrupts.
  - applications can't control I/O devices.
- But:
  1. Application can rewrite interrupt vectors.
  2. Some devices accessed via *memory*
- Hence need to protect memory also, e.g. define *base* and *limit* for each program:



- Accesses outside allowed range are protected.

Memory Protection Hardware



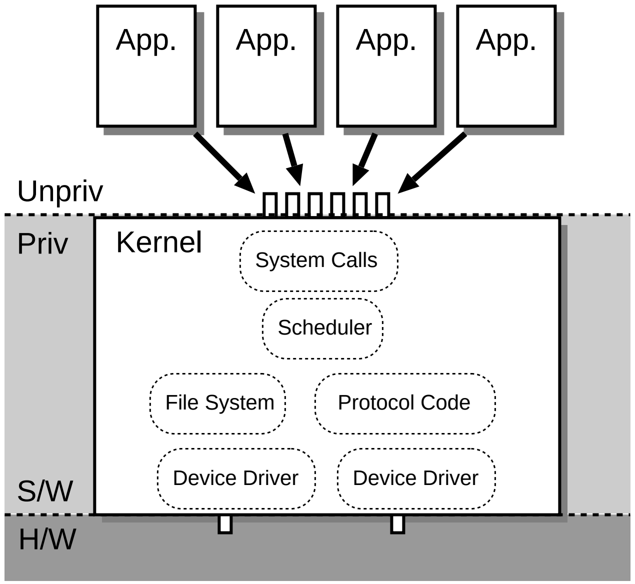
- Hardware checks every memory reference.
- Access out of range $\Rightarrow$ vector into operating system (just as for an interrupt).
- Only allow *update* of base and limit registers in kernel mode.
- Typically disable memory protection in kernel mode (although a bad idea).
- In reality, more complex protection h/w used:
  - main schemes are *segmentation* and *paging*
  - (covered later on in course)

Protecting the CPU

- Need to ensure that the OS stays in control.
  - i.e. need to prevent any a malicious or badly-written application from 'hogging' the CPU the whole time.

  $\Rightarrow$ use a *timer* device.
- Usually use a *countdown* timer, e.g.
  1. set timer to initial value (e.g. `0xFFFF`).
  2. every *tick* (e.g. $1\mu s$), timer decrements value.
  3. when value hits zero, interrupt.
- (Modern timers have programmable tick rate.)
- Hence OS gets to run periodically and do its stuff.
- Need to ensure only OS can load timer, and that interrupt cannot be masked.
  - use same scheme as for other devices.
  - (viz. privileged instructions, memory protection)
- Same scheme can be used to implement time-sharing (more on this later).

Kernel-Based Operating Systems



- Applications can't do I/O due to protection

  ⇒ operating system does it on their behalf.

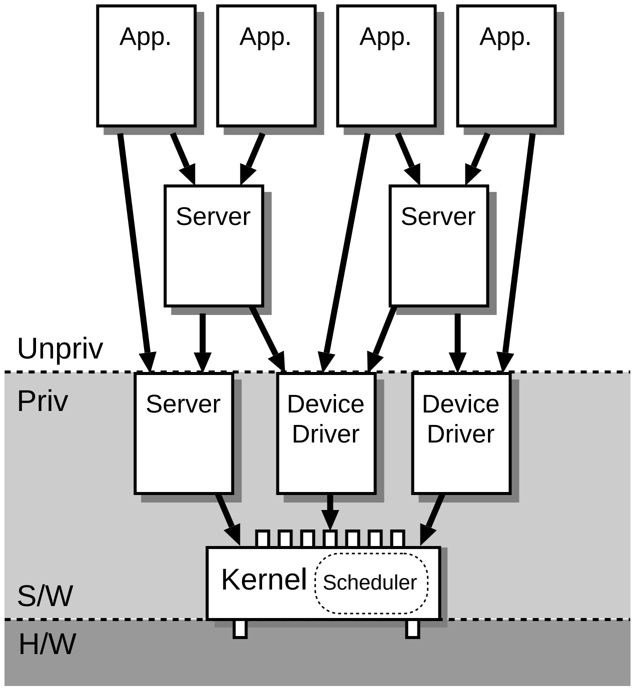
- Need secure way for application to invoke operating system:

  ⇒ require a special (unprivileged) instruction to allow transition from user to kernel mode.

- Generally called a *software interrupt* since operates similarly to a real (hardware) interrupt. . .

- Set of OS services accessible via software interrupt mechanism called *system calls*.

Microkernel Operating Systems



- Alternative structure:
  - push some OS services into *servers*.
  - servers may be privileged (i.e. operate in kernel mode).
- Increases both *modularity* and *extensibility*.
- Still access kernel via system calls, but need new way to access servers:

  ⇒ interprocess communication (IPC) schemes.

Kernels versus Microkernels

So why isn't everything a microkernel?

- Lots of IPC adds overhead

  $\Rightarrow$ microkernels usually perform less well.

- Microkernel implementation sometimes tricky: need to worry about concurrency and synchronisation.
- Microkernels often end up with redundant copies of OS data structures.

Hence today most common operating systems blur the distinction between kernel and microkernel.

- e.g. linux is a "kernel", but has kernel modules and certain servers.
- e.g. Windows NT was originally microkernel (3.5), but now (4.0 onwards) pushed lots back into kernel for performance.
- Still not clear what the best OS structure is, or how much it really matters. . .

Operating System Functions

- Regardless of structure, OS needs to *securely multiplex resources*:
  1. protect applications from each other, yet
  2. share physical resources between them.
- Also usually want to *abstract* away from grungy harware, i.e. OS provides a *virtual machine*:
  - share CPU (in time) and provide each app with a virtual processor,
  - allocate and protect memory, and provide applications with their own virtual address space,
  - present a set of (relatively) hardware independent virtual devices,
  - divide up storage space by using filing systems, and
  - do all this within the context of a security framework.
- Remainder of this part of the course will look at each of the above areas in turn. . .

Process Concept

- From a user's point of view, the operating system is there to execute programs:
  - on batch system, refer to *jobs*
  - on interactive system, refer to *processes*
  - (we'll use both terms fairly interchangeably)
- Process $\neq$ Program:
  - a program is *static*, while a process is *dynamic*
  - in fact, a process $\triangleq$ "a program in execution"
- (Note: "program" here is pretty low level, i.e. native machine code or *executable*)
- Process includes:
  1. program counter
  2. stack
  3. data section
- Processes execute on *virtual processors*