

# Computing Systems

Week 5 Memory and Storage

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Lecture 5  
Memory & Storage



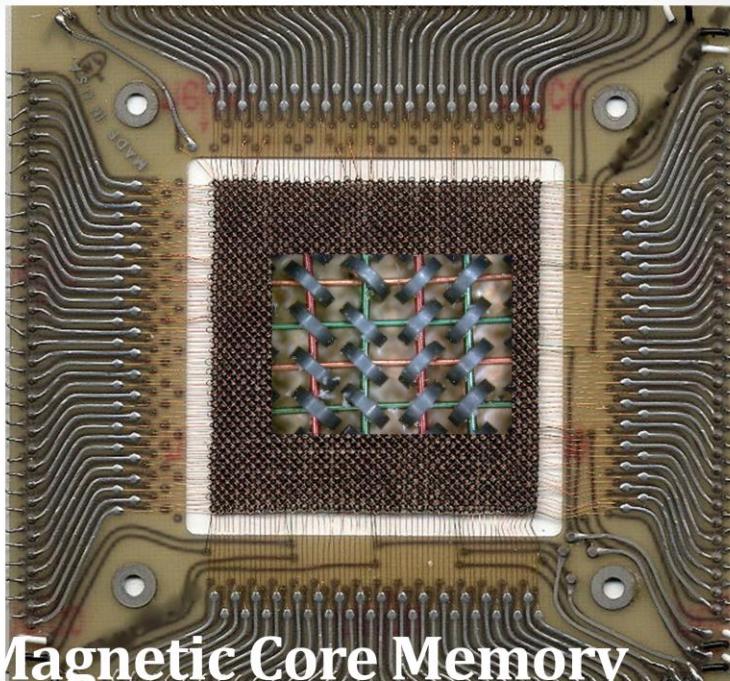
BY SA

# Storage Hierarchy

- **Primary Storage**
  - Main **RAM** and on **CPU** storage
- **Secondary Storage**
  - **Hard Drive** and **Flash/SSD**
- **Tertiary Storage**
  - **Tape & Optical** media in robotic access system  
(automatic **loading/unloading** of media)
- **Offline Storage**
  - **Tape & Optical** media **backups**

Primary storage has (more or less) direct access from CPU, Secondary storage requires use of I/O channels and interfaces.

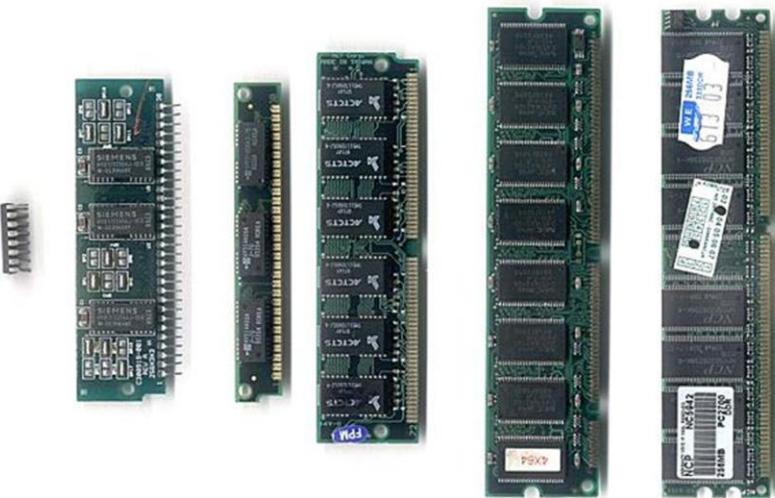
Tertiary storage requires automated media loading and unloading facilities



## Magnetic Core Memory

**Early Computer memory uses Magnetic Core Memory, this card would be about 10cms a side. In the centre there is little magnetic cores, magnets, with wires in between them. Magnets would store a charge, and you set a magnet's charge to store or clear a charge stored in the magnet. This gave a basic storage capability. It was still used in the early space shuttle as it was very reliable, well understood technology. Very resistant to damage and could maintain its contents for a long period of time even when power was switched off. Not really used in modern systems.**

## DRAM- Dynamic Random Access Memory



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DRAM – is used in modern computer systems.  
Different chips from various eras.

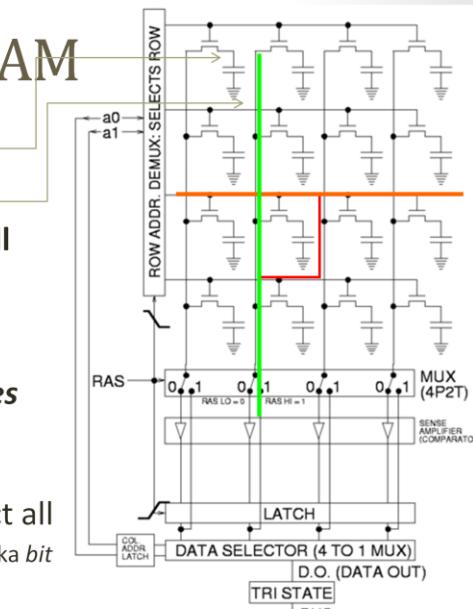
More recent on the right, contain a number of different DRAM chips on one circuit board which slots into the computer. Modern DRAM modules might contain quite large capacities up to several Gigabytes in one module, whereas earlier memory modules chips may have contains only a few KB of RAM-.

DRAM memory: At left is a Dual in-line Package (DIP) dynamic RAM chip – the other memory modules are more modern. From left to right: DIP, SIPP, SIMM (30-pin), SIMM (72-pin), DIMM (168-pin), DDR DIMM (184-pin).

[http://commons.wikimedia.org/wiki/File:RAM\\_n.jpg](http://commons.wikimedia.org/wiki/File:RAM_n.jpg)

# Structure of DRAM

- Transistor & capacitor pair for each storage cell (bit)
  - Individual cells are very simple
- **Word (or address) lines** connect all the cells in each row
- Two **data lines** connect all cells in each column (aka *bit lines*, only one shown)



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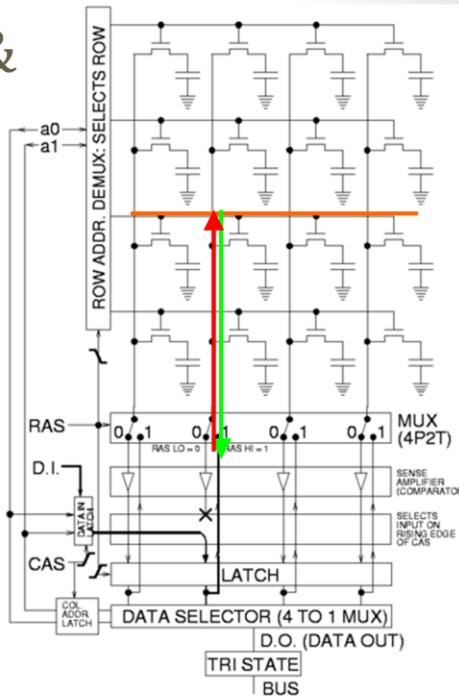
Capacitor is an electrical device that is able to store a charge for a period of time. Memory cell is simple it has a transistor and a capacitor. A row of these components are connected along a word or address line CONNECTING ALL CELLS IN EACH ROW. Two data lines connect all cells in each column, only one is shown. By setting a value to activate an address line and another to address a column, you can address an individual memory cell or BIT. Each cell stores a single 0 or 1 value. We can refer to cell if we know it's address line and column. For reading and writing the signal makes one address line active at the same time. A whole word would normally be read at the same time. Cell value is copied down to the sense amplifier (buffer). Write operation it is the same idea, values are put into buffer, the line is activated, a charge is sent up the address line to the memory cells.

# DRAM Read & Write

Signal sent to make one **address line** active at a time

For **read**, active cell from each column copied to a **buffer** (the *sense amplifier*)

For **write** operation, bits from the **buffer** are sent via the **data lines** to reset the values in the **current address line**



## Using DRAM

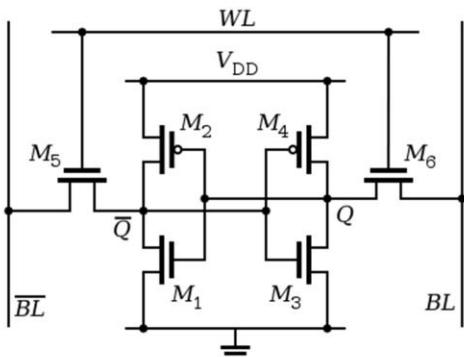
- **Capacitors** lose charge over time
- Without actively **refreshing memory**, contents quickly lost
- Current standards require cells to be refreshed every ~ **64ms**
- **Magnetic & radiation** interference can cause bits to '**flip**' – DRAM available with **parity** checking or **error correcting code (ECC)**
  - Adds to **cost** of memory & system

64 ms – milliseconds – 1/1,000<sup>th</sup> of a second.  
Thousandth.

You can buy DRAM with / without ECC.

For most home computer use normal to use the DRAM without ECC as random BIT flip is not very common. Some business uses need DRAM with ECC.

## SRAM – Static Ram



A single **SRAM** bit cell uses  
6 or more *transistors*

- Refresh is **not** required
  - But still **volatile**: memory is **lost** when unpowered
- More **expensive**, but can be **faster** and use **less power** than **DRAM**
- Can be easier to **integrate**, as **no** need for **refresh circuitry**

A long as power is on it keeps it's value. Use less power than DRAM as they do not need refreshed.

More circuitry is involved therefore it is more expensive. It can be faster. Can be easier to integrate into some systems as there is no need to have special circuitry to refresh the memory.

# Long Term Storage

- **RAM** is relatively *expensive & power hungry*
- **Good** for storing *active programs* in a running computer
- **Wasteful** for storing *inactive programs* and *data*
- Totally *useless* for storage when computer is switched *off*

# Storage

- **Disks**
  - **Floppy Disks** – removable & portable media
  - **Hard Drives** – fixed & portable
  - **Optical media** – CD, DVD & Blu-Ray
- **Tape storage**
  - **Large capacity archive media**
- **Flash memory**
  - **USB** flash drives
  - **Solid-State Drives (SSD)**

# Cache Memory

- Will look in this in more detail later
- General principle:
  - Use a small amount of **high performance memory** as a **local copy** of data stored in some **cheaper but lower performing memory**
- Examples:
  - **CPU** may have a cache storing copy of some data from main memory (**RAM**)
  - Disk drives may have **RAM** chips to cache data recently used

Limits dependency on using the disk itself to read and write data to allow faster access.

## Quick quiz

- Join the ‘Socrative’ app ‘Room 642124’ and try the quick quiz.

## 8", 5¼ " and 3½" floppy disks



Data stored in orientation of magnetic particles  
Typical capacities of **500KB-1MB**, **140KB-720KB** and **1.44-2.88MB** respectively

3 ½ - used widely up to 7 years ago or so.

Note: A wide range of data formats and capacities existed for each of these standard disk sizes.

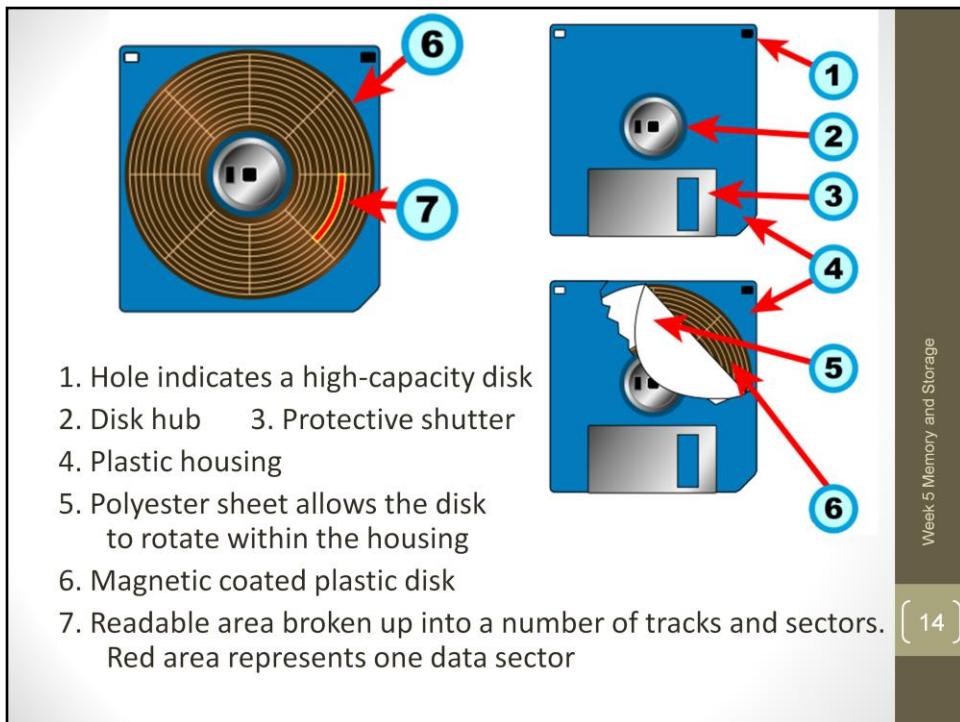
Lots of detail and tables at  
[http://en.wikipedia.org/wiki/Floppy\\_disk](http://en.wikipedia.org/wiki/Floppy_disk)

More important for us are the common features of all of these:

Larger unformatted capacity, smaller usable formatted capacity, flexible disk in either flexible or rigid case.

3½" disk also featuring sliding cover to protect the disk from damage.

If possible bring disks to class – even allow them to be broken open if possible...



3 ½ - protective shutter, hard outer case. Disk is coated in magnetic particles. Most floppy disks have the sectors arranged so that the sector angle is the same. There is the same amount of data on each sector so that the disk rotates at the same speed. There could be more data on the sectors at the outside of the disk but that would slow things down as the disk would have to rotate at different speeds. It was complicated earlier on.

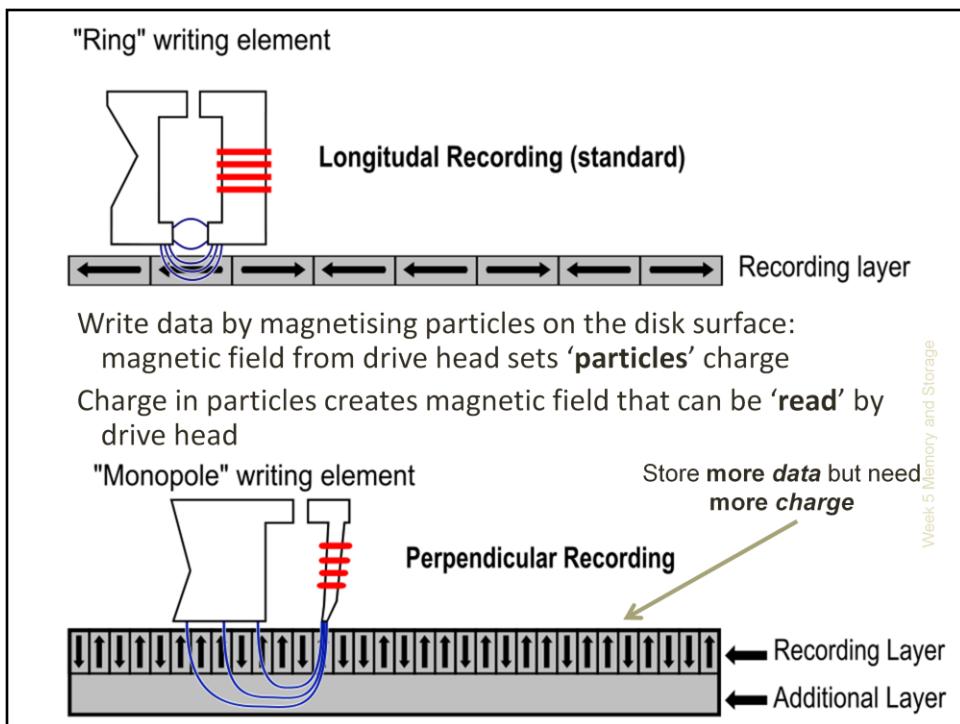
## Hard Disks



**Data stored on hard **non-magnetic** platters**

**Read heads, platters and control in a single sealed device**

Hard disks can slow down and speed up therefore more data can be stored in the outer sectors. Disk head float a minuscule distance above the disk. Disks are normally sealed.



This applies to both floppy and hard disks.  
 Magnetic particles are lined up one way or another representing 0 or 1. Perpendicular is more recent and allows more data to be stored / packed but needs more charge, current.

# Hard Disk Technology



- Platters coated with thin layer of **magnetic material (10-20nm)**
- Typical **rotation speed of 7,200 RPM**
- Heads float **nano-meters** above **platter**
- Modern hard disks are hermetically sealed units including **read/write** heads and controller
  - **1970's** hard disks had **removable packs** consisting of the platters themselves. Drives would be about the size of a **washing machine**

10-20nm (nanometre -- equal to one billionth of a metre) thick coating of magnetic material compare to typical sheet of copier paper will be 70,000-180,000nm thick! Particles of smoke could not fit between the gap.

# Disk Slowdown causes

- **Spin-up time**
  - Many drives will switch off automatically to save power; takes time to **restart**
- **Seek time**
  - **Data** may be **anywhere** on **disk**; Time to **move** read **head** into **correct position**
- **Latency**
  - **Time** for **disk** to **rotate** until **correct sector** is present at *read/write* head
- **Fragmentation**
  - Single **file** may exist in **sections** scattered over **disk**; Time to **move** between **sections**

# Disk Speedup

- **RPM: Revolutions Per Minute**
  - **Notebook** disks typically **5,400 RPM**
  - **Desktop** disks typically **7,200 RPM**
  - **Server** disks can be over **10,000 RPM**
- **'Average Access Time'**
  - (sometimes referred to as **latency**)
  - From **all speed factors**, measure in **ms**
- **Burst speed/Transfer Rate**
  - **MB/sec** – **MegaBytes per second**

To speed up.

Average Access Time → all delay times added together.

Burst speed → maximum speed from a hard disk, when you have taken out the seek time delays.

# Hard Disk Numbers

- Some typical disk drive stats
  - **Capacity 500GB – 6TB**
    - Seagate is now shipping the ‘world’s first’ **8TB** hard drives surpassing the previous storage capacity limits in a single **3.5-inch** hard disk drive.(26<sup>th</sup> August 2014)
  - **Spin up time:** May take **several seconds**
  - **Seek Time:** 4 and **7ms**
  - **Average access time/latency:** < 3 ms
  - **Data transfer rate:** **250-350 MB/sec**
  - **Higher** performance disks are available...
    - At a **cost**

2 TB – terabyte → One trillion (1,000,000,000,000) bytes

# Tape



## Sequential data store

- Very slow for random access
- Can have **high speeds** for saving/restoring **sequential** data

*Still used for data archiving*

- Modern tape cartridge formats up to **5TB (StorageTek T10000C)**



See them in 70s films, Bond film.

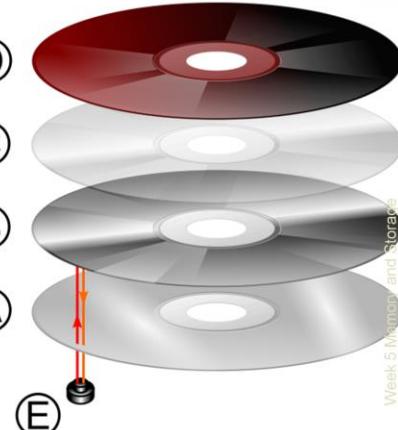
Tape gives a sequential data store, very slow for random access, but have very high speed for saving and restoring data in order. Tape is still used for data archiving servers and by ISPs. It is very cheap, one cartridge can store up to 3TB, therefore can store more than and is cheaper than a comparable hard disk.

## Optical Disks

- **CD, DVD and Blu-Ray disks** are forms of *optical* media
- **Lasers** used to *etch* and *scan microscopic holes* on the internal *surface* of disks
- **Transparent layer** protects read/write surface
  - Resistant to minor scratches
- **700MB (CD), 4.7GB (DVD), 25/50GB (Blu-Ray)**

Optical Disks → possibly have a limited life span left.

- A. A **polycarbonate** disc layer *protects* the disc
- B. **Shiny** layer *reflects* the *laser*. Data encoded using pits and bumps in reflective layer.
- C. A layer of **lacquer** *protects* the reflective layer.
- D. **Artwork** is screen printed on the top of the disc.
- E. A **laser** beam *reads* the CD and is *reflected back* to a sensor, which *converts* it into *electronic data*



All have similar layout to above.

Note: The wikipedia original states that the data is burned into the polycarbonate layer. In contrast the text book (HCW) and other sources claim that the pits and burned into the reflective material instead of the top of the polycarbonate layer. I've gone with the latter...

## CD/DVD/Blu-Ray

- All use a spiral track with constant track size
- The **smaller** the **wavelength** of the **light**, the **more tracks** can be **packed** onto the **disk**
- **Blue light has shorter wavelength than Red**
- **DVD & Blu-Ray** may be **dual layer**, with **two layers on a single disc**
- Focussing the **light beam** allows either **layer** to be **read/written**

Data spirals out from the centre of the disk. Blue light has shorter wavelength than Red. CD used red layer.

## Read/Write Optical Media

- Special **dye** layer before **reflective** layer can have **pits burned** in it by **writer**
- Normal drives can read as usual
  - **Write drives** can produce **higher power beams** to **mark, melt or distort** the **dye layer**
- *Lots of formats* –write once (+/-R) and rewritable (+/-RW/RE)
- Dye can decay – affecting lifespan of disc
  - But modern discs should last **10s to 100s** of years

*Lots of formats* –write once (+/-R) and rewritable (+/-RW/RE)

# Flash Storage

Portable Hard Disk  
Drive – Typical  
Capacity 250GB –  
500GB (2010)

Flash memory cards  
and USB memory  
sticks – Typical  
Capacity 2GB-32GB  
(2010)

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Portable drive shown is actually several years old, with an 80GB capacity – it is now possible to buy USB memory sticks with greater capacity (though at time of writing they tend to be rather chunky!)

Memory cards shown (Compact Flash, SD, SDHC, Memory Stick, Memory Stick Pro and Memory Stick Pro Duo) have been collected over many years – with capacity ranging from 16MB (!) to 4GB. The Compact Flash card (the largest card) has just 32MB capacity. USB memory sticks were free with conference attendance or membership gifts.

# Flash Memory

- Transistors with a **fourth insulated connection**
  - Additional gate can hold charge for many years, allowing flash **RAM** to store data without power
- Memory cells **fail** over time – **Memory Wear**
  - 100,000 to 1,000,000 program/erase cycles
  - **Wear levelling** and memory block management can extend lifetime
  - Using flash for memory cache or **frequent compiling** can cause serious damage!
- Range of **speeds & lifetimes** – and **costs**

Note: Not all flash memory is the same; Flash memory with longer expected lifetime or higher rated performance can cost 2 to 4 times as much as basic flash memory for the same capacity. Flash RAM can store data without power.

*Wear levelling* and memory block management can extend lifetime by saving the data on a different area when resaving it. Bargain Flash memory for good prices may have a shorter life time.

## Solid State Drives

- **RAM** as a 'hard disk'
- Usually **Flash**
  - **DRAM** possible, but needs constant power!
- **Higher performance** and **cost** than normal disk drives –lower capacity, lower power use
- *Memory wear* still an issue – can be paired with a normal hard drive
  - *Embedded control chips* can distribute use of memory to maximise lifespan of drive '*memory wear levelling*'

Solid State Drives → Relatively recent → use RAM as Hard disk → used for Lap tops.

Place o/s files on SSD but user files and memory cache on the Hard Disk

# SSD VS HD



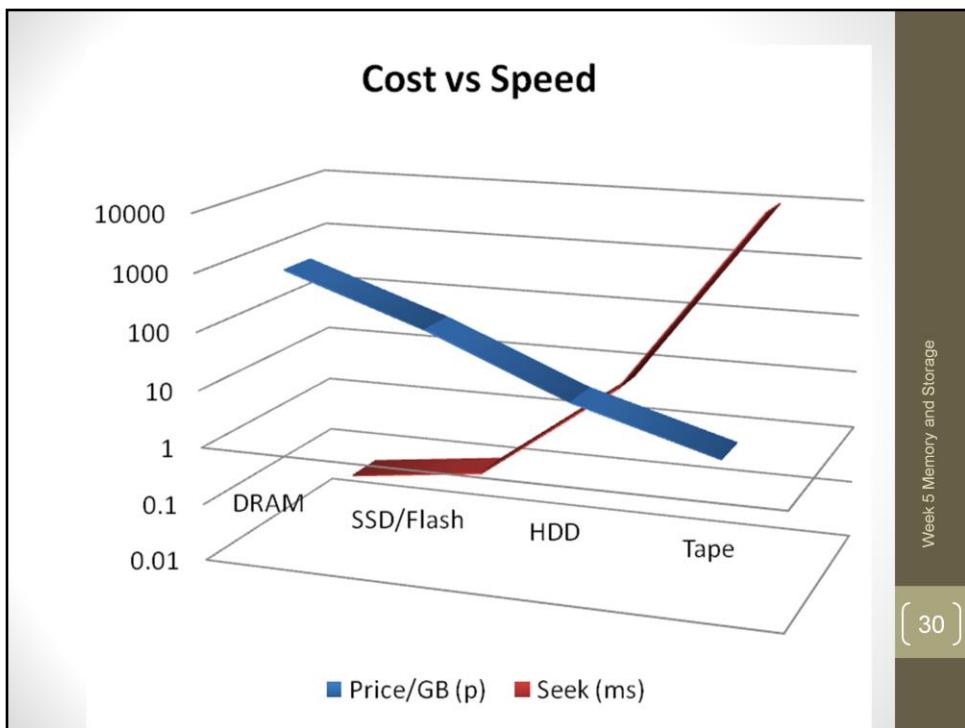
	SSD	HD
Spin up:	Instant	Seconds
Seek time:	< 0.1ms	5 - 10ms
Latency:	Low	3 – 6 ms
Fragmentation:	No effect	Reduces response time
Typical Transfer rate:	300 MBps (Can be much higher!)	300 MBps
Typical Cost (2011):	£1/GB	£0.15/GB

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Comparison of SSD to HD.

SSD data will be fragmented but will have no effect.



DRAM is most expensive but has fastest seek time.  
Scale on left is logarithmic.

# Hacking MicroSD Cards

- For the full blog on this topic go to  
<http://www.bunniestudios.com/blog/?p=3554>
- Some **SD cards** contain *vulnerabilities* that allow arbitrary **code execution** — on the memory **card itself**.
- On the dark side, code execution on the memory card enables a class of **MITM (*man-in-the-middle*)** attacks, where the card seems to be behaving one way, but in fact it does something else.
- On the light side, it also enables the possibility for hardware enthusiasts to gain access to a **very cheap** and **ubiquitous** source of **microcontrollers**.

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## Hacking MicroSD Cards cont.

- Flash memory is really **cheap**. So cheap, in fact, that it's **too good to be true**.
- In reality, all flash memory is **riddled** with **defects** — without exception. The **illusion** of a contiguous, **reliable storage media** is crafted through **sophisticated error correction** and **bad block management functions**. This is the result of a constant arms race between the engineers and mother nature; with every **fabrication process shrink**, **memory** becomes **cheaper** but more **unreliable**.
- Likewise, with every generation, the engineers come up with more **sophisticated** and **complicated algorithms** to **compensate** for mother nature's propensity for entropy and **randomness** at the atomic scale.

## Hacking MicroSD Cards cont.

- The quality of the flash **chip(s)** integrated into **memory cards** varies widely.
- It can be anything from **high-grade factory-new** silicon to material with over **80% bad sectors**.
- Those concerned about **e-waste** may (or may not) be pleased to know that it's also common for **vendors** to use **recycled flash chips** salvaged from **discarded parts**.
- **Larger vendors** will tend to offer more **consistent quality**, but even the largest players staunchly **reserve the right** to **mix and match flash chips** with **different controllers**, yet sell the **assembly** as the **same part number** — a nightmare if you're dealing with implementation-specific bugs.

## Quick quiz

- Join the ‘Socrative’ app ‘Room 642124’ and try the quick quiz.

# Required Reading For Next Week

- HCW:
  - Part 7 How the Internet Works: Introduction and Chapters 24-28, p 308-357
  - (Skip 322/323, 326/327, skim 338-349)
  - *P319 – Bus topology comments not quite right!*

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# Further Reading

- Wikipedia:
  - Computer Data Storage & related articles
- PCH
  - Chapter 12 – Computer Memory



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