Overview

- SSD Overview
- History of flash memory storage
  - Focus on SSDs
- SSD Components
  - Controller
  - Memory cell structure
- SSD vs other methods of storage
What is an SSD?

- No moving parts a la the traditional hard-disk drive
- Usually uses NAND-based flash memory as opposed to electromechanical storage
  - Can use other types of flash memory as well
- Awesome beyond belief
History of Flash memory

1984
Flash memory created

1988
Intel creates first commercial NOR type flash chip

1995
First NAND-based removable media format

1999
BitMICRO introduced 18GB SSD

2007
Fusion-io introduce SSD with 320 GB

2009
OCZ Technology demo a 1 TB flash SSD

2009
Micro Technology announce SSD using 6 gigabits/sec interface

2015
Memory Hierarchy

- Retains data after power off
- Faster access speeds than mechanical HDD storage
- Lower storage density than mechanical hard drive and other tertiary storage
- Slower access speeds than random access memory
- Trade storage size for performance?
- Sony magnetic tape can hold 148 GB per square inch
Component Overview

- **Interface with PC**
  - SATA, SAS, PCI-e, etc

- **Controller**
  - Error correction/recovery
  - Wear leveling (prolong life)
  - Caching
  - Garbage collection

- **Memory Structure**

- **Cache/Buffer**

- **NAND Memory**
Memory Elements

- **SLC: Single-Layer Cell**
  - 1-bit per cell (0/1)
- **MLC: Multi-Layer Cell**
  - 2-bits per cell (00-11)
- **TLC: Triple-Layer Cell**
  - 3-bits per cell (000-111)
- **SLC** most reliable and fastest, but most expensive
- **MLC/TLC** trade speed and reliability for higher storage density and cheaper costs
NAND and NOR Flash

- NOR-based flash memory tend to have longer life cycles and better reliability compared to NAND.
- NAND memory usually has higher storage densities.
- NAND has faster sequential access speeds while NOR has better random access speeds.
- NAND requires controller management.

![Random Read Access Performance vs. Large Data Size](chart.png)
Controller

- Performs wear-leveling to ensure longer SSD lifespan
- Deals with bad sectors
  - Identifies and maps them to ensure minimal data corruption
- Error Code correction
- Manages the buffer within the SSD
- Garbage collection
- Interfacing with host
- Sets up read/write accesses
Wear Leveling

- Reduces premature wear in NAND flash devices, i.e. failure times for all cells should be around equal instead of any one failing early
- **Dynamic Wear Leveling**
  - Pools available free data blocks and selects block with lowest erase count for next write
  - Good for dynamic data that is often overwritten or modified
- **Static Wear Leveling**
  - Similarly chooses block with least wear
  - Monitors erase count and moves static data to blocks with high erase counts periodically to free up blocks with low erase counts for other data
DRAM/Cache

- Keeps data on wear-leveling and block placement
- Same function as cache on mechanical HDD
- Can be used to accelerate write speeds
Trim

- Over time data will be written to and removed from an SSD. Which data should we keep and which should we remove?
- SSDs store data in flash memory cells that are grouped into pages, which are then grouped into blocks. These cells can only be written to when they are empty.
- **Trim** allows an operating system to inform a SSD which blocks of data are no longer considered in use. This effectively enables garbage collection for the SSD.
## SSD vs. HDD

<table>
<thead>
<tr>
<th>Feature</th>
<th>HDD</th>
<th>SSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price per GB</td>
<td>$0.033</td>
<td>$0.50</td>
</tr>
<tr>
<td>Capacity (Consumer)</td>
<td>6 TB</td>
<td>1 TB</td>
</tr>
<tr>
<td>Random Read Latency</td>
<td>6ms - 8ms</td>
<td>~0.1 ms</td>
</tr>
<tr>
<td>Fragmentation</td>
<td>All over</td>
<td>Irrelevant</td>
</tr>
<tr>
<td>Power Usage</td>
<td>4W idle, 6W load</td>
<td>0.5W idle, &lt; 2W load</td>
</tr>
<tr>
<td>Noise</td>
<td>Sad</td>
<td>Silent</td>
</tr>
</tbody>
</table>
Storage Density and Prices

- Currently:
  - 3TB HDD: $100
    - $0.033/GB
  - 1TB SSD: $500
    - $0.50/GB
- Consumer SSDs not available in capacities beyond 1TB per drive
  - More drives leads to higher overall failure rate
- HDDs readily available up to 6TB per drive

Data sources: Mkomom.com, Gartner, and Pingdom (December 2011)
The SSD outperforms the HDD by a large margin in random access time because all data can be retrieved directly from various locations. HDDs must spin up before they can access most data which contributes to the large latency.
Gotta Go Fast (Increasing R/W speeds in solid state technology)

- RAID 0 SSD configurations can increase R/W speeds up to 2x
  - Decreases reliability
- Use volatile memory (e.g. RAM) as secondary storage
  - RAM drives/disks
- Integrating DRAM into an SSD
- Need to ensure host interface has enough bandwidth
  - PCI-e x16 v4.0: 31 GB/s
  - SATA 3: 6 Gbps = 750 MB/s
  - Thunderbolt: 20 Gbps
Applications

- Shorter application launch times, boot times, load times, etc. for impatient people like us
- Usage in databases and servers to utilize as secondary cache to minimize response time
- Downloading data with a gigabit connection requires fast write speeds as to not bottleneck the data transfer
References

- http://www.anandtech.com/show/5067/understanding-tlc-nand/1
- http://www.pcmag.com/article2/0,2817,2404260,00.asp