Storage: HDD, SSD and RAID

Johan Montelius

KTH

2017
Why?

Give me two reasons why we would like to have secondary storage?
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Gigabyte Z170 Gaming

- 2 PCIe x16/x4
- 4 PCIe x1
- 2 USB 3.1
- 6 USB 3.0
- 4 USB 2.0
- 6 SATA-III
- 2 SATA Express
- 1 M.2
- 1 gigabit Ethernet
- 4 DDR4 SDRAM
Computer architecture

CPU

SDRAM

memory bus up to 160 Gb/s
Computer architecture

- CPU
- SDRAM
- PCIe x16 up to 128 Gb/s
- memory bus up to 160 Gb/s
Computer architecture

CPU

- PCIe x16 up to 128 Gb/s
- PCIe x4

GPU

SDRAM

- Memory bus up to 160 Gb/s

Control Hub

- USB up to 10 Gb/s
- SATA up to 6 Gb/s
- SAS up to 12 Gb/s
Computer architecture

- **CPU**
  - PCIe x16 up to 128 Gb/s
  - SDRAM memory bus up to 160 Gb/s

- **GPU**
  - PCIe x16 up to 128 Gb/s

- **Control Hub**
  - PCIe x4
  - USB up to 10 Gb/s
  - SATA up to 6 Gb/s
  - SAS up to 12 Gb/s

- **BIOS**
- **Keyboard**
- **Audio**
- **Network**
Computer architecture

- **CPU**: SDRAM memory bus up to 160 Gb/s
- **GPU**: PCIe x16 up to 128 Gb/s
- **Control Hub**: PCIe x4
  - USB up to 10 Gb/s
  - SATA up to 6 Gb/s
  - SAS up to 12 Gb/s

- **BIOS**
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Computer architecture

- **CPU**
  - PCIe x16 up to 128 Gb/s
  - PCIe x4
  - Control Hub
    - USB up to 10 Gb/s
    - SATA up to 6 Gb/s
    - SAS up to 12 Gb/s
    - BIOS
    - keyboard
    - audio
    - network

- **GPU**
  - PCIe x16 up to 128 Gb/s

- **SDRAM**
  - Memory bus up to 160 Gb/s

- **Control Hub**
  - < 1 ns
  - < 10 ns
Computer architecture

- **CPU**
  - PCIe x16 up to 128Gb/s
  - Memory bus up to 160 Gb/s

- **GPU**
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- **SDRAM**
  - PCIe x16 up to 128Gb/s
  - USB up to 10Gb/s
  - SATA up to 6Gb/s
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- **Control Hub**
  - BIOS
  - Keyboard
  - Audio
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- **BIOS**
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- **Network**

- **< 1 ns**
- **< 10 ns**

- **10 µs - 10 ms**
70 percent of the code of an operating system is code for device drivers.
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System architecture

application

user space

I/O library

kernel space

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how to interact with a device

driver

device

A register to read the status of the device.
A register to instruct the device to read or write.
A register that holds the data.

I/O-bus could be separate from memory bus (or the same).
The driver will use either special I/O instructions or regular load/store instructions.
how to interact with a device

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**driver**

**status**

**device**
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char read_from_device() {

    while (STATUS == BUSY) {} // do nothing, just wait

    COMMAND = READ;

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    return DATA;

}
int read_request(int pid, char *buffer) {

    while (STATUS == BUSY) {} 

    COMMAND = READ;

    interrupt->process = pid;
    interrupt->buffer = buffer;

    block_process(pid);

    scheduler();
}
int interrupt_handler() {

    int pid = interrupt->pid;
    *(interrupt->buffer) = DATA;

    ready_process(pid);
}

This is very schematic, more complicated in real life.
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process state

The kernel is interrupt driven.
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Direct Memory Access

Allow devices to read and write to buffers in physical memory.
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```c
int write_request(int pid, char *string, int size) {
    while (STATUS == BUSY) {} 
    memcpy(string, buffer, size)
    COMMAND = WRITE;
    blocked->pid = pid;
    block_process(pid);
    scheduler();
}
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DMA often limited to lower memory addresses.
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Block devices used as interface to disk drives that provide persistent storage.
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All though all storage devices are presented using the same abstraction, they have very different characteristics.

*To understand the challenges and options of the operating system, you should know the basics of how storage devices work.*
Anatomy of a HDD

- track/cylinder
- sectors per track varies
- sector size: 4K or 512 bytes
- platters: 1 to 6
- heads: one side or two sides
- Only one head at a time is used (no parallel read).
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Historically sectors address by cylinder-head-sector (CHS), due to incompatible standards the limitation was:

- Cylinder: 1024 (10-bits)
- Heads: 16 (4-bits)
- Sectors per cylinder: 63 (6-bits)
- Number of sectors: 1 Mi
- Largest disk assuming 512 Byte sectors: 512 MiByte

Today, sectors are addresses linearly 0..n, Linear Block Addressing (LBA):

- 28-bit or 48-bit address
- Up to 256 Ti sectors
- Largest disk assuming 4 KiByte sectors: 1 PiByte
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`sudo hdparm -I /dev/sda`

`dmesg | grep ata2`
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> dmesg | grep ata2
```
HDD - Hard Disk Drive

Seagate Desktop

- Total capacity: 2 TiByte
- Form factor: 3.5"
- Rotational speed: 7,200 rpm
- Connection: SATA III
- Cache size: 64 MiByte
- Read throughput: 156 MByte/s

ST2000DM001, aprx price, October 2016, 900:-
Seagate Desktop

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Seagate Cheetah 15K
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HDD - Hard Disk Drive

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- read throughput: 204 MByte/s

ST3300657SS, aprx price, October 2016, 2.200:-
access time

- seek time: time to move arm to the right cylinder

...
access time

- seek time: time to move arm to the right cylinder
- rotation time: time to rotate the disk
access time

- seek time: time to move arm to the right cylinder
- rotation time: time to rotate the disk
- read time: read one or more sectors
HDD - shoot out

- Seagate Desktop
  - Rotation speed: 7200 rpm
  - Average seek time: < 10 ms
  - Average rotation time: 4 ms
  - Average time to read a sector: < 14 ms
  - Capacity: 2 TiByte
  - Approx. price: 900 SEK
  - Cost capacity: 0.44 SEK/GiByte

- Seagate Cheeta 15K
  - Rotation speed: 15000 rpm
  - Average seek time: < 4 ms
  - Average rotation time: 2 ms
  - Average time to read a sector: < 6 ms
  - Capacity: 600 GiByte
  - Approx. price: 2200 SEK
  - Cost capacity: 3.70 SEK/GiByte
HDD - shoot out

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  - Seagate Desktop: approx. 900:-
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- Rotational speed should be high.
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- The density i.e. how many sectors in each track is important.
read/write performance

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- The density i.e. how many sectors in each track is important.
- The communication with the drive should be fast.
- Typical read and write performance is between 150 MiByte/s to 250 MiByte/s.
who’s in control

Historically, the Operating System was in complete control:

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- it knew the layout cylinder-head-sector (CHS),
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- would schedule disk operations to minimize arm movement.

Today, the drive can often make a better decision: it knows, but might not reveal, the layout. The operating system can help in grouping operations together, allowing the drive to decide in what order they should be done (Native Command Queuing).

There is a reason why MS-DOS is called MS-DOS.
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Samsung 850 EVO

- total capacity: 250 GiByte
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- read throughput: 540 MiByte/s

MZ-75E250B/EU, aprx price, October 2016, 1000:-
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MZ-75E250B/EU, aprx price, October 2016, 1000:-
SanDisk Ultra SDXC

- form factor: SDXC
- capacity: 64 GiByte
- read performance: 80 MiByte/s
- aprx price, October 2016, 300:-
SanDisk Ultra SDXC

- form factor: SDXC
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SanDisk Ultra SDXC

- form factor: SDXC
- capacity: 64 GiByte
- read performance: 80 MiByte/s
SD cards - flash memory

SanDisk Ultra SDXC

- form factor: SDXC
- capacity: 64 GiByte
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approx price, October 2016, 300:-
NAND - flash storage

memory bank
NAND - flash storage

memory bank
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memory bank

erase blocks ~256 KiByte
NAND - flash storage

memory bank

erase blocks ~256 KiByte

pages ~4KiByte
NAND - flash storage

You have constant time access to any page.

memory bank

erase blocks ~256 KiByte

pages ~4KiByte
NAND - flash storage

- You have constant time access to any page.
- You can only write to (or program) an erased page.

memory bank

erase blocks ~256 KiByte

pages ~4KiByte
You have constant time access to any page. You can only write to (or program) an erased page. You can only erase a block.
<table>
<thead>
<tr>
<th>Drive</th>
<th>Capacity</th>
<th>Price</th>
<th>SEK/GiByte</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDD Desktop</td>
<td>2 TiByte</td>
<td>900:-</td>
<td>44 öre</td>
</tr>
<tr>
<td>HDD Performance</td>
<td>600 GiByte</td>
<td>2.200:-</td>
<td>3.70:-</td>
</tr>
<tr>
<td>SSD Desktop</td>
<td>250 GiByte</td>
<td>1000:-</td>
<td>4:-</td>
</tr>
</tbody>
</table>
SATA-III - 6 Gb/s, most internal HDD and SSD today
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aprx price, October 2016, 4.599:-
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aprx price, November 2017, 2.400:-
SSD on the memory bus

HP NVDIMM 8GB

[Image of HP NVDIMM 8GB]
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**aprx price, October 2016, ???**
Next year?

Intel Optane - 3D XPoint NVDIMM
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In the pipeline
Intel Optane - 3D XPoint NVDIMM

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- total capacity: 512 GiByte
Next year?

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Increase capacity, performance and/or reliability

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RAID
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- Multiple disks that can provide:
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RAID

- Multiple disks that can provide:
  - capacity: looks like a 20 TiByte disk but is actually 10 2TiByte disks
  - performance: spread a file across ten drives, read and write in parallel
  - reliability: write the same file to several disks, if one crashes - not a problem
Alternatives:
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the abstraction layer

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- A device driver in the kernel knows that we have several disks but the kernel presents it as one disk to the application layer.
- The application layer knows that we have several disks but provides a API to other applications that looks a single drive.
RAID levels

- RAID 0: *stripe* files across several drives.

- RAID 1: keep a complete mirror copy of each file.

- RAID 2-6: spread a file plus parity information across several drives.
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application layer, simple to understand

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I/O and memory buses, protocols such as SATA, SCSI, USB etc

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Summary

application layer, simple to understand

now it’s a bit structured
I/O and memory buses, protocols suchs as SATA, SCSI, USB etc

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system calls: open, read, write, lseek ...

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