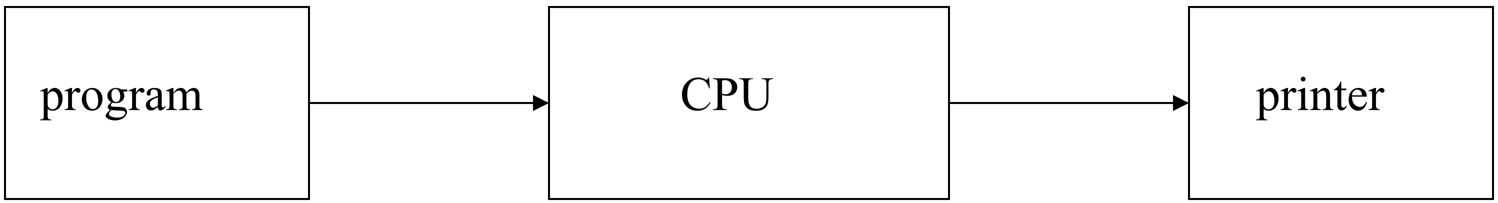
Advanced Operating Systems (CS 202)

OS Evolution and Organization

Dawn of computing



- Pre 1950 : the very first electronic computers
  - valves and relays
  - single program with dedicated function

- Pre 1960 : stored program valve machines
  - single job at a time; OS is a program loader

Phase 0 of OS Evolution (40s to 1955)

- No OS
  - Computers are exotic, expensive, large, slow experimental equipment
  - Program in machine language and using plugboards
  - User sits at console: no overlap between computation, I/O, user thinking, etc..
    - Program manually by plugging wires in
    - Goal: number crunching for missile computations
- Imagine programming that way
  - Painful and slow

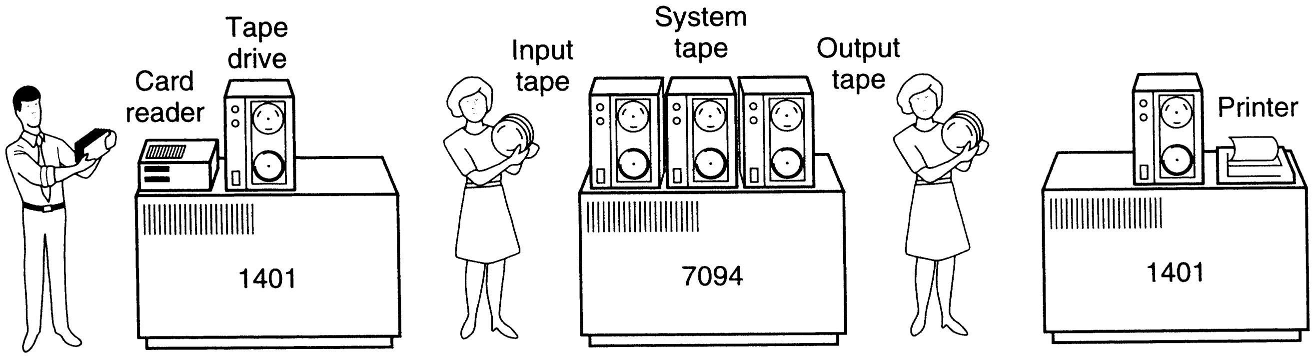
OS progress in this period

- Libraries of routines that are common
  - Including those to talk to I/O devices
  - Punch cards (enabling copying/exchange of these libraries) a big advance!
  - Pre-cursor to OS

Phase 1: 1955-1970

- Computers expensive; people cheap
  - Use computers efficiently – move people away from machine
  - OS becomes a batch monitor
    - Loads a job, runs it, then moves on to next
    - If a program fails, OS records memory contents somewhere
    - More efficient use of hardware but increasingly difficult to debug

- Batch systems on *mainframe* computers
- collections of jobs made up into a *batch*
- example: IBM 1401/7094
  - card decks spooled onto magnetic tape and from tape to printer



- example: English Electric Leo KDF9
  - 32K 48-bit words, 2μsec cycle time
  - punched paper-tape input 'walk-up' service or spooling via mag tape

Advances in technology in this stage

- Data channels and interrupts
  - Allow overlap of I/O and computing
  - Buffering and interrupt handling done by OS
  - Spool (buffer) jobs onto “high speed” drums

Phase 1, problems

- Utilization is low (one job at a time)
- No protection between jobs
- Short jobs wait behind long jobs
  - So, we can only run one job at a time
- Coordinating concurrent activities
- Still painful and slow (but less so?)

Advances in OS in this period

- Hardware provided memory support (protection and relocation)
- Multiprogramming (not to be confused with time sharing)
- Scheduling: let short jobs run first
- OS must manage interactions between concurrent things
  - Starts emerging as a field/science
- OS/360 from IBM first OS designed to run on a family of machines from small to large

Some important projects

- Atlas computer/OS from Manchester U. (late 50s/early 60s)
  - First recognizable OS
  - Separate address space for kernel
  - Early virtual memory
- THE Multiprogramming system (early 60s)
  - Introduced semaphores
  - Attempt at proving systems correct; interesting software engineering insights

Not all is smooth

- Operating systems didn't really work
- No software development or structuring tools; written in assembly
- OS/360 introduced in 1963 but did not really work until 1968
  - Reported on in mythical man month
- Extremely complicated systems
  - 5-7 years development time typical
  - Written in assembly, with no structured programming
  - Birth of software engineering?

Phase 2: 1970s

- Computers and people are expensive
  - Help people be more productive
  - Interactive time sharing: let many people use the same machine at the same time
  - Emergence of minicomputers
    - Terminals are cheap
  - Keep data online on fancy file systems
  - Attempt to provide reasonable response times (Avoid thrashing)

Important advances and systems

- Compatible Time-Sharing System (CTSS)
  - MIT project (demonstrated in 1961)
  - One of the first time sharing systems
  - Corbato won Turing award in 1990
  - Pioneered much of the work in scheduling
  - Motivated MULTICS

MULTICS

- Jointly developed by MIT, Bell Labs and GE
- Envisioned one main computer to support everyone
  - People use computing like a utility like electricity – sound familiar? Ideas get recycled
- Many many fundamental ideas: protection rings, hierarchical file systems, devices as files, …
- Building it was more difficult than expected
- Technology caught up

Unix appears

- Ken Thompson, who worked on MULTICS, wanted to use an old PDP-7 laying around in Bell labs
- He and Dennis Richie built a system designed by programmers for programmers
- Originally in assembly. Rewritten in C
  - If you notice for the paper, they are defending this decision
  - However, this is a new and important advance: portable operating systems!
- Shared code with everyone (particularly universities)

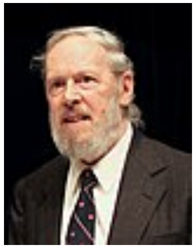
Unix (cont'd)

- Berkeley added support for virtual memory for the VAX
- DARPA selected Unix as its networking platform in arpanet
- Unix became commercial
  - …which eventually lead Linus Torvald to develop Linux

Some important ideas in Unix

- OS written in a high level language
- OS portable across hardware platforms
  - Computing is no longer a pipe stove/vertical system
- Pipes
  - E.g., grep foo file.txt | wc -l
- Mountable file systems
- Many more (we'll talk about unix later)
- 1983 Turing Award

Ken Thompson



Dennis M. Ritchie

Phase 3: 1980s

- Computers are cheap, people expensive
  - Put a computer in each terminal
  - CP/M from DEC first personal computer OS (for 8080/85) processors
  - IBM needed software for their PCs, but CP/M was behind schedule
  - Approached Bill Gates to see if he can build one
  - Gates approached Seattle computer products, bought 86-DOS and created MS-DOS
  - Goal: finish quickly and run existing CP/M software
  - OS becomes subroutine library and command executive

New advances in OS

- PC OS was a regression for OS
  - Stepped back to primitive phase 1 style OS leaving the cool developments that occurred in phase 2
- Academia was still active, and some developments still occurred in mainframe and workstation space

Phase 4: Networked systems 1990s to 2010s

- Machines can talk to each other
  - its all about connectivity
- We want to share data not hardware
- Networked applications drive everything
  - Web, email, messaging, social networks, …
- Protection and multiprogramming less important for personal machines
  - But more important for servers

Phase 4, continued

- Market place continued horizontal stratification
  - ISPs (service between OS and applications)
  - Information is a commodity
  - Advertising a new marketplace
- New network based architectures
  - Client server
  - Clusters
  - Grids
  - Distributed operating systems
  - Cloud computing (or is that phase 5?)

New problems

- Large scale
  - Google file system, mapreduce, …
- Concurrency at large scale
  - ACID (Atomicity, Consistency, Isolation and Durability) in Internet Scale systems
    - Very large delays
    - Partitioning
- Security and Privacy

Phase 5: 2010s -- ??

- New generation?
- Mobile devices that are powerful
- Sensing: location, motion, …
- Cyberphysical systems
- Computing evolving beyond networked systems
  - But OS for them looks largely the same
  - Is that a good idea?

OS model and Architectural Support

Sleeping Beauty Model

- Answer: Sleeping beauty model
  - Technically known as *controlled direct execution*
  - OS runs in response to “events”; we support the switch in hardware
  - Only the OS can manipulate hardware or critical system state
- Most of the time the OS is sleeping
  - Good! Less overhead
  - Good! Applications are running directly on the hardware

What do we need from the architecture/CPU?

- Manipulating privileged machine state
  - Protected instructions
  - Manipulate device registers, TLB entries, etc.
  - Controlling access
- Generating and handling “events”
  - Interrupts, exceptions, system calls, etc.
  - Respond to external events
  - CPU requires software intervention to handle fault or trap
- Other stuff
  - Mechanisms to handle concurrency, Isolation, virtualization …

Protected Instructions

- OS must have exclusive access to hardware and critical data structures

- Only the operating system can
  - Directly access I/O devices (disks, printers, etc.)
    - Security, fairness (why?)
  - Manipulate memory management state
    - Page table pointers, page protection, TLB management, etc.
  - Manipulate protected control registers
    - Kernel mode, interrupt level
  - Halt instruction (why?)

Privilege mode

- Hardware restricts privileged instructions to OS
- Q: How does the HW know if the executed program is OS?
  - HW must support (at least) two execution modes: OS (kernel) mode and user mode
- Mode kept in a status bit in a protected control register
  - User programs execute in user mode
  - OS executes in kernel mode (OS == “kernel”)
  - CPU checks mode bit when protected instruction executes
  - Attempts to execute in user mode trap to OS

Switching back and forth

- Going from higher privilege to lower privilege
  - Easy: can directly modify the mode register to drop privilege
- But how do we escalate privilege?
  - Special instructions to change mode
    - System calls (`int 0x80, syscall, svc`)
    - Saves context and invokes designated handler
      - You jump to the privileged code; you cannot execute your own
    - OS checks your syscall request and honors it only if safe
  - Or, some kind of event happens in the system

Types of Arch Support

- Manipulating privileged machine state
  - Protected instructions
  - Manipulate device registers, TLB entries, etc.
  - Controlling access
- Generating and handling "events"
  - Interrupts, exceptions, system calls, etc.
  - Respond to external events
  - CPU requires software intervention to handle fault or trap
- Other stuff

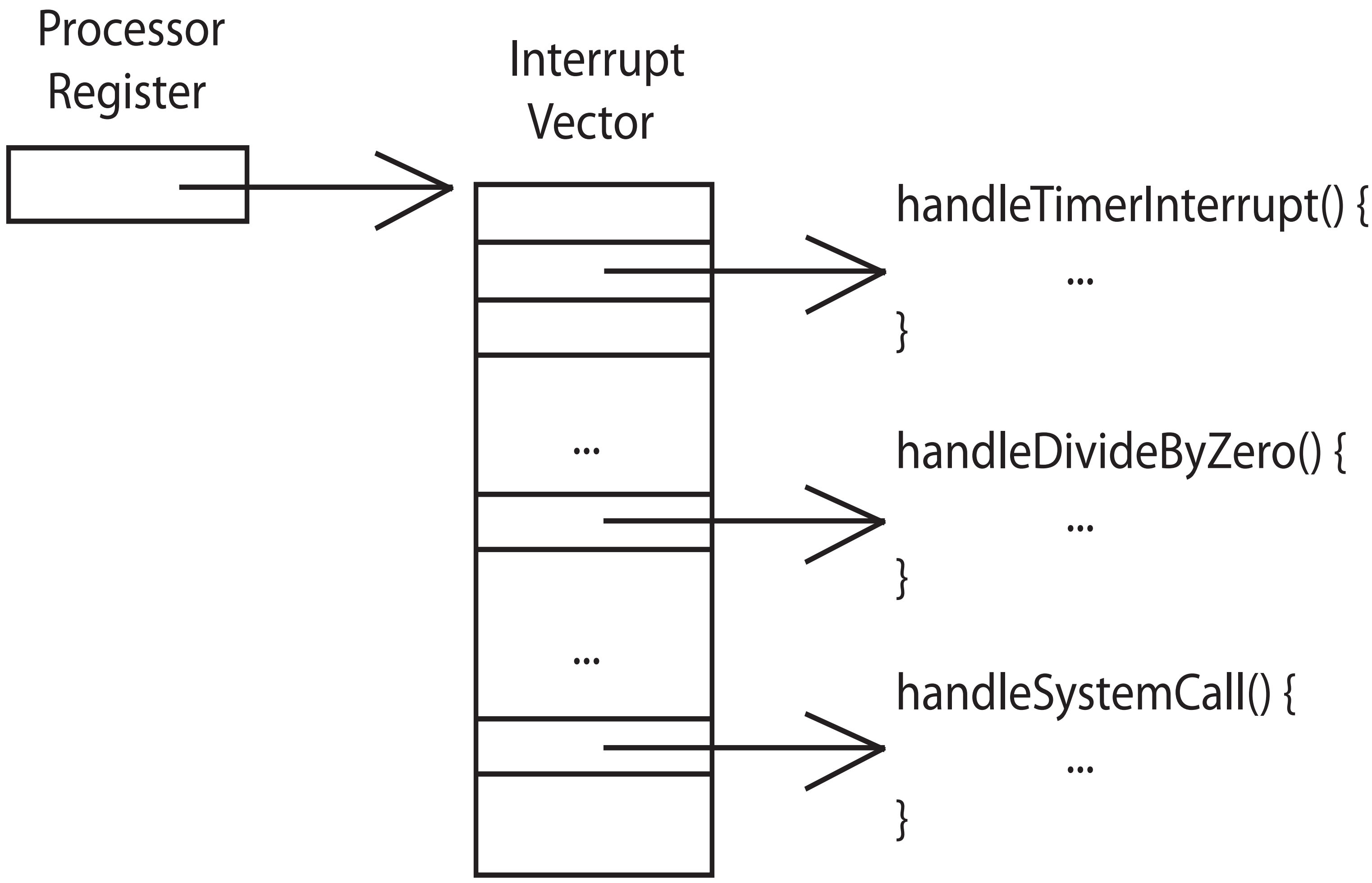
Events

- An event is an “unnatural” change in control flow
  - Events immediately stop current execution
  - Changes mode, context (machine state), or both

- The kernel defines a handler for each event type
  - Event handlers always execute in kernel mode
  - The specific types of events are defined by the machine

- Once the system is booted, OS is one big event handler
  - all entry to the kernel occurs as the result of an event

Handling events – Interrupt vector table



Categorizing Events

- This gives us a convenient table:

	Unexpected	Deliberate
Synchronous	fault	syscall trap
Asynchronous	interrupt	signal

- Terms may be slightly different by OS and architecture
  - E.g., POSIX signals, asynch system traps, async or deferred procedure calls

Faults

- Hardware detects and reports "exceptional" conditions
  - Page fault, memory access violation (unaligned, permission, not mapped, bounds…), illegal instruction, divide by zero

- Upon exception, hardware "faults" (verb)
  - Must save state (PC, regs, mode, etc.) so that the faulting process can be restarted
  - Invokes registered handler

Handling Faults

- Some faults are handled by “fixing” the exceptional condition and returning to the faulting context
  - Page faults cause the OS to place the missing page into memory
  - Fault handler resets PC of faulting context to re-execute instruction that caused the page fault

Handling Faults

- The kernel may handle unrecoverable faults by killing the user process
  - Program fault with no registered handler
  - Halt process, write process state to file, destroy process
  - In Unix, the default action for many signals (e.g., SIGSEGV)

- What about faults in the kernel?
  - Dereference NULL, divide by zero, undefined instruction
  - These faults considered fatal, operating system crashes
  - Unix panic, Windows "Blue screen of death"
    - Kernel is halted, state dumped to a core file, machine locked up

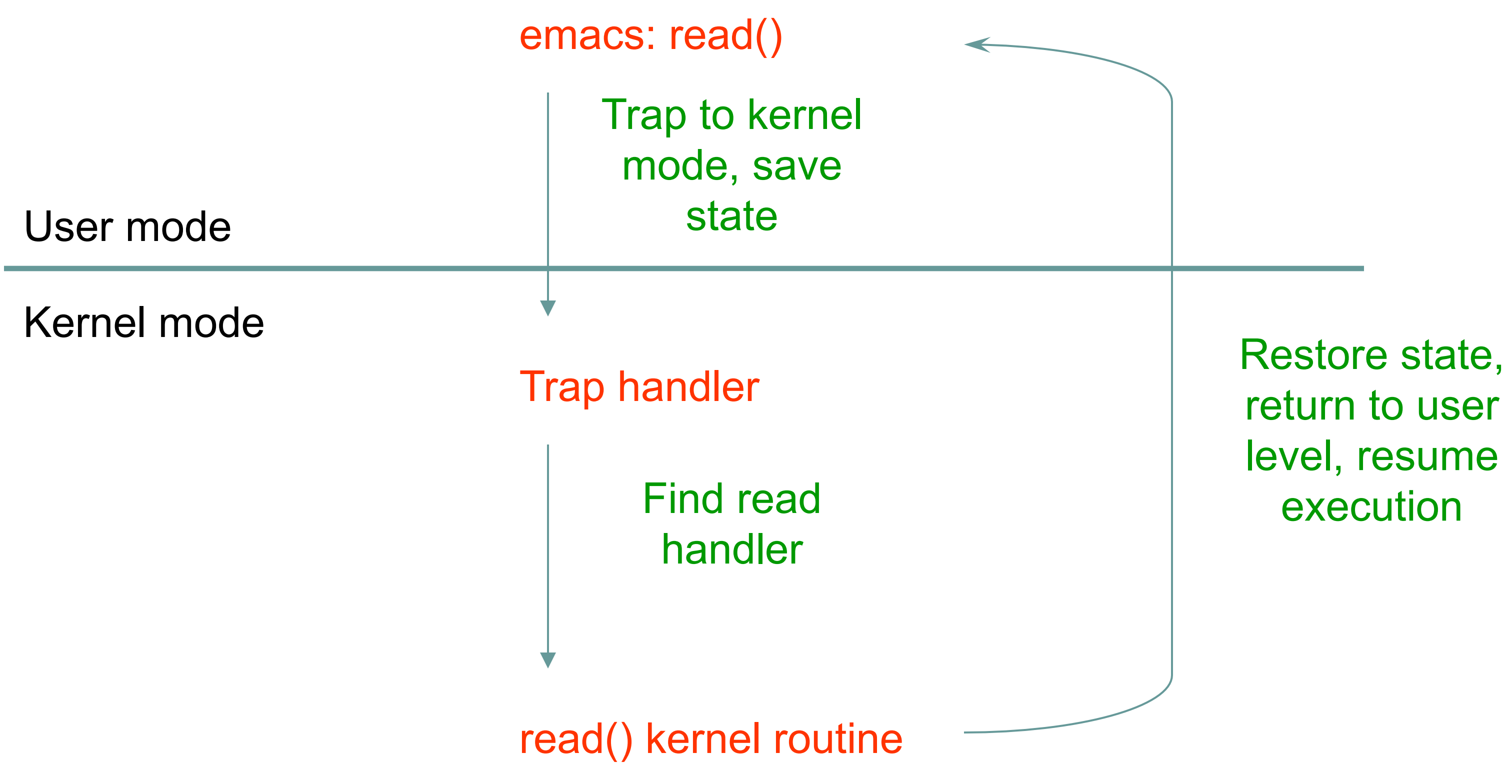
Categorizing Events

	Unexpected	Deliberate
Synchronous	fault	syscall trap
Asynchronous	interrupt	signal

System Calls

- For a user program to do something “privileged” (e.g., I/O) it must call an OS procedure
  - Known as crossing the protection boundary, or a protected procedure call
- Hardware provides a system call instruction that:
  - Causes an exception, which invokes a kernel handler
    - Passes a parameter determining the system routine to call
  - Saves caller state (PC, regs, mode) so it can be restored
    - Why save mode?
  - Returning from system call restores this state

System Call


emacs: read()
Trap to kernel mode, save state
User mode
Kernel mode
Trap handler
Find read handler
read() kernel routine
Restore state, return to user level, resume execution

System Call Questions

- There are hundreds of syscalls. How do we let the kernel know which one we intend to invoke?
  - Before issuing **int $0x80** or **sysenter**, set **%eax/%rax** with the syscall number

- System calls are like function calls, but how to pass parameters?
  - Just like calling convention in syscalls, typically passed through **%ebx, %ecx, %edx, %esi, %edi, %ebp**