Lecture Topics

- Role of system software
- System calls, exceptions, & interrupts
- Processor support for interrupts

MP1 Handin and Demo Schedule

- Code must be committed to master/main branch on GitLab by
  - 9:59AM on 2/18 (11:59PM on 2/18 for ZJUI)
- Handin Demo
  - Monday 2/22, Starts at 6 PM: All ZJUI Students and Last names from A to J
  - Tuesday 2/23, Starts at 6 PM: Last names from K to Z

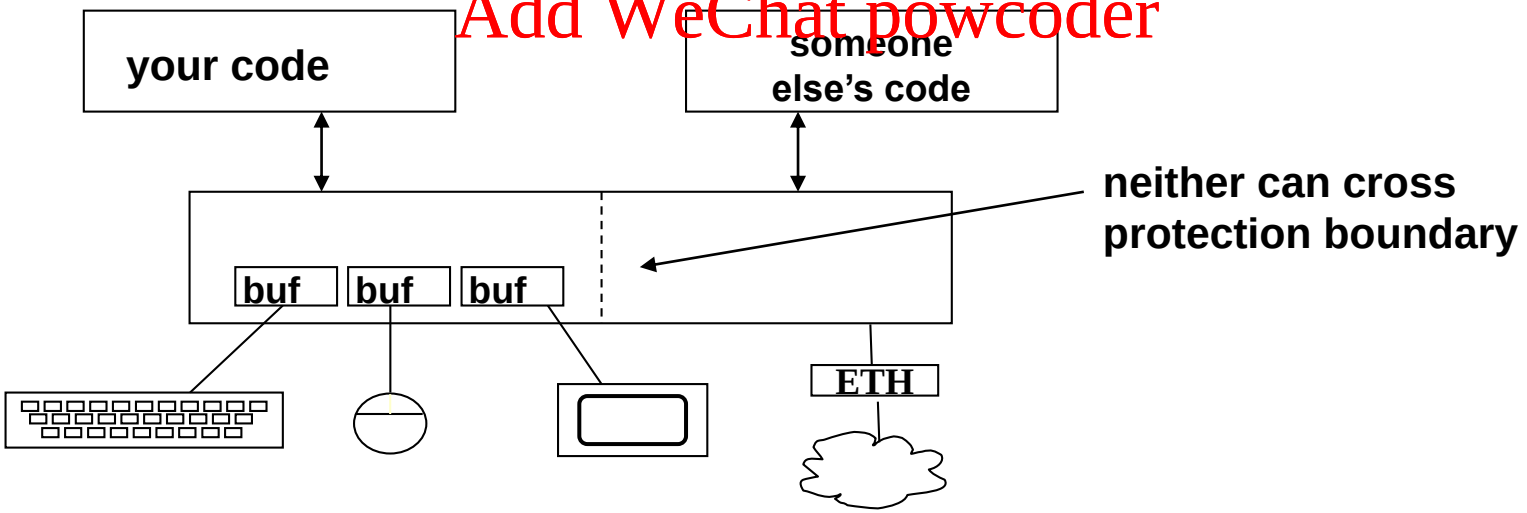
Role of System Software (1)

- System software serves three purposes
  - virtualization
  - protection
  - abstraction (particularly hiding asynchrony)

- virtualization:
  - the illusion of multiple/practically unlimited resources
- protection:
  - reduce/eliminate the chance of accidental and/or malicious destruction of data/results by another program

Role of System Software (2)

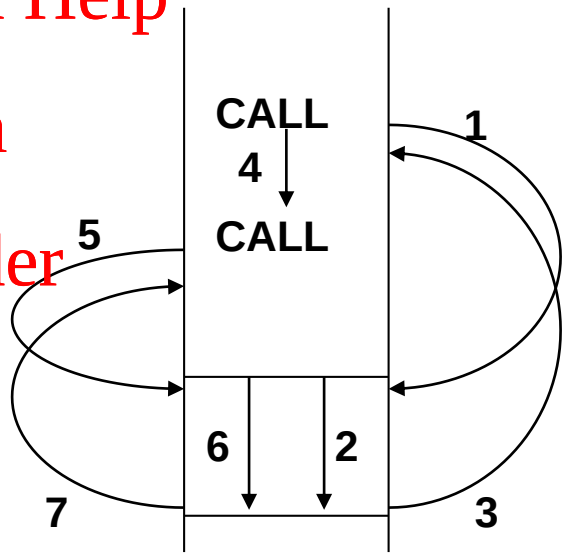
- abstraction:
  - hide fundamentally asynchronous nature of processor/device interaction
  - provide simpler and more powerful interfaces (integrated w/protection)



System Calls, Interrupts, and Exceptions (1)

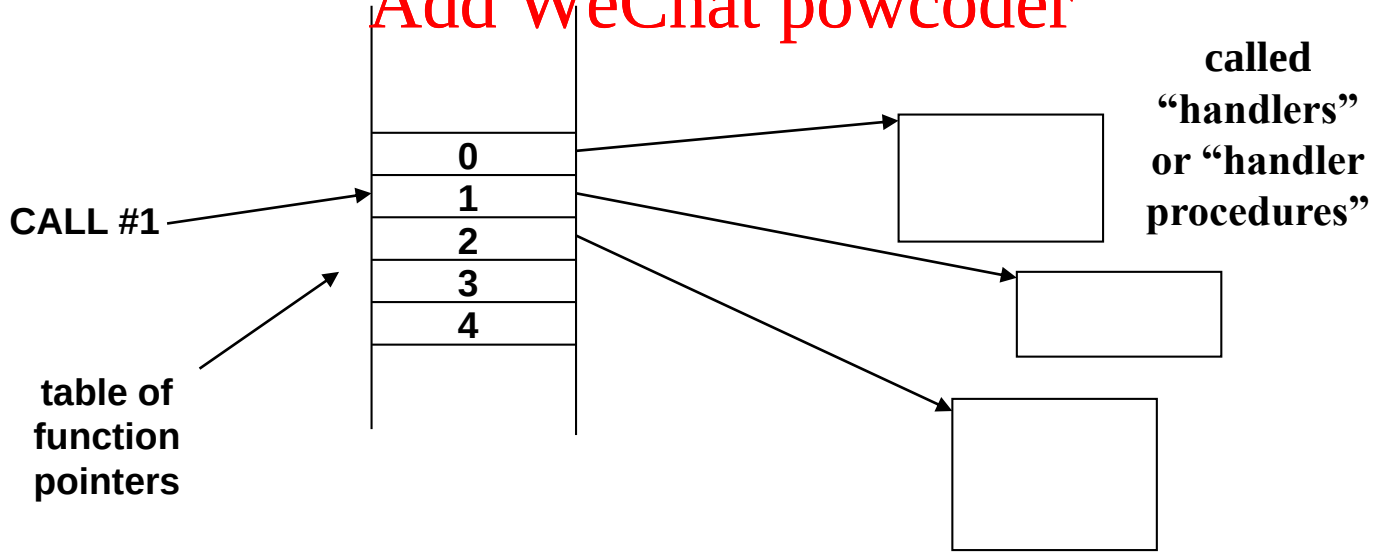
- recall that subroutines allow a programmer to encapsulate common operations

- the operating system
  - want to provide an interface including common operations
  - BUT don't want to re-link programs
  - NOR rely on everyone having exactly the same OS version



System Calls, Interrupts, and Exceptions (2)

- solution
  - add a level of indirection!
- with indirection
  - to rewrite OS, just change the table
  - application code does not change



System Calls, Interrupts, and Exceptions (3)

- in LC-3, we used the TRAP instruction; in x86, it's the INT instruction:

INT 8-bit imm. #(PUSH EIP), EIP ← table[imm8]

  - the RTL is actually a little more complicated, as you'll see later in course
  - called a trap (after instruction, or trap door through protection boundary)
  - also called a system call (for operating system)

System Calls, Interrupts, and Exceptions (4)

- vector tables/jump tables
  - i.e., tables of function pointers
  - convenient abstraction for many procedure-like activities
- Question:
  - What happens if software does something wrong, e.g.,
    - accesses a non-existent memory location?
    - issues an illegal/undefined instruction? divides by 0?
- What do we do to handle problems?
  - state machine that you *design* for processor may have don't cares
  - state machine that you *build* will do something (may be unknown)
  - so just let it run! (e.g., 6502 did so… and programmers used!)

System Calls, Interrupts, and Exceptions (5)

- a better solution: **exceptions!**
  - processor maps each problem to a vector #
  - calls procedure in vector table by #

- Where else might we use vector tables?

- Consider processor interactions with devices
  - a disk access takes about 10 milliseconds
  - new machines in lab: 10 ms = 32 million cycles

- should processor sit around asking, “Are my data here yet?”

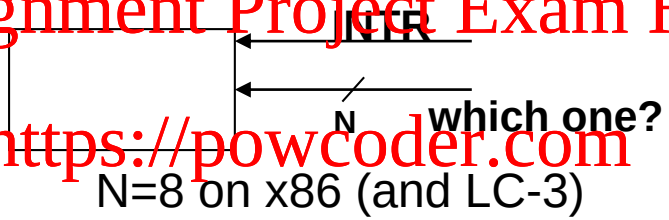
System Calls, Interrupts, and Exceptions (6)

  - analogous to posting a letter to a friend in Europe
  - and checking your mailbox every minute for a reply
  - instead, have your mail carrier ring your doorbell when it arrives
  - **in a processor, we call that an interrupt**

- How can we use a vector table for interrupts?
  - each device has a vector #
  - call corresponding procedure in vector table when device generates a request for service
- x86 ISA
  - uses one table for all three kinds
  - called the Interrupt Descriptor Table (IDT)

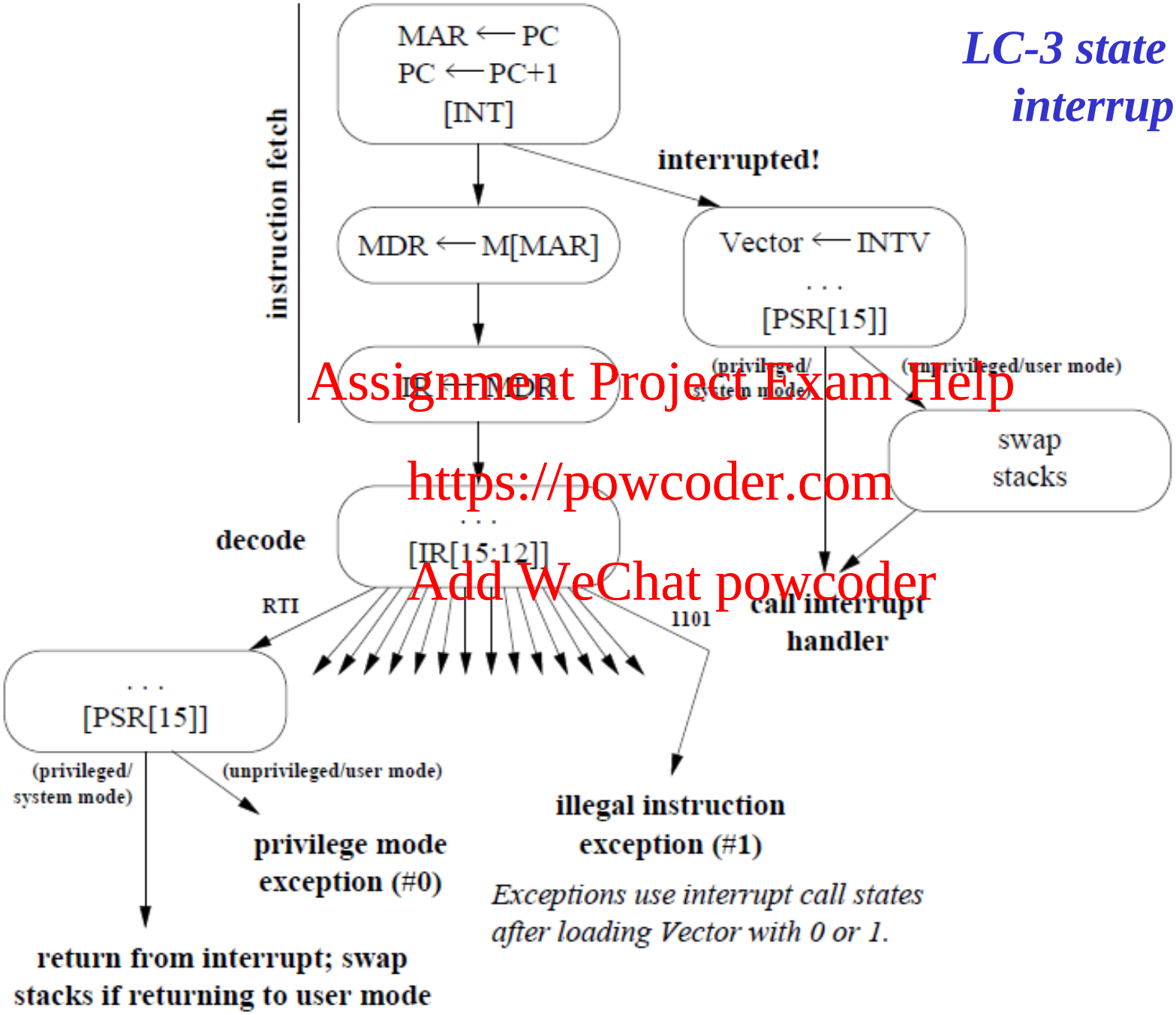
Processor Support for Interrupts (1)

- How does a processor support interrupts?
- Logically…

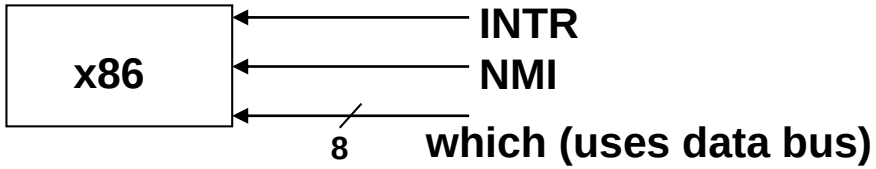


- How should we change a processor's state machine to incorporate interrupts?

LC-3 state machine interrupt support



Processor Support for Interrupts (2)



- x86 allows software to block interrupts with a status flag (in EFLAGS)
- normal interrupts occur only when the interrupt enable flag (IF) is set
- some interrupts are too important
  - e.g., memory errors, power warnings, etc.
  - these are NOT maskable, and use a separate input to processor
  - called non-maskable interrupts (NMI)

Interrupt Descriptor Table

- as mentioned earlier
  - x86 uses a single vector table
  - the Interrupt Descriptor Table (IDT)
  - hold vectors for interrupts, exceptions, and system calls
- note that this picture is partly OS-specific
  - the exception vector numbers are specified by Intel – Why?
    - A: generated directly by processor's state machine
  - programmable interrupt controller (PIC) will be discussed later;
    - range of vectors generated is programmable, and is shown for Linux 2.4
  - note that a single entry is used for all system calls in Linux

Interrupt Descriptor Table

0x00–0x1F defined by Intel	0x00	division error	
	⋮		
	0x02	NMI (non-maskable interrupt)	
	0x03	breakpoint (used by KGDB)	
	0x04	overflow	
	⋮		
	0x0B	segment not present	
	0x0C	stack segment fault	
	0x0D	general protection fault	
	0x0E	page fault	
	⋮		
0x20–0x27 master 8259 PIC	0x20	IRQ0 — timer chip	example of possible settings
	0x21	IRQ1 — keyboard	
	0x22	IRQ2 — (cascade to slave)	
	0x23	IRQ3	
	0x24	IRQ4 — serial port (KGDB)	
	0x25	IRQ5	
	0x26	IRQ6	
	0x27	IRQ7	
0x28–0x2F slave 8259 PIC	0x28	IRQ8 — real time clock	
	0x29	IRQ9	
	0x2A	IRQ10	
	0x2B	IRQ11 — eth0 (network)	
	0x2C	IRQ12 — PS/2 mouse	
	0x2D	IRQ13	
	0x2E	IRQ14 — ide0 (hard drive)	
	0x2F	IRQ15	
0x30–0x7F	⋮	APIC vectors available to device drivers	
0x80	0x80	system call vector (INT 0x80)	
0x81–0xEE	⋮	more APIC vectors available to device drivers	
0xEF	0xEF	local APIC timer	
0xF0–0xFF	⋮	symmetric multiprocessor (SMP) communication vectors	

Interrupts, System calls, and Exceptions

Characteristics of *interrupts, system calls, and exceptions* with respect to a program being executed

Type	Generated by	Asynchronous	Unexpected
Interrupts	external device	**YES**	**YES**
Exceptions	invalid opcode or operand	**NO**	**YES**
System calls	deliberate, via INT instruction	**NO**	**NO**

Device I/O

- How does a processor communicate with devices?
- Two possibilities
  - independent I/O — use special instructions and a separate I/O port address space
  - memory-mapped I/O — use loads/stores and dedicate part of the memory address space to I/O
- x86 originally used only independent I/O
  - but when used in PC, needed a good interface to video memory
  - solution? put card on the bus, claim memory addresses!
  - now uses both, although ports are somewhat deprecated