Supporting an Operating System Part 2: IO, System Calls, and Boot

CSE 378 Spring 2009

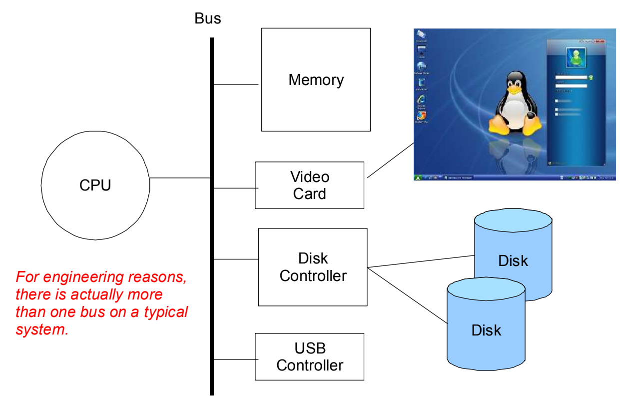
Review

- The exception architecture provides a protected way to cause a jump into OS code:
  - PC is set to trap handler entry point
  - This is the only way to set Status to privileged mode
- Memory mapping provides a general facility for introducing components into the datapath without introducing new instructions

Overview of IO

- All external interactions are IO
  - Keyboard, display, disk, network, scanner, camera, etc.
- It would be a mistake to tightly couple IO devices to CPU architecture
  - E.g., don't want to have a “write to disk” instruction
  - Why?
- Similarly, it would be a mistake to tightly couple IO devices to an operating system's implementation
- Finally, we'd even like to decouple the application code from the OS (i.e., portable languages/applications)

A General View of IO



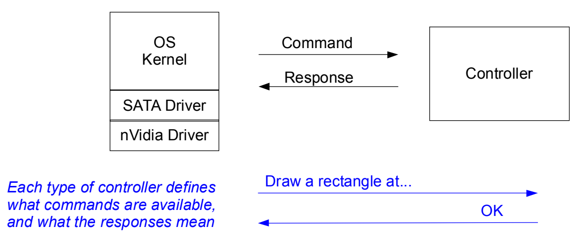
Controller ↔ Device Interface

- Presents a standard interface that isolates upstream components (bus, CPU, OS) from specific devices
  - Hitachi vs. Seagate drive
  - VGA vs. DVI vs. HDMI display

CPU / OS ↔ Controller

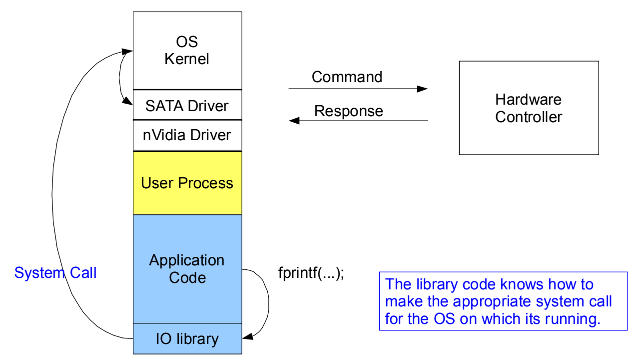
- Controller offloads work from CPU
  - CPU tells video card *"Draw a (width=300, height=200) blue filled rectangle at pixel location (400, 525)"*
- Don't want to impede use of controllers that are invented after the CPU and/or OS are created
  - CPU
    - No special instructions to talk with controllers
    - Instead, controllers are memory mapped
  - OS
    - Encapsulate code that understands how to talk with controller in a driver
    - Allow introduction of driver to OS after OS has been installed
      - E.g., put new driver in special directory that OS looks at during boot

CPU / OS ↔ Controller



- Command issued using a store word (sw) on CPU
- Response read using a load word (lw) on CPU

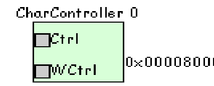
Application ↔ OS



Cebollita / SMOK

- Cebollita includes all of these concepts
  - An iolib.s library
  - An os with (built-in) drivers that talk with controllers
  - Hardware controller components that talk with IO devices
    - SMOK implements these controllers as well
- Character controller
  - Output side is the display (character display, not pixels)
  - Input side is the keyboard
- Disk controller
  - Input and output sides are a disk

Cebollita/SMOK Character IO



- Operates *asynchronously*
- Output side:
  - Bit 15: If one, indicates the device is ready to print a character
  - Bit 14: If on, indicates that a keyboard character is available
  - Bits 0-7: The keyboard character
- Input side:
  - Bit 15: Start a character write.
  - Bit 14: Clear the "keyboard character ready" status bit.
  - Bits 0-7: The character to write if bit 15 is on.

Example Use: Write a Character

- $t0 has the memory mapped address of the character controller
- $a0 has the character to write

```
– wait:  lw   $t1, 0($t0)
         andi $t1, $t1, 0x8000
         beq  $t1, $0, wait
         ori  $t1, $a0, 0x8000
         sw   $t1, 0($t0)
```

- This is a busy wait loop
- This is also polled I/O

How Do We Read a Character

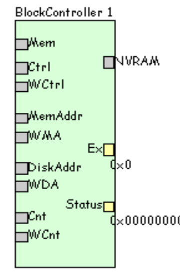
- Using busy wait and polled I/O
- Code:

Disk I/O

Note: We're talking about the physical devices, not files. "File" is an operating system abstraction.

- The logical organization of a disk is as an array of blocks
  - Blocks are typically in the range 512B to 8KB
  - The disk's unit of addressing is the block
- Disks are direct memory access (DMA) devices
  - They read/write direction from/into memory

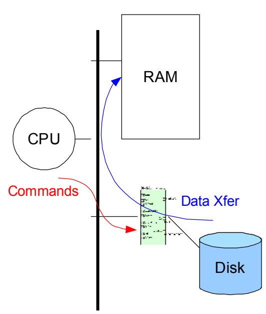
Cebollita/SMOK Block Controller



- Four inputs:
  - Control (commands)
    - Bit 15: start a read
    - Bit 14: start a write
    - Bit 13: clear exceptions
  - Memory address (for DMA)
  - Disk Address (block number)
  - Count (#blocks to transfer)
- Outputs:
  - Status: indicates state of device
    - Bit 15: busy reading
    - Bit 14: busy writing
    - Bit 13: exception has occurred
    - Bits 0-7: Exception cause
      - Bit 0: I/O completion
      - Bit 1: bad memory address
      - ...

Reading a Disk Block

- Busy wait to start:
  - Read the device status until bits 15 and 14 are 0
  - Write the address of a buffer in memory to the memory address port
  - Write the disk block address to the disk address port
  - Write the block count to the count port
  - Write 0x40000 to the control port
- Busy wait to recognize completion:
  - Loop reading status until bit 15 is 1
  - Bit 13 should now be on, and bits 0-7 should have value 0
  - Write 0x2000 to the control input to clear the exception



Integrating the Block Controller

- Each of the four inputs is memory mapped
  - 0x40000010: control
  - 0x40000014: memory (buffer) address
  - 0x40000018: disk (block) address
  - 0x4000001C: block count
- The status output is also memory mapped:
  - 0x40000010
- The exception output could be used to provide interrupt driven IO, rather than polled

Interrupt Driven I/O

- How can the OS tell when the transfer is done?
  - Could sit in a busy loop reading the controller status
    - Busy waiting
  - Could check every once in a while
    - Polling
  - Or... the controller could raise an I/O completion interrupt
- Interrupts are "asynchronous exceptions"
  - They cause a transfer of control to the trap handler
  - When they occur has nothing to do with the instruction currently being executed by the CPU

Polling vs. Completion Interrupts

- It should be obvious what the advantages of completion interrupts are
- Cebollita uses polling and busy waits...

Next Topic: System Calls

- System calls are "protected procedure calls" of methods implemented in the OS
  - These methods have root privilege (so can do IO, for instance)
- Invoked using a special instruction, syscall
  - syscall causes an exception (i.e., jump to trap handler)
  - The cause register indicates a syscall happened
- jal vs. syscall
  - jal: caller decides what next PC will be
  - syscall: callee decides what next PC will be (trap handler)

syscall convention

- Just like procedure call, we need a convention to define how to pass arguments and how to get return values
  - We could also have a convention about saving registers, but...
  - Because OS must handle interrupts, it must be prepared to save everything itself
    - Why?
- Since the caller isn't specifying a next PC address, we also need to communicate which OS method to invoke
  - Passed as a system call number (an int)
- Cebollita conventions:
  - $v0: syscall number (which method to invoke)
  - $a0 ...: argument(s)
  - $v0: return value

Cebollita iolib

```
.text
        .global printInt
printInt:
        ori     $v0, $0, 1
        lw      $a0, 0($sp)
        syscall
        jr      $ra

        .global readInt
readInt:
        ori     $v0, $0, 5
        syscall
        jr      $ra

       ...
```

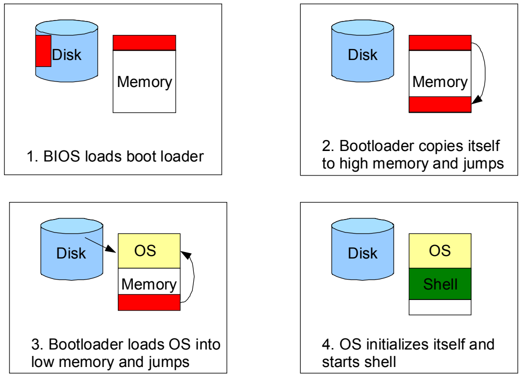

Next Topic: Boot

- When machine is powered on, need to load the OS
- But:
  - Registers are nonsense
  - Memory is nonsense
- Need some “initial program” that isn't nonsense
  - BIOS, stored in NVRAM (non-volatile RAM)
- BIOS contains a very small, OS independent program
  - Loads block 0 of boot device into memory at location 0
  - Branches to location 0

Boot

- Block 0 of the boot device contains the boot loader
- The boot loader has enough smarts to load the remainder of the OS into memory
- It then branches to the entry point of the OS, which initializes itself
- Once initialized (booted), the OS launches some initial process(es)
  - The login process, or...
  - A shell

Cebollita Boot In Pictures



Wrap Up

- That's pretty much everything
  - As always, Cebollita favors simple above all else
    - Real systems make some other decisions
- HW5 is about implementing a machine capable of supporting all these mechanisms
  - New hardware components are introduced into datapath
  - New control is required
  - (Possibly some modification of software, e.g., the OS)