15-410

"Computers make very fast, very accurate mistakes."

--Brandon Long

Hardware Overview
Jan. 19, 2004

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Synchronization

Today's class

- Not exactly Chapter 2 or 13

Project 0

- Due tonight at midnight
- Consider *not* using a late day
  - Could be a valuable commodity later
- Remember, this is a warm-up
  - Reliance on these skills will increase rapidly

Upcoming

- Project 1
- Lecture on “The Process”

Synchronization

Personal Simics licenses

- Simics machine-simulator software is licensed
- We have enough "seats" for the class
  - Should work on most CMU-network machines
  - Will not work on most non-CMU-network machines
- Options
  - CMU "Address extension" service (non-encrypted VPN)
  - "Personal academic license" for a personal Linux box
    - » locked to your personal machine (MAC address)
    - » apply at www.simics.net (top right of page)

Synchronization

Simics on Windows?

- Simics simulator itself is available for Windows
- 15-410 build/debug infrastructure is not

Options

- Dual-boot, VMware
- Usability via X depends on network latency
- Port to cygwin (may be non-trivial)
- There are those Andrew cluster machines...

Outline

Computer hardware

CPU State

Fairy tales about system calls

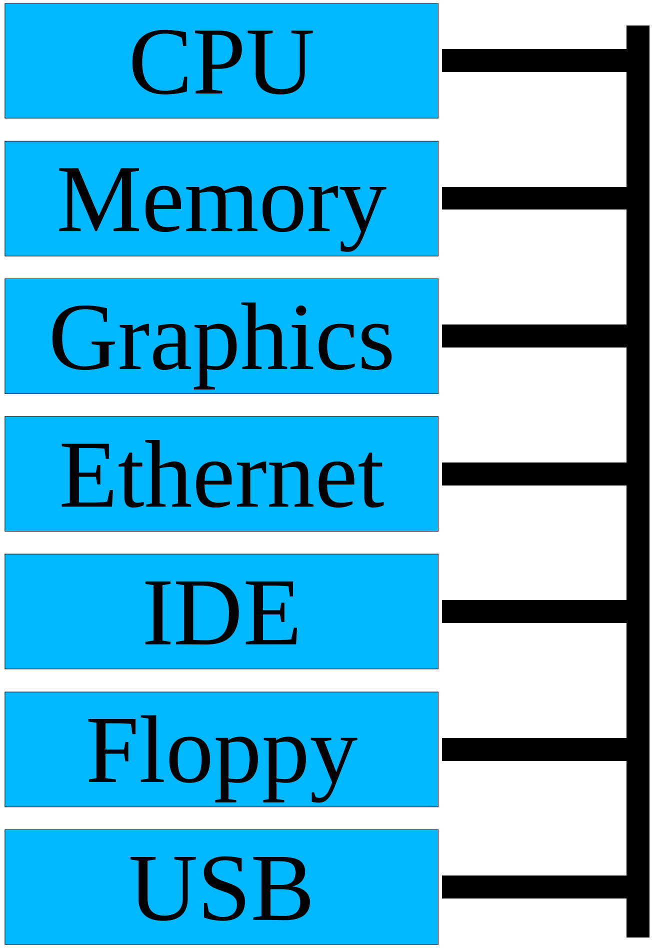
CPU context switch (intro)

Interrupt handlers

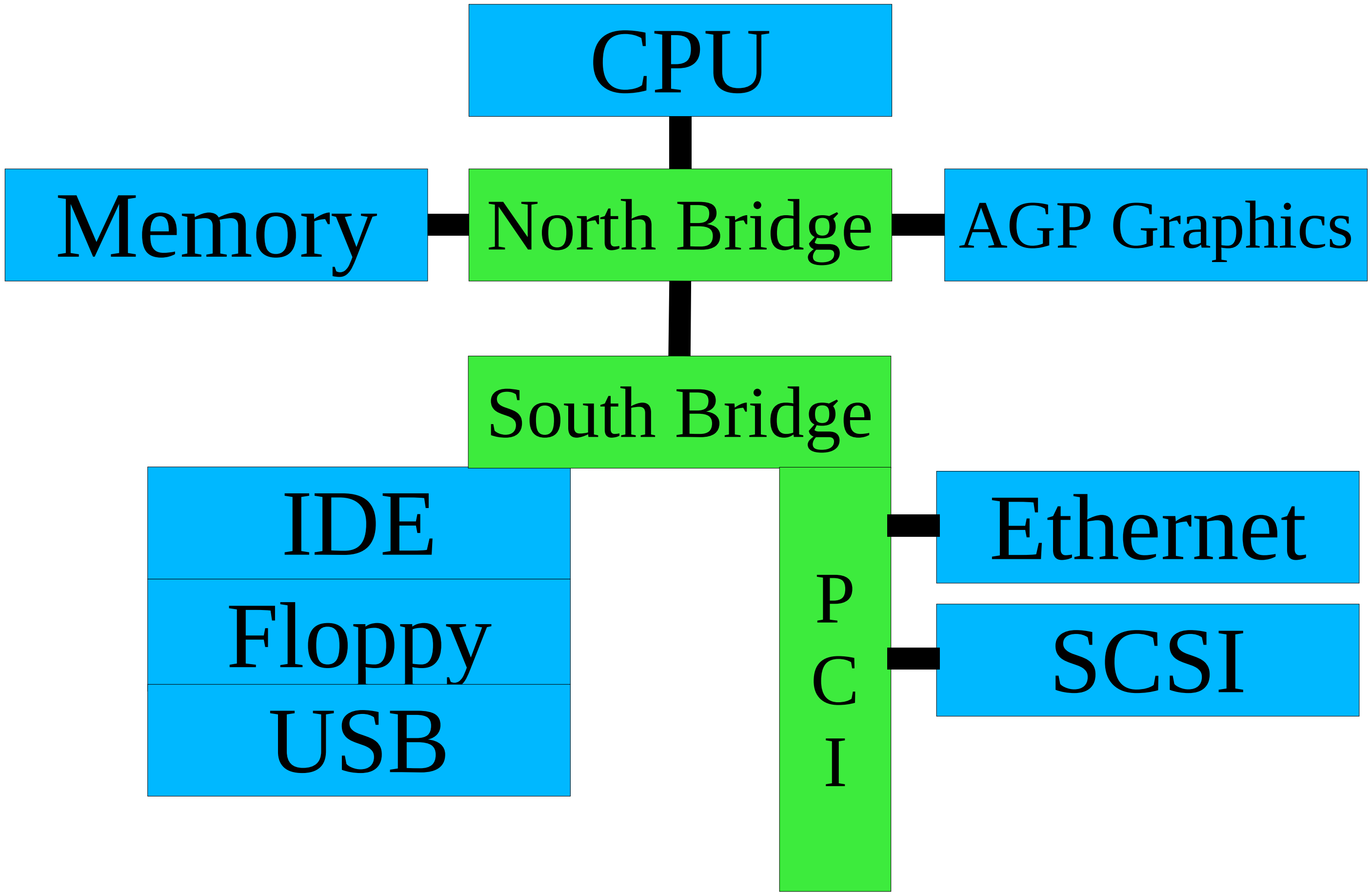
Interrupt masking

Sample hardware device – countdown timer

Inside The Box - Historical/Logical



Inside The Box - Really



CPU State

User registers (on Planet Intel)

- General purpose - %eax, %ebx, %ecx, %edx
- Stack Pointer - %esp
- Frame Pointer - %ebp
- Mysterious String Registers - %esi, %edi

CPU State

Non-user **registers, a.k.a....**

Processor status register(s)

- **Currently running: user code / kernel code?**
- **Interrupts on / off**
- **Virtual memory on / off**
- **Memory model**
  - **small, medium, large, purple, dinosaur**

CPU State

Floating Point Number registers

- Logically part of "User registers"
- Sometimes another "special" set of registers
  - Some machines don't have floating point
  - Some processes don't use floating point

Story time!

Time for some fairy tales

- The getpid() story (shortest legal fairy tale)
- The read() story (toddler version)
- The read() story (grade-school version)

The Story of getpid()

User process is computing

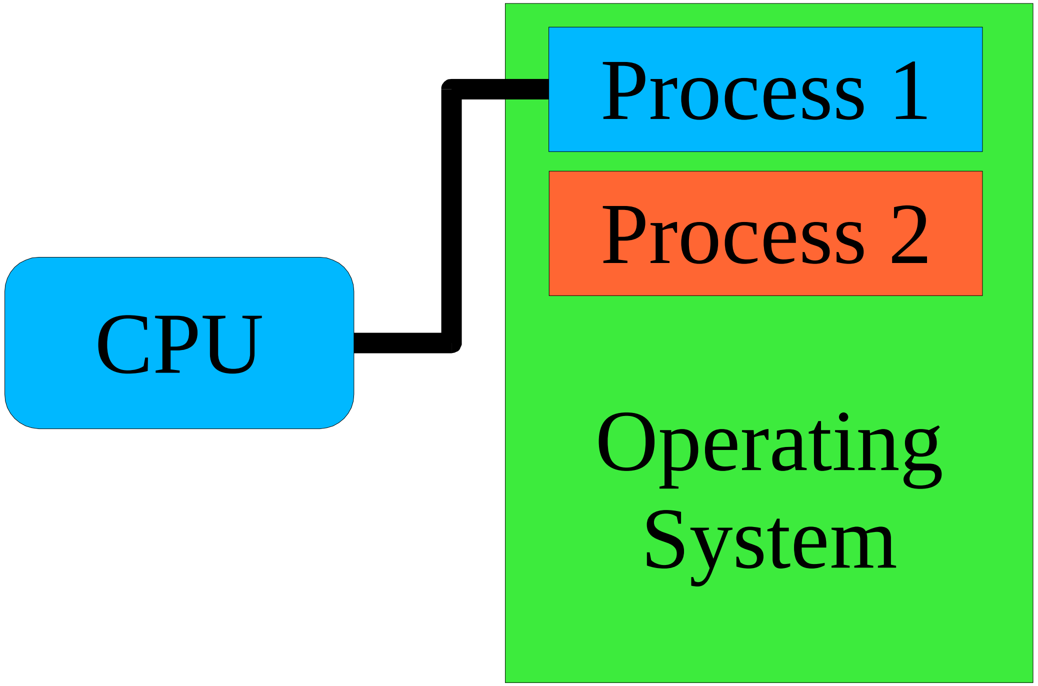
- User process calls getpid() library routine
- Library routine executes TRAP(314159)

The world changes

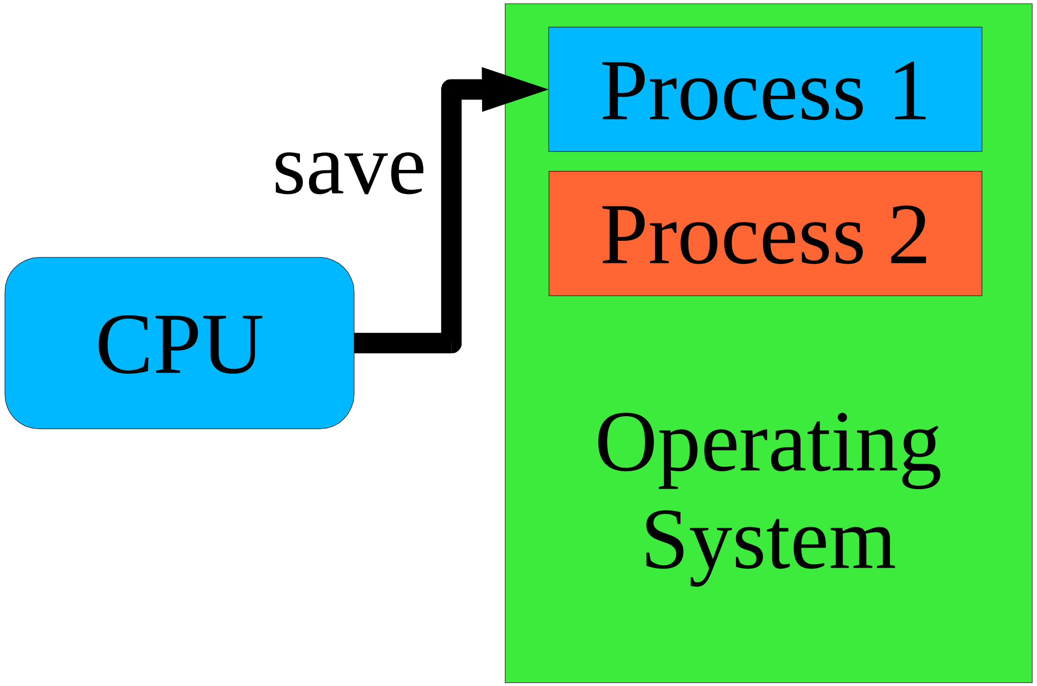
- Some registers dumped into memory somewhere
- Some registers loaded from memory somewhere

The processor has *entered kernel mode*

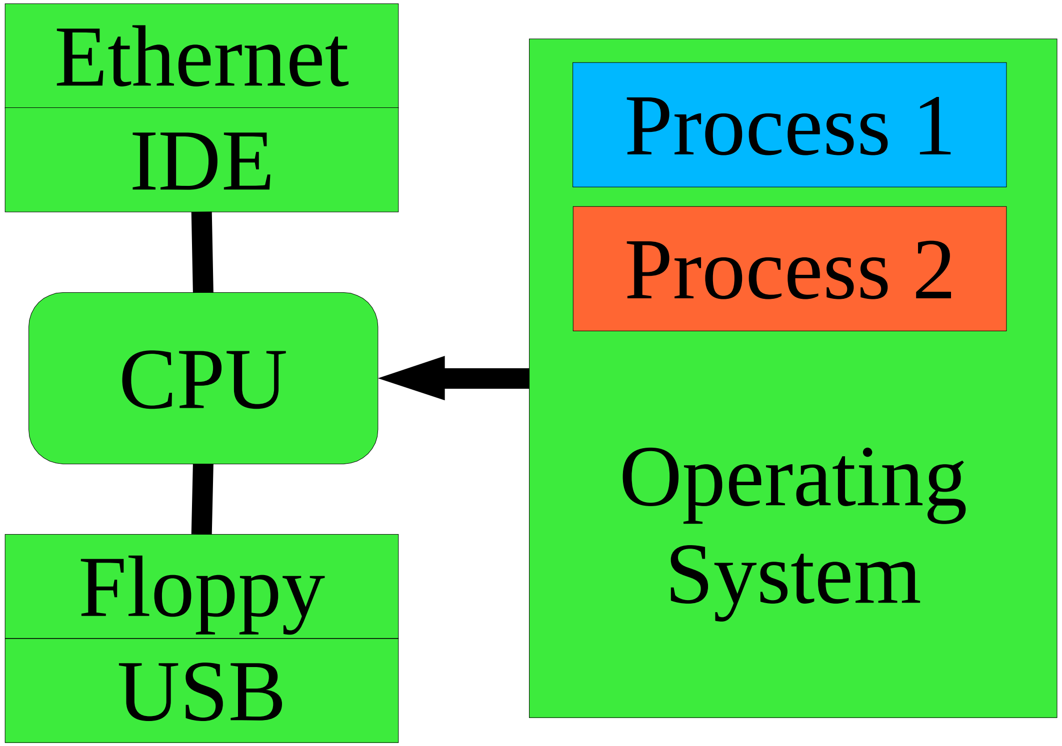
User Mode



Entering Kernel Mode



Entering Kernel Mode



The Kernel Runtime Environment

Language runtimes differ

- ML: no stack, "nothing but heap"
- C: stack-based

Processor is more-or-less agnostic

- Some assume/mandate a stack

Trap handler builds kernel runtime environment

Depending on processor

- Switches to correct stack
- Saves registers
- Turns on virtual memory
- Flushes caches

The Story of getpid()

Process in kernel mode

- running->u_reg[R_EAX] = running->u_pid;

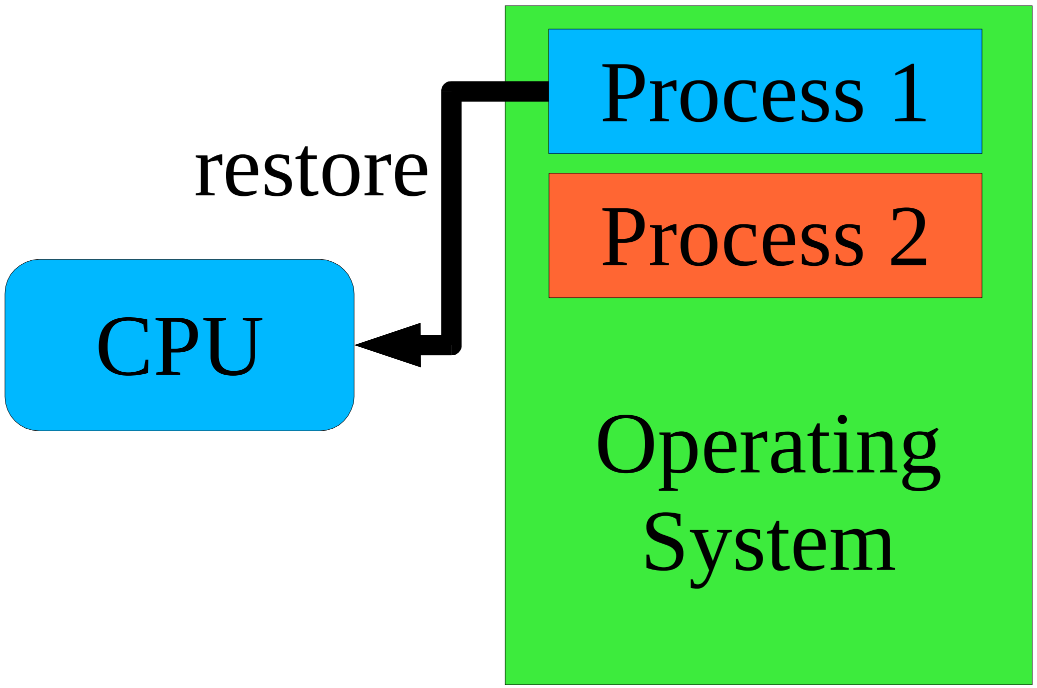
Return from interrupt

- Processor state restored to user mode
  - (modulo %eax)

User process returns to computing

- Library routine returns %eax as value of getpid()

Returning to User Mode



The Story of getpid()

What's the getpid() system call?

- C function you call to get your process ID
- "Single instruction" which modifies %eax
- Privileged code which can access OS internal state

A Story About read()

User process is computing

```
count = read(7, buf, sizeof (buf));
```

User process "goes to sleep"

Operating system issues disk read

Time passes

Operating system copies data

User process "wakes up"

Another Story About read()

P1: read()

- Trap to kernel mode

Kernel: tell disk: "read sector 2781828"

Kernel: switch to running P2

- Return to user mode - but to P2, not P1!
- P1 is "blocked in system call"
  - Part-way through driver code
  - Marked "unable to execute more instructions"

P2: compute 1/3 of Mandelbrot set

Another Story About read()

Disk: done!

- Asserts “interrupt request” signal
- Interrupt to kernel mode
- Run “disk interrupt handler” code

Kernel: switch to P1

- Return from interrupt - but to P1, not P2!

Interrupt Vector Table

How should CPU handle *this particular* interrupt?

- **Disk interrupt ⇒ invoke disk driver**
- **Mouse interrupt ⇒ invoke mouse driver**

Need to know

- **Where to dump registers**
  - **often: property of current process, not of interrupt**
- **New register values to load into CPU**
  - **key: new program counter, new status register**
    - » **These define the new execution environment**

Interrupt Dispatch/Return

Table lookup

- Interrupt controller says: this is interrupt source #3
- CPU fetches table entry #3
  - Pre-programmed table base-pointer
  - Table entry size defined by hardware

Save old processor state

Modify state according to table entry

Start running interrupt handler

"Return from interrupt" process

- Load saved processor state back into registers
- Restoring program counter reactivates "old" code

Example: x86/IA32

CPU saves old processor state

- Stored on “kernel stack”

CPU modifies state according to table entry

- Loads new privilege information, program counter

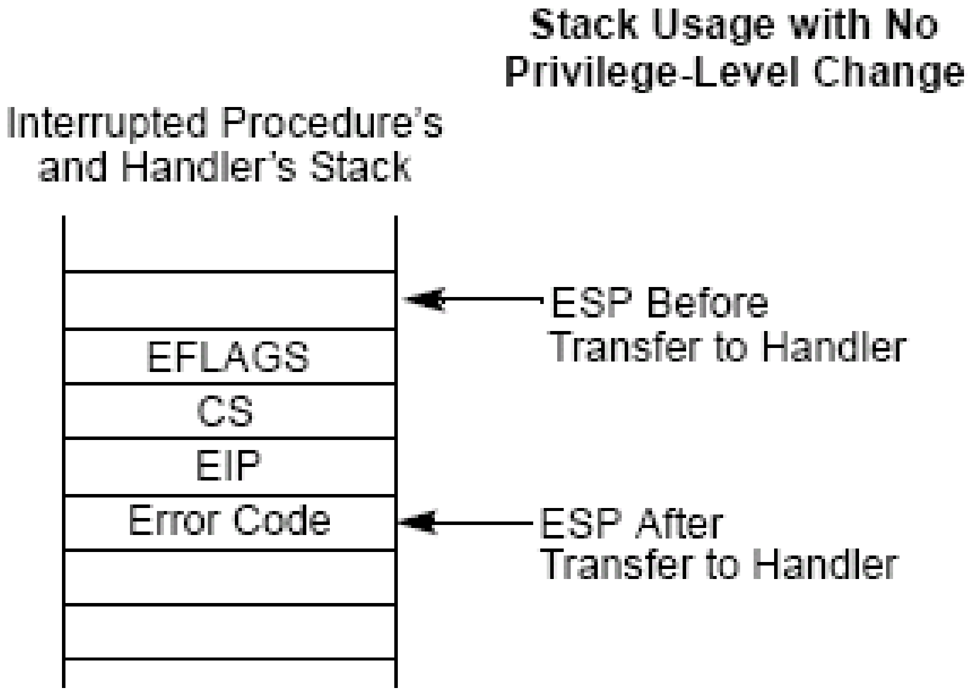
Interrupt handler begins

- Uses kernel stack for its own purposes

Interrupt handler completes

- Empties stack back to original state
- Invokes “interrupt return” instruction

IA32 Single-Task Mode Example



From intel-sys.pdf

Interrupt/Exception while in kernel mode (Project 1)

Hardware pushes registers on current stack, NO STACK CHANGE

- EFLAGS (processor state)
- CS/EIP (return address)
- Error code (certain interrupts/faults, not others: see intel-sys.pdf)

Race Conditions

Two concurrent activities

- **Computer program, disk drive**

Execution sequences produce various “answers”

- **Disk interrupt *before* or *after* function call?**

Execution orders are not controlled

- **Either outcome is possible “randomly”**

System produces random “answers”

- **One answer or another “wins the race”**

Race Conditions – Disk Device Driver

"Top half" wants to launch disk-I/O requests

- **If disk is idle, send it the request**
- **if disk is busy, queue request for later**

Interrupt handler action depends on queue empty/non

- **Queue empty ⇒ let disk go idle**
- **Queue non-empty ⇒ transmit next request**

Various outcomes possible

- **Disk interrupt *before* or *after* "device idle" test?**

System produces random "answers"

- **Queue non-empty ⇒ transmit next request**
- **Queue non-empty ⇒ let disk go idle**

Race Conditions – Driver Skeleton

```
dev_start(request) {
  if (device_idle)
    start_device(request);
  else
    enqueue(request);
}

dev_intr() {
  ...finish up previous request...
  if (new_request = head()) {
    start_device(new_request);
  }
}
```

Race Conditions – Good Case

aaaaaa *User process*	*Interrupt handler*
`if (device_idle)`	
`enqueue(request)`	
	`INTERRUPT`
	`...`
	`start_device (new_request);`
	`RETURN FROM INTERRUPT`

Race Conditions – Bad Case

aaaaaa *User process*	*Interrupt handler*
`if (device_idle)`	
	`INTERRUPT`
	`...`
	`device_idle = 1;`
	`RETURN FROM INTERRUPT`
`enqueue(request)`	

What Went Wrong?

"Top half" ran its algorithm

- Examine state
- Commit to action

Interrupt handler ran *its* algorithm

- Examine state
- Commit to action

Various outcomes possible

- Depends on exactly when interrupt handler runs

System produces random "answers"

Interrupt Masking

Two approaches

- Temporarily suspend ("mask") device interrupt while checking and enqueueing
  - Will cover further before Project 1
- Or use a lock-free data structure
  - [left as an exercise for the reader]

Considerations

- Avoid blocking *all* interrupts
  - [not a big issue for 15-410]
- Avoid blocking too long
  - Part of Project 3 grading criteria

Timer – Behavior

Simple behavior

- Count something
  - CPU cycles, bus cycles, microseconds
- When you hit a limit, signal an interrupt
- Reload counter to initial value
  - Do it “in background” / “in hardware”
  - (Don't wait for software to do reload)

Summary

- No “requests”, no “results”
- Steady stream of evenly-distributed interrupts

Timer – Why?

Why interrupt a perfectly good execution?

Avoid CPU hogs

```
for (;;) ;
```

Maintain accurate time of day

- Battery-backed calendar counts only seconds (poorly)

Dual-purpose interrupt

- Timekeeping
  - ++ticks_since_boot;
- Avoid CPU hogs
  - force process switch

Summary

Computer hardware

CPU State

Fairy tales about system calls

CPU context switch (intro)

Interrupt handlers

Interrupt masking

Sample hardware device – countdown timer