IO: Interacting with the outside world

- Input and Output Devices
  - Video
  - Disk
  - Keyboard
  - Sound
  - ...

Communication with IO devices

- Processor needs to get info to/from IO device
  - Two ways:
    - In/out instructions
      - Read/write value to “io port”
    - Devices have specific port numbers
    - Memory mapped
      - Regions of physical addresses not actually in DRAM
      - But mapped to IO device
        - Stores to mapped addresses send info to device
        - Reads from mapped addresses get info from device

A view of the world

- 2 “socket” system (each with 2 cores)
- Real systems: more IO devices

A view of the world

- Chip 0 requests read of 0x100100
- Request goes to all devices
A view of the world

• Chip 0 requests read of 0x100100
• Request goes to all devices, which check address ranges

Speaking of VGA video

• You all wrote a VGA controller early (hwk2)
  • Read a ROM with an image
  • Real ones: read a RAM
  • How to draw? CPU writes to physical memory mapped to video card RAM
  • Video card sees write and updates its internal RAM
  • The rest: FSM just like you did
  • (Except 3D accelerators)

Exploring Memory Mappings on Linux

• You can see what devices have what memory ranges on linux with `lspci -v`
  (at least those on the PCI bus)

00:02.0 VGA compatible controller: Intel Corporation Core Processor Integrated Graphics Controller (rev 02)
  Subsystem: Lenovo Device 215a
  Flags: bus master, fast devsel, latency 0, IRQ 30
  Memory at f2000000 (64-bit, non-prefetchable) [size=4M]
  Memory at d0000000 (64-bit, prefetchable) [size=256M]
  I/O ports at 1800 [size=8]
  Capabilities: [90] Message Signalled Interrupts: Mask- 64bit- Queue=0/0 Enable+
  Capabilities: [d0] Power Management version 2
  Capabilities: [a4] PCI's advanced features <t>
  Kernel driver in use: i915
  Kernel modules: i915

A simple “IO device” example

• Read (physical) address 0xFFFF1000 for “ready”
• If ready, read address 0xFFFF1004 for data value
• IO device will go to next value automatically on read
• Write a value to 0xFFFF1008 to output it

```
read_devr:
  la $t0, 0xFFFF1000
loop:
  lw $t1, 0($t0)
  beqz $t1, loop
  lw $v0, 4($t0)
  jr $ra
```

Who can remind us what this is called (last lecture)?
A handful of questions...

- How do we use physical addresses?
  - Programs only know about virtual addresses right?
  - **Only OS accesses IO devices:**
    - OS knows about physical addresses, and can use them

- What about caches?
  - Won't the first `lw` bring the current value of `0xFFFF1000` into the cache?
  - And then subsequent requests just hit the cache?

- Pages have attributes, including cacheability
  - IO mapped pages marked non-cacheable
  - Also, prevent speculative loads (e.g., out-of-order)
  - Remember: speculative only fine as long as nobody knows

---

Hard disks

- Viewed from above:
  - Disks are circular platters of spinning metal
  - Multiple tracks (concentric rings)
  - Each track divided into sectors
  - Modern disks: addressed by "logical block"
  - (Real disks are actually circular...)

---

Hard disks

- Read/written by "head"
  - Moves across tracks ("seek")
  - After seek completes, wait for proper sector to rotate under head.
  - Reads or writes magnetic medium by sensing/changing magnetic state (this takes time as the desired data 'spins under' the head)

---

Hard disks

- Want to read data on blue curve (imagine circular arc)
  - First step: seek—move head over right track
  - Takes time ("seek"), disk keeps spinning
Hard disks

- Want to read data on blue curve (imagine circular arc)
  - First step: seek—move head over right track
    - Takes time (Tseek), disk keeps spinning
    - Now head over right track… but data needs to move under head
    - Second step: wait (Trotate)

A few things about HDD performance

- **Tseek:**
  - Depends on how fast heads can move
  - And how far they have to go
    - OS may try to schedule IO requests to minimize Tseek

- **Trotate:**
  - Depends largely on how fast disk spins (RPM)
    - Also, how far around the data must spin, but usually assume avg
      - OS cannot keep track of position, nor schedule for better
  - Takes time (Ttrotate), disk keeps spinning
  - Now head over right track… but data needs to move under head
  - Second step: wait (Ttrotate)
  - Third: as data comes under head, start reading
  - Takes time for data to pass under read head (Tread)

- **Tread:**
  - Takes time for data to pass under read head (Tread)

Disk Drive Performance

- Suppose on average
  - Tseek = 10 ms
  - Ttrotate = 3.0 ms
  - Tread = 5 usec/ 512-byte sector
  - What is the average time to read one 512-byte sector?
    - 10 ms + 3 ms + 0.05 ms = 13.05 ms
    - Reading 1 sector a a time: 512 byte/ 13.05 ms => ~40KB/sec
**Disk Drive Performance**

- Suppose on average
  - Tseek = 10 ms
  - Trotate = 3.0 ms
  - Tread = 5 usec/ 512-byte sector

- What is the average time to read one 512-byte sector?
  - $10 \text{ ms} + 3 \text{ ms} + 0.005 \text{ ms} = 13.005 \text{ ms}$

- What is the average time to read 1MB of (contiguous) data?
  - 1MB = 2048 sectors
  - $10 + 3 + 0.005 \times 2048 = 23.24 \text{ ms} \approx 43 \text{ MB/sec}$

---

**Disk Drive Performance**

- Suppose on average
  - Tseek = 10 ms
  - Trotate = 3.0 ms
  - Tread = 5 usec/ 512-byte sector

- What is the average time to read one 512-byte sector?
  - $10 \text{ ms} + 3 \text{ ms} + 0.005 \text{ ms} = 13.005 \text{ ms}$

- What is the average time to read 1MB of (contiguous) data?
  - 1MB = 2048 sectors
  - $10 + 3 + 0.005 \times 2048 = 23.24 \text{ ms} \approx 43 \text{ MB/sec}$

- Larger contiguous reads: approach 100 MB/sec
  - Amortize Tseek + Trotate (key to good disk performance)

---

**Disk Performance**

- Hard disks have caches (spatial locality)
- OS will also buffer disk in memory
  - Ask to read 16 bytes from a file?
  - OS reads multiple KB, buffers in memory

- "Defragmenting" (Windows):
  - Improve locality by putting blocks for same files near each other

---

**Disk Performance**

- Hard disks have caches (spatial locality)
- OS will also buffer disk in memory
  - Ask to read 16 bytes from a file?
  - OS reads multiple KB, buffers in memory

---

**Transferring the data to memory**

- OS asks disk to read data
  - Disk read takes a long time (15 ms => millions of cycles)
  - Does OS poll disk for 15M cycles looking for data?

---

**Transferring the data to memory**

- OS asks disk to read data
  - Disk read takes a long time (15 ms => millions of cycles)
  - Does OS poll disk for 15M cycles looking for data?
  - No—disk interrupts OS when data is ready.
Transferring the data to memory

- OS asks disk to read data
- Disk read takes a long time (15 ms => millions of cycles)
- Does OS poll disk for 15M cycles looking for data?
- No—disk interrupts OS when data is ready.
- Ready: version 1
  - Disk has data, needs it transferred to memory
  - OS does "memcpy" like routine:
    - Read hdd memory mapped IO
    - Write appropriate location in main memory
    - Repeat
    - For many KB to a few MB

DMA: Direct Memory Access

- Alternative: DMA
  - When OS requests disk read, sets up DMA
  - "Read this data from the disk, and put it in memory for me"
  - DMA controller handles "memcpy"
  - Ready (version 2.0): data is in memory
  - Frees up CPU to do useful things

Hard disk: reliability

- Hard disks fail relatively easily
  - Spinning piece of metal
  - With head hovering <1mm from platter
  - Hard drive failures: major pain...
  - Anyone ever have one?

Reliability

- Solution to functionality problem?
  - Level of indirection
- Solution to performance problem?
  - Add a cache
- Solution to a reliability problem?
  - ___?

RAID: Reliability

- Redundant Array of In-expensive Disks (RAID)
  - Keep 2 hard-drives with identical copies of the data
  - One fails? Replace it, copy the other drive to it, resume
    - Can work from other drive while waiting for replacement
    - Performance?
RAID: Reliability

- Redundant Array of In-expensive Disks (RAID)
  - Keep 2 hard-drives with identical copies of the data
  - One fails? Replace it, copy the other drive to it, resume
    - Can work from other drive while waiting for replacement
  - Performance?
    - Writes to both drives in parallel (no cost)
    - Improve performance: twice the bandwidth

- Performance?
  - Reads from either drive
  - Improve performance: twice the bandwidth

- Downside?
  - Cost: need to buy 2x as many disks for 1x the space
  - Still: pretty popular (I have it on my home linux box)
  - Also very easy

RAID: All sorts of things

- Mirroring data (prev slides): “RAID 1”
- Tons of other RAID configurations:
  - RAID 0: striping—performance, not reliability
  - Parity schemes: reduce overhead for num disks > 2
  - Still give reliability and good performance
- Many covered in detail in your book
  - Good to know they exist, may be good solution to a problem one day
  - Don’t fret the obscure ones too much

Other devices

- Wide variety of IO devices
  - Most basically work the same way from high-level
  - Read/write proper physical memory location(s)
  - Reality: each device has its own protocol
    - Requires device driver: Software module that handles protocol details of specific device
    - Example of?

Next Up: OSes

- Working our way up the system
  - Just talked about how data is stored on disks...
  - Next time: how do we make a coherent filesystem?
- Followed up by various other bits of OS knowledge
  - How does the system boot?
  - How are programs scheduled?
  - For that matter where do they come from?