COSC 511: Computer Architecture
Data Storage (Part 2)

Week 10

Last Week

- Analog vs Digital Data Storage
  - This included a discussion of some really old storage mediums.
- Hard Drives
  - Components of a traditional Hard Drive
  - How Hard Drives store data
  - Source of latency
- Fragmentation
  - Why it happens
  - Why it is a problem
  - How to fix it

Solid State Drives

SATA HDD
80-300 MB/s*

SATA SSD
200-550 MB/s

NVMe SSD
2.6-6 GB/s

*For 7200 RPM drives.

Solid State Drives

- Why are SSDs faster than HDDs?
  - The seek time is dramatically less, and also, more consistent.
    - Reminder:
      - Hard Drive Average Seek Time: 9ms
      - SSD Average Seek Time: 0.16ms
  - HDD seek time will vary depending on how much movement the head has to make.
    - SSDs don't have any mechanical components, so the seek time is more consistent.

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Solid State Drives

- SATA SSDs and NVMe SSDs both use the same storage technology

But...

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Why?

Solid State Drives

- SATA – Serial Advanced Technology Attachment
  - First introduced in 2000
    - Theoretical Maximum Speed: 150 MB/s
  - SATA 2 – Released in April 2004
    - Theoretical Maximum Speed: 300 MB/s
    - Minor Revisions:
      - SATA 2.5 – Released in August 2005
      - SATA 2.6 – Released in February 2007

SATA HDD
80-300 MB/s

Solid State Drives

- SATA – Serial Advanced Technology Attachment
  - SATA 3 – Released in July 2008
    - Theoretical Maximum Speed: 600 MB/s
    - Minor Revisions
      - SATA 3.1 – Released in July 2011
      - SATA 3.2 – Released in August 2013
      - SATA 3.3 – Released in February 2016
      - SATA 3.4 – Released in June 2018
      - SATA 3.5 – Released in July 2020

Solid State Drives

- SATA was originally created for HDDs
  - As HDD technology improved, drives became faster
  - The SATA standard was revised to account for faster drives
  - As SSDs became commonplace, the standard was again revised
    - But limitations of the standard's design still make it a bottleneck for SSDs
      - Workaround: PCIe SSDs

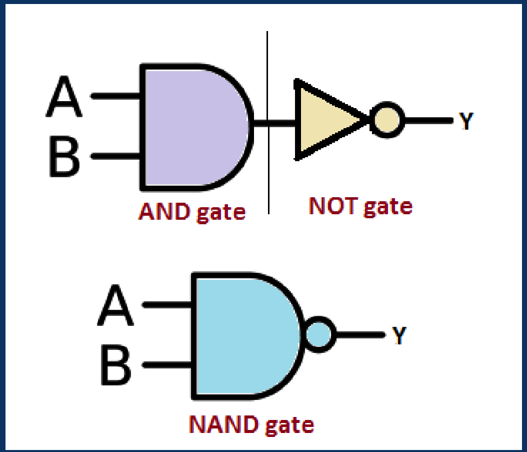
Solid State Drives

- SATA was originally created for HDDs
  - PCIe SSDs are a suitable workaround, but they are bulky
  - PCIe was not designed for SSD usage
    - There was no design standard for PCIe SSDs to follow.
    - Different PCIe SSDs required different drivers.

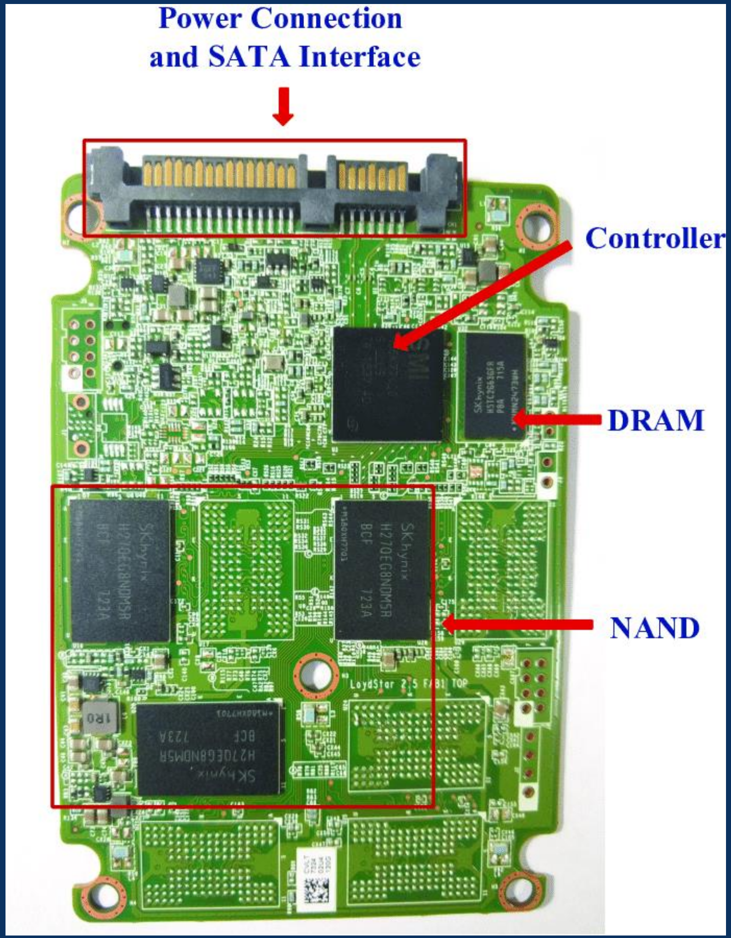
- NVMe – Non-Volatile Memory Express
  - First launched in January 2013
  - Specifically designed for SSDs, which removed the bottleneck
  - Since the standard is intended for SSDs, no requirement for different drivers

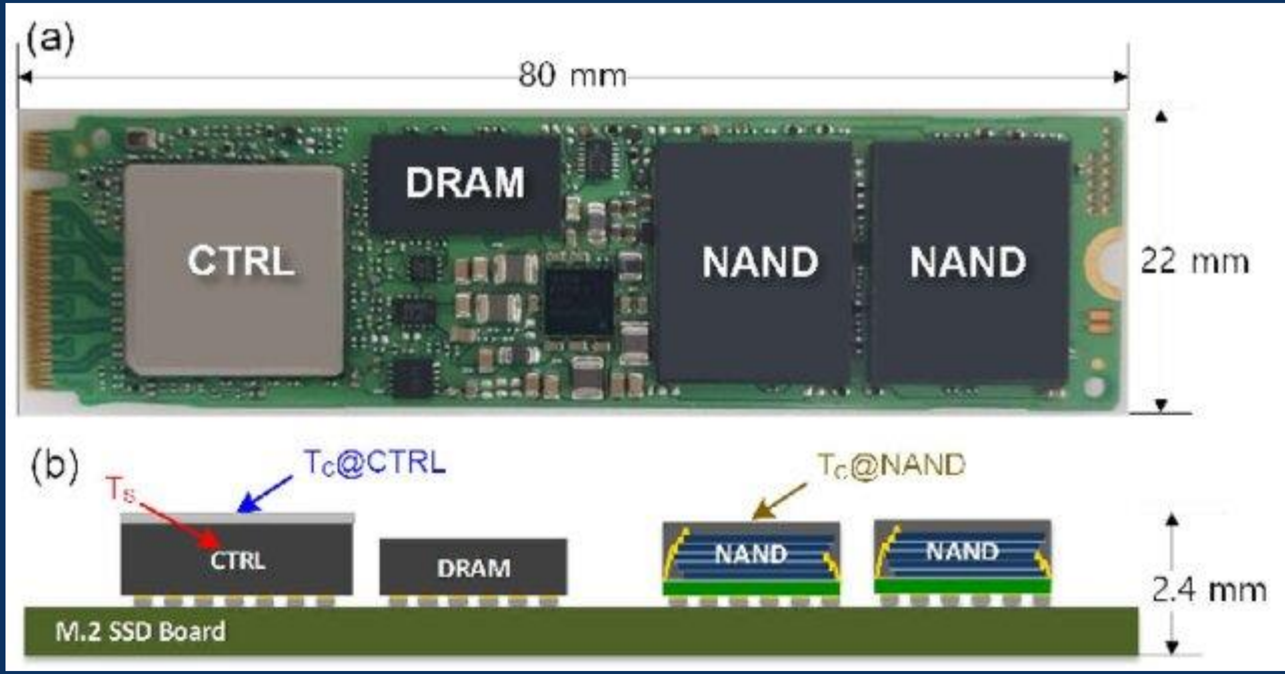
Solid State Drives

- Components
  - Controller
    - Integrated Circuit that controls the SSD's operations
    - More Info
  - DRAM
    - On-board cache that temporarily holds data before it is written to permanent storage
  - NAND
    - NAND Flash – This is where the data gets written to and read from
  - Is this how SATA or NVMe SSDs work?



Solid State Drives





Solid State Drives

- NAND Flash uses “floating gate transistors”
  - These types of transistors retain their charge state even when power is cut
- Floating Gates have two possible states:
  - Charged, which means 0
  - Not charged, which means 1
- The SSD controller is responsible for handling reading and writing
  - It writes by altering the charge state of the NAND gates.
  - It reads by checking the charge state of the NAND gates.

- It’s much more complicated than this, but unless you’re a working on engineering a new SSD, this is really all you need to know.

Solid State Drives

- Why is paging to an SSD worse than paging to a hard drive?
  - You already know the answer to this. ☺

- Why is paging to a hard drive worse than paging to an SSD?
  - SSD seek times are much better than a hard drive.
    - Reminder:
      - Hard Drive Average Seek Time: 9ms
      - SSD Average Seek Time: 0.16ms
  - SSDs do not have a seek time penalty like hard drives do.
  - Fragmentation still happens on SSDs, but it does not matter.
  - You can still defragment an SSD if you want, but you shouldn't!

Solid State Drives

- Why shouldn't you defragment an SSD?
  - NAND flash has a limited number of write cycles.
  - The write cycle limit is a side effect of physical damage caused to the NAND every time a write operation occurs. More detail here.
  - Defragmentation is a write-heavy operation.
    - Since defragmentation is write-heavy, it just helps to kill your NAND faster.
    - There is no performance benefit for doing it.
    - Actually, SSDs will deliberately fragment your data!

Solid State Drives

X	X	X	X	X	X	X	X	X	X

Solid State Drives

X	X	X	X	X	X	X	X	X	X
X	X	X	X	X					

Solid State Drives

- SSDs deliberately introduce fragmentation to prevent the same NAND cells from being used much more frequently than others.
  - This is called wear leveling.
  - One of the many jobs that the SSD controller has is to manage wear leveling.

- So:
  - Hard Drive fragmentation is bad and we should try to limit it.
  - SSD fragmentation is good and we should just let it happen.

Solid State Drives

- Pros
  - Faster than mechanical hard drives
  - Seek time is consistent regardless of where data is physically located
  - Fragmentation (which is unavoidable anyway) is not a problem.
    - Actually, it's a good thing!

- Cons
  - NAND storage has a finite number of write cycles
  - Much more susceptible to bit rot than mechanical hard drives
    - This makes them less reliable for long-term storage of infrequently accessed data.
  - Operating temperatures are much hotter than hard drives

Solid State Drives

- Bit Rot
  - Gradual corruption of stored data caused by minor failures in a storage medium.

- Hard Drive Bit Rot
  - Occurs when the magnetic states stored on the drive platter are reversed.
  - High temperatures are the main cause of magnetic state reversal.

- SSD Bit Rot
  - Occurs when the electrical charge stored in a NAND cell leaks out.
  - Issues with cell insulation are the main cause of electrical charge leakage.

Solid State Drives

- Preventing Bit Rot
  - Hard Drives
    - Use giant magnetoresistance to reduce the likelihood of bit rot
    - Use error correction to fix bit rot when it is detected
  - Solid State Drives
    - Use error correction to fix bit rot when it is detected
    - Occasionally rewrite cells so that the charge state is refreshed
- These prevention techniques only work if the storage medium is not sitting unused for an extended period of time.
  - Bitten by SSD Bit Rot