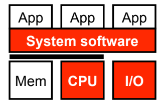
ECE 590.03
Fundamentals of Computer Systems and Engineering

IO Devices

IO: Interacting with the outside world

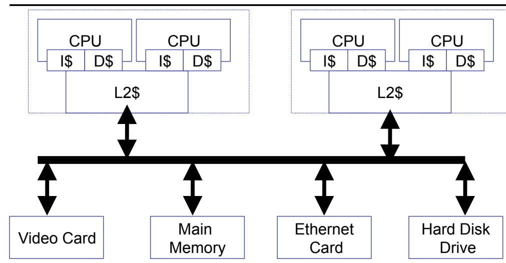


- Input and Output Devices
  - Video
  - Disk
  - Keyboard
  - Sound
  - …

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

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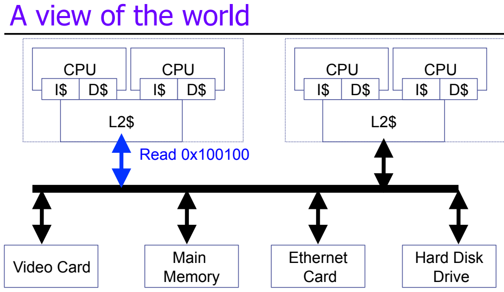

- Chip 0 requests read of 0x100100

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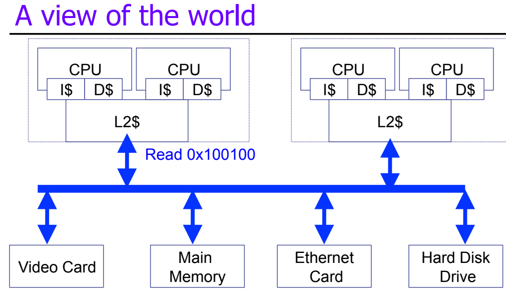

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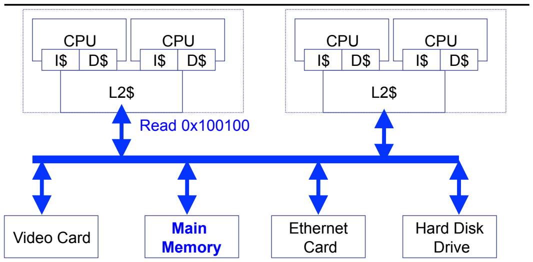
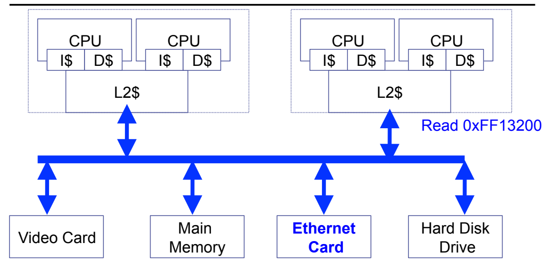


- Chip 0 requests read of 0x100100
- Request goes to all devices, which check address ranges

A view of the world



- Other address ranges may be for a particular device

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] PCIe advanced features <?>
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_dev:
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?
- 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?

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    - OS knows about physical addresses, and can use them
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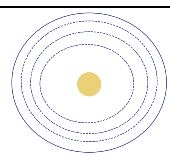
  - And then subsequent requests just hit the cache?
  - **Pages have attributes, including cacheability**
    - IO mapped pages marked non-cacheable
    - Also, prevent speculative loads (e.g., out-of-order)
    - Remember: speculative only fine as long as nobody knows

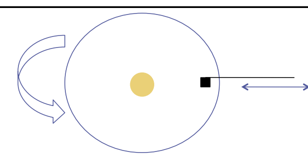
Hard disks



- 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"

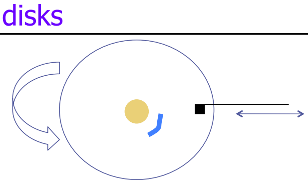
(Real disks are actually circular…)

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



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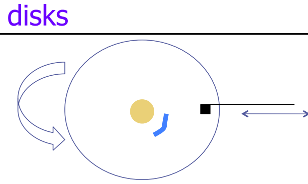

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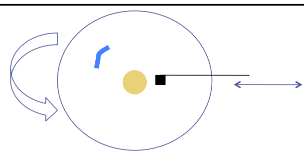

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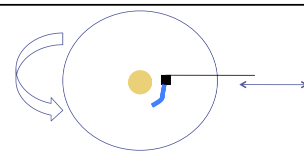

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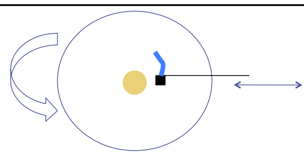

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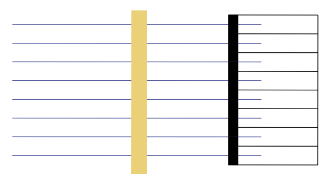
  - Takes time for data to pass under read head (Tread)

Hard Disks: from the side



- Multiple platters, each with a head above and below
  - Two sided surface
  - Heads all stay together ("cylinder")
  - Heads not actually touching platters: just **very** close

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
- Tread:
  - Depends on RPM + how much data to read

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 ms + 3 ms + 0.05 ms = 13.05 ms
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  - 10 + 3 + 0.005 * 2048 =23.24 ms => ~43MB/sec
- Larger contiguous reads: approach **100MB/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

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

Transferring the data to memory

- OS asks disk to read data
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- 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?
  - …?

Reliability

- Solution to functionality problem?
  - Level of indirection
- Solution to performance problem?
  - Add a cache
- Solution to a reliability problem?
  - Add error checking and correction
    - For HDD's checking is easy: "wont read data"
    - Simplest correction: keep 2 copies

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?

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      - 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
      - Which memory locations to read/write etc
    - Example of?

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      - **Abstraction!**

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 mater where do they come from?