Storage: HDD, SSD and RAID

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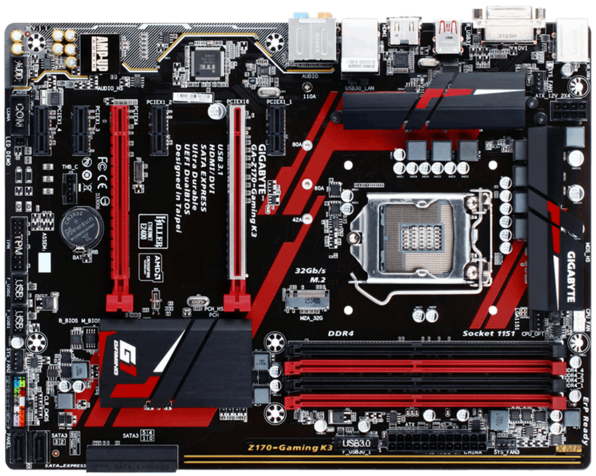
Why?

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

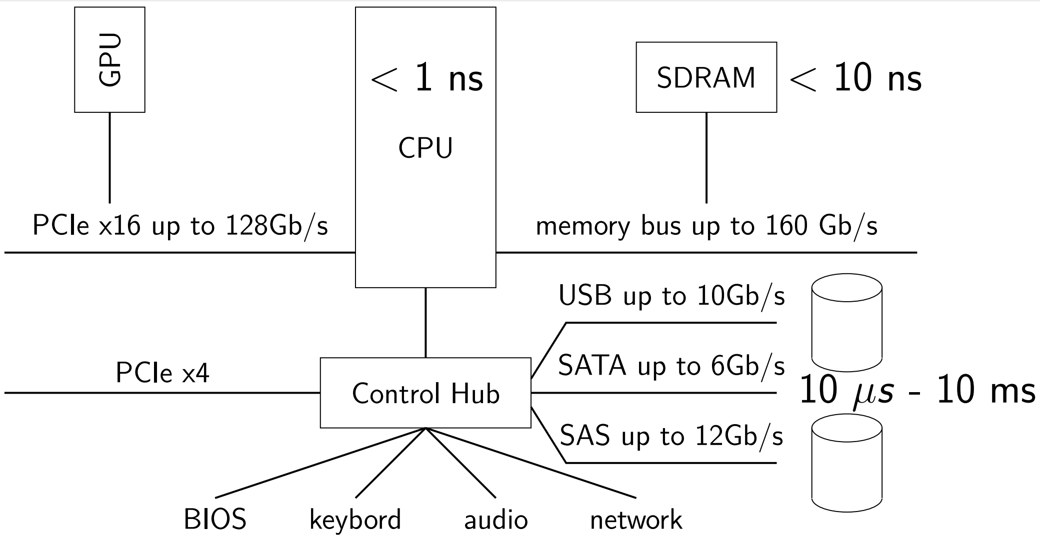
Computer architecture

Gigabyte Z170 Gaming

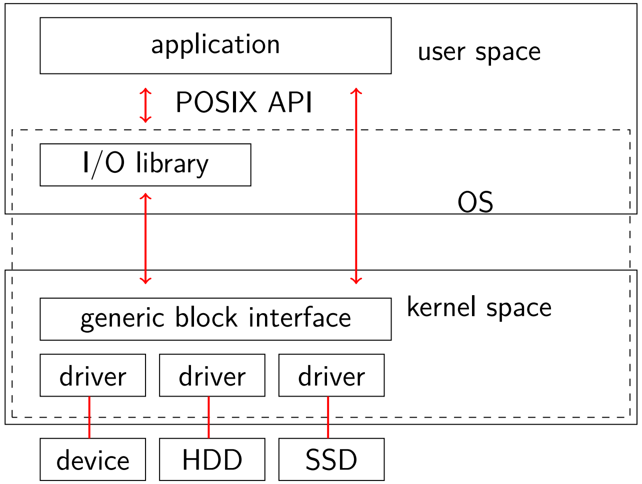


- 2 PCIe x16/x4
- 4 PCIe x1
- 2 USB 3.1
- 6 USB 3.0
- 4 USB 2.0
- 6 SATA-III
- 2 SATA Express
- 1 M.2
- 1 gigabit Ethernet
- 4 DDR4 SDRAM

Computer architecture

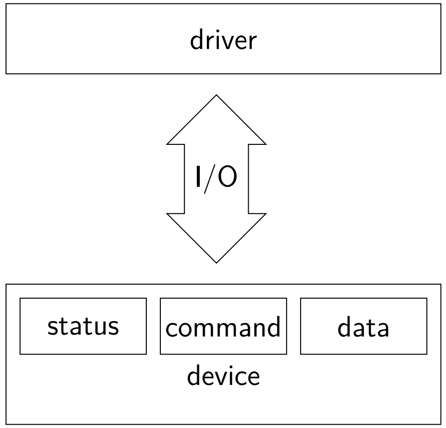


System architecture



70 percent of the code of an operating system is code for device drivers.

how to interact with a 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.

if you have the time

```
char read_from_device() {

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

  COMMAND = READ;

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

  return DATA;

}
```


asynchronous I/O and interrupts

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

  while(STATUS == BUSY) {}

  COMMAND = READ;

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

  block_process(pid);

  scheduler();
}
```

asynchronous I/O and interrupts

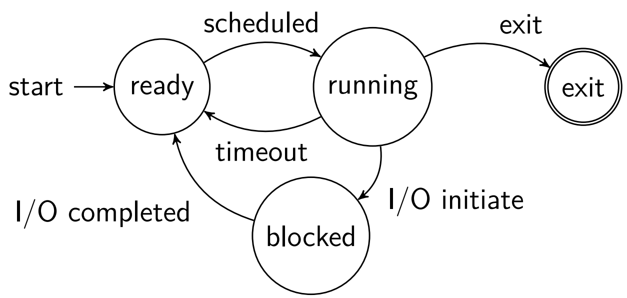
```
int interrupt_handler() {

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

  ready_process(pid);
}
```

This is very schematic, more complicated in real life.

process state



The kernel is interrupt driven.

Direct Memory Access

Allow devices to read and write to buffers in physical memory.

```
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();
}
```


the device driver

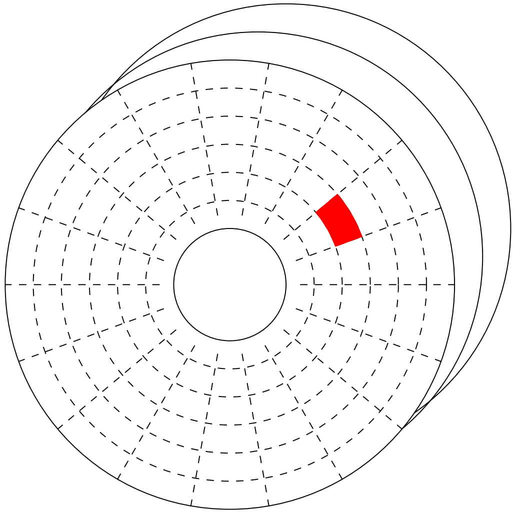
Each physical device is controlled by a *device driver* that provides the abstraction of a *character device* or *block device*.

Block devices used as interface to disk drives that provide persistent storage.

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).

Sector addressing

- Historically sectors address by cylinder-head-sector (CHS), due to incompatibe standars 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

> `sudo fdisk -l` *(to list disks)*
> `sudo sudo hdparm -g /dev/nvme0n1`

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

aprx price, October 2016, 900:-

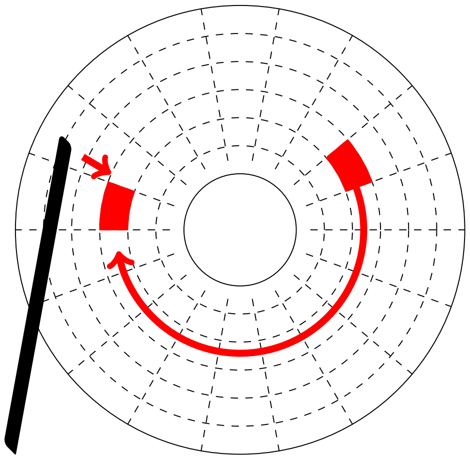
HDD - Hard Disk Drive

Seagate Cheetah 15K

- total capacity: 600 GiByte
- form factor: 3.5"
- rotational speed: 15.000 rpm
- connection: SAS-3
- cache size: 16 MiByte
- read throughput: 204 MByte/s

aprx price, October 2016, 2.200:-, no longer available

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: < 14ms
- capacity: 2 TiByte
- aprx. price: 900:-
- 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: < 6ms
- capacity: 600 GiByte
- aprx. price: 2.200:-
- cost capacity: 3.70 SEK/GiByte

read/write performance

If a sector is 512 bytes, it takes 10ms to find and read a sector, and we want to reaad 512 MiBytes then .....?

- Time to find first sector is less relevant.
- If sectors that belong to the same file are close to each other we minimize movement of arm.
- Rotational speed should be high.
- 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:

- it knew the layout cylinder-head-sector (CHS),
- could order data in segments that were close to each other and,
- would schedule disk operations to minimize arm movement.

Today, the drive can often make a better decission:

- it knows, but might not reveal, the layout.
- The operating system can help in grouping operations togheter, 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.

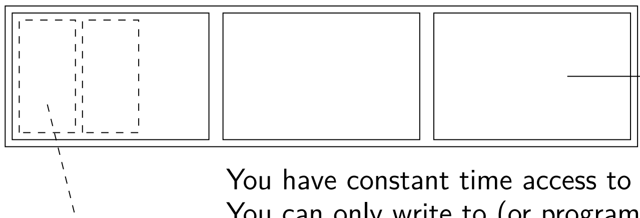
SSD - Solid State Drive

Seagate Firecuda 120

- total capacity: 500 GiByte
- form factor: 2.5"
- connection: SATA III
- random access: 10 μ s
- read throughput: 560 MiByte/s

aprx price, November 2020, 1150:-

NAND - flash storage



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

price performance

Drive	Capacity	Price	SEK/GiByte
HDD Desktop	2 TiByte	900:-	44 öre
SSD Desktop	500 GiByte	1150:-	2.30:-

2018 figures: SSD 2.75:-/GiByte 2016 figures: SSD 4:-/GiByte

SSHD - Hybrid SSD/HDD

Seagate Firecuda - SSHD

- total capacity: 2 TiByte
- form factor: 3.5"
- rotational speed: 7.200 rpm
- connection: SATA-III
- SSD cache: 8 GiByte
- cache size: 64 MiByte
- read throughput: 210 MByte/s

Seagate Firecuda SSHD, aprx price, November 2018, 1.200:-

Bus limitations

- SATA-III - 6 Gb/s, most internal HDD and SSD today
- SAS-3 - 12 Gb/s, enterprise RAID HDD
- USB3.1 - 10 Gb/s, everything
- PCI Express 3.0 x16 - 128 Gb/s, what is it used for?

An SSD has a read througput of 500 MiByte/s which is a .... b/s?

SSD on the PCIe bus

WD BLACK AN1500

- total capacity: 1 TiByte
- connection: PCI Express 3.0 x8
- read performance: 6500 MByte/s
- write performance: 4100 MByte/s
- price : 2900:-

2019 November, Corsair Neutron 400 GB, 3.399:-
2016 October, Intel SSD 400 GB, 4.599:-

The M.2 connector

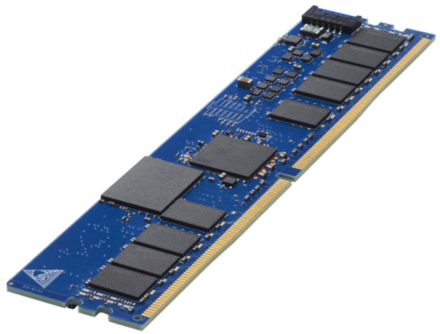
Corsair MP 400 1TB

- total capacity: 1 TiB
- form factor: M.2-
- connection: PCI Express 3.0 x4
- read performance: 3480 MByte/s
- write performance: 1880 MByte/s
- price: 1500:-

November 2019, Samsung 512 GB, 1.890:-
November 2018, Samsung 512 GB, 2.890:-

SSD on the memory bus

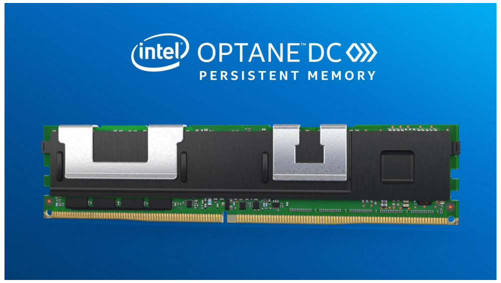
HP NVDIMM 16GB



- regular DRAM backued up by Flash
- total capacity: 16 GiByte
- form factor: DDR4 SDIM
- bus speed: 2666 MT/s
- price: aprx 8000:-

Yes!

Intel Optane DC NVDIMM 512GB



- total capacity: 512 GiByte
- price: 7.900 USD

Increase capcity, performance and/or reliability

Redundant Array of Independet Disks
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 parallell
- reliability: write the same file to several disks, if one crashes - not a problem

the abstraction layer

Alternatives:

- The cabinet that holds the disks present itself as one drive.
- 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.

Summary

application layer, simple to understand

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

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all devices have a generic API
device drivers that know what they are doing

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

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hardware - a complete mess