ECE 590.03
Fundamentals of Computers Systems and Engineering

Exceptions and Interrupts

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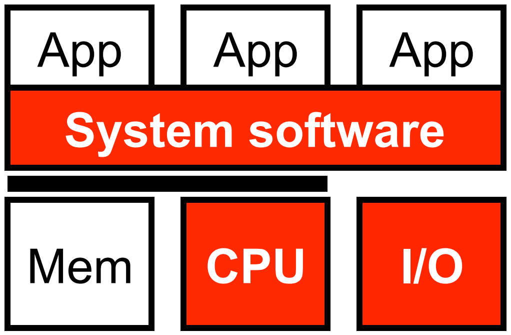

- Interrupts:
  - Notification of external events
- Exceptions:
  - Situations caused by program, requiring OS
- Also:
  - A bit about the OS

External Events

- Focus so far: running an application
  - Low level coding (assembly)
    - We don’t worry so much about C etc in this class
  - How to execute the instructions…
  - And store the data…
  - And give the illusion of a uniform address space…

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  - How to execute the instructions…
  - And store the data…
  - And give the illusion of a uniform address space…
- System software (OS) has to deal with external events
  - Which may come at un-expected times
  - Data arrives on network…
  - Disk complete read request…
  - Fixed interval timer…

First question: Finding out?

- Suppose we expect an outside event
  - E.g., requested disk drive read something…
  - It will get back to us later with data (think 10M cycles)

- How do we know when its done?
  - Option 1: **Polling**
    - Ask it periodically
    - "Are we there yet?" No… "Are we there yet?" No
    - Downside: can be inefficient (processor busy asking)

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    - Downside: can be inefficient (processor busy asking)
  - Option 2: **Interrupts**
    - "Read a book, I'll tell you when we are there"
    - External device signals to processor when it needs attention

Interrupts

- Step 1: External device raises an interrupt
  - "Hey, processor! I need your attention!"
  - Different interrupt numbers, specifies which one it is
  - Multiple interrupts at once?
    - Interrupt controller prioritizes which one goes to processor

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  - Jumps into interrupt handler (and saves current PC)
  - Switches into **privileged mode**

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- Step 4: OS returns from interrupt
  - Jumps back to application code, leaving privileged mode

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    - Or…

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    - Or an interrupt happens during interrupt vector is setup?
    - Or…
    - OS can enable/disable interrupts (privileged instruction)
      - Allows it to prevent problematic situations
      - "Look, this is important, don't bother me right now!"

Speaking of OS code… where is it?

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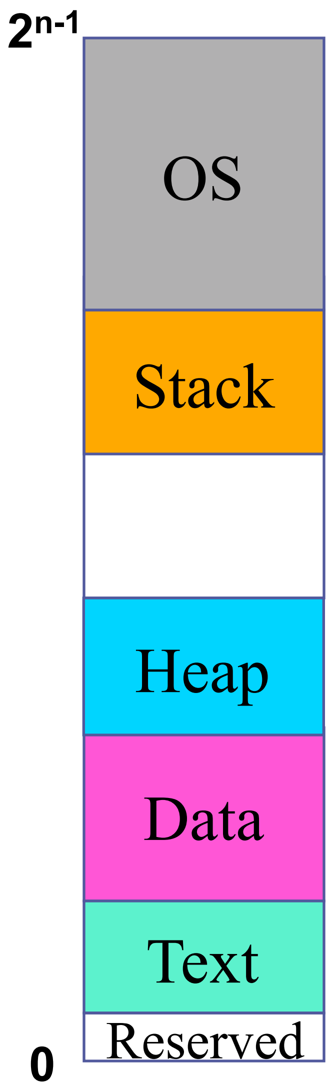
- Where does OS code reside?
  - In memory….
  - But doesn't application think it has all of memory to itself?
  - Well sort of…
    - It doesn't think anything exists past the top of the stack…
    - So the OS "lives" there
    - Same physical pages mapped into all processes' address spaces
    - Privileged bit in page table prevents access by "normal" code
      - Mapping only "valid" when in privileged mode



Timer Interrupt: Heart of multitasking

- Common interrupt: timer interrupt
  - "Ticks" at fixed interval
  - Gives OS a chance to change currently running program
  - …and keep track of the current time
  - …and anything else it needs to do
- This is what lets your computer run multiple programs
  - The OS switches between them quickly
  - Enabled by timer interrupt giving control to OS

Exceptions: Like interrupts, but not…

- Interrupts: external events
  - Asynchronous—don’t really “belong to” any current instruction
- Exceptions: unusual circumstances for an instruction
  - Belong to one particular instruction
  - Examples:
    - Page fault: load or store missing translation
    - Divide by 0
    - Illegal instruction
      - Bits do not encode any valid instruction
      - Or, privileged instruction from user code

Interrupts vs Exceptions

- Exceptions:
  - Processor must (typically) tell OS which instruction caused it
  - OS may want to restart from same instruction
    - Example: page fault for valid address (on disk)
  - Or OS may kill program:
    - Segmentation fault: (or other fatal signal)
    - Aside: OS sends "signals" to program to kill them
      - Segfault = SIGSEGV
      - Programs can "catch" signals and not die…
      - But not in this class…
- Interrupts: no particular instruction
  - But OS will always restart program after last complete insn
- Both require **precise state**: insns either done, or not
  - Division between "done and not done" in program order

Precise state

- Instructions either done or not: sounds obvious right?
  - Problem: “half done” instructions: pipeline splits into stages
    - Need to ensure **no** state change (reg or mem) if not done
  - Also: need “clean” division.
    - Instructions before exception, all done
    - Instructions after (and including) exception, no effect

- For interrupts:
  - Must be precise, but division can be anywhere.

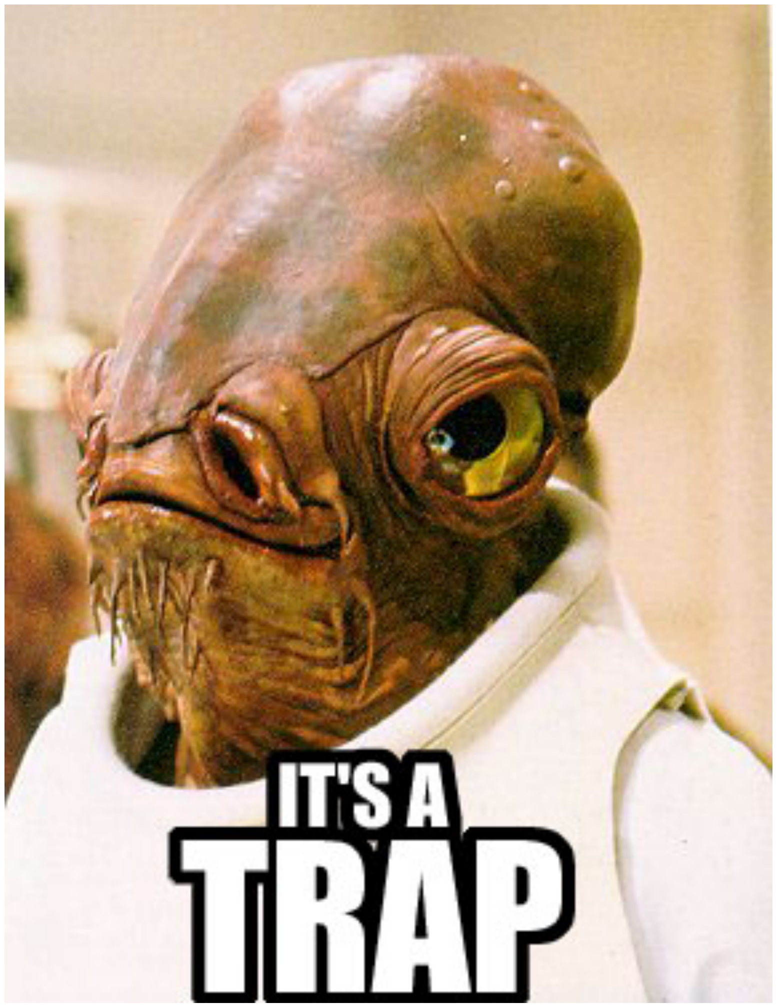
Handling Exceptions

- Exceptions handled just like interrupts
  - Some ISAs just give them interrupt numbers
  - Others have separate numbering for exceptions

System calls: Exceptions on purpose

- Programs need OS to do things for them
  - Read/write IO devices (including printing, disks, network)
  - Tell “real” time of day
  - Spawn new processes/execute other programs
  - …
  - Any interaction with the “outside world”

Did you all watch Star Wars yet?



System calls: Exceptions on purpose

- Programs need OS to do things for them
  - Read/write IO devices (including printing, disks, network)
  - Tell "real" time of day
  - Spawn new processes/execute other programs
  - …
  - Any interaction with the "outside world"
- Make a system call (syscall) to do this
  - Special instruction which **traps** into OS
  - Basically just causes exception—specifically for this purpose
  - OS gets control (in privileged mode), and does what program asked
    - Knows what program wants by arguments in registers
    - May deny request and not do it…then returns an error

System calls: Kind of slow

- Bothering OS for stuff: kind of slow
  - Empty pipeline…
  - Transfer control/change privilege
  - Have OS figure out what you want…
  - Then do it…
  - Then drain pipeline again
  - Then jump back into program
- For long tasks, overhead to enter/leave is amortized
  - Reading disk (very slow)
- For short tasks, overhead is very high
  - Get current time of day

Avoiding slowness

- Userspace (not OS) libraries help avoid by buffering
    - Example: malloc
    - Malloc does not ask OS for more memory on every call
    - Instead, malloc asks OS for large chunks of memory
    - Then manages those chunks itself (in user space)
    - Pedantic annoyance: malloc is not a system call!
    -

Vsyscalls: a slick trick

- Linux has a slick trick: vsyscalls
  - Don't actually make a system call!
  - Example: get current time of day
    - Just needs to read an int (time in seconds)
  - OS maps vsyscall page into all processses
    - Read/execute only
    - All processes map to same physical page
  - OS writes current time to fixed location on this page
    - On each timer interrupt
  - gettimeofday "system call" actually not a system call
    - Just library function which jumps onto vsyscall page
    - Code there reads time and returns it

Wrap-up

- Summary:
  - Interrupts: Notification of external events
  - Exceptions: Unusual things for an instruction
  - Both: handled by OS, very similar behavior
  - System calls: Ask OS to do something (also, like exception)

Going to talk about IO next

Then more on Oses, and then some on networking

Then swing back and do pipelines

Then done!