# Storage: HDD, SSD and RAID

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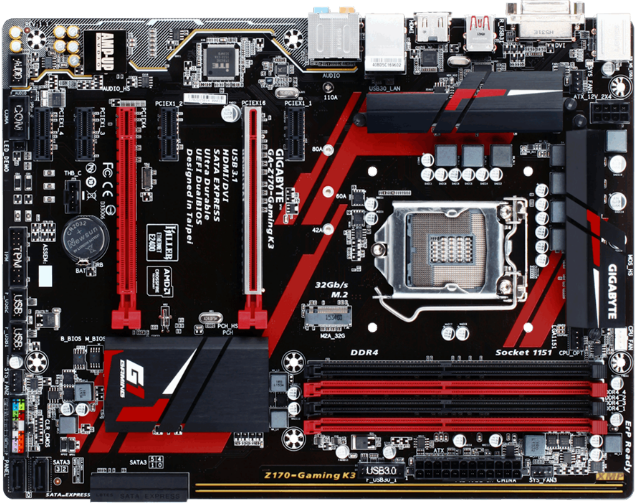
# Why?

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

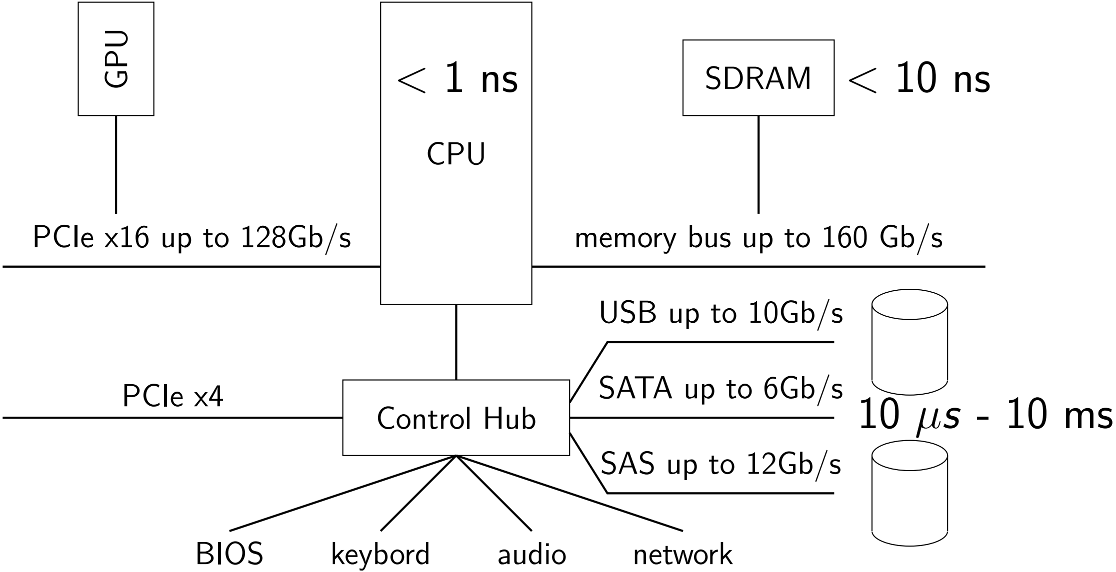
# Computer architecture

## Gigabyte Z170 Gaming

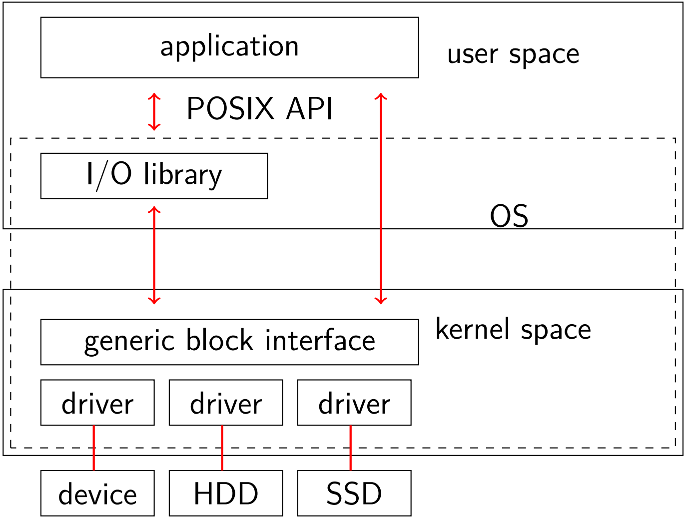



- 2 PCIe x16/x4
- 4 PCIe x1
- 2 USB 3.1
- 6 USB 3.0
- 4 USB 2.0
- 6 SATA-III
- 2 SATA Express
- 1 M.2
- 1 gigabit Ethernet
- 4 DDR4 SDRAM

# Computer architecture

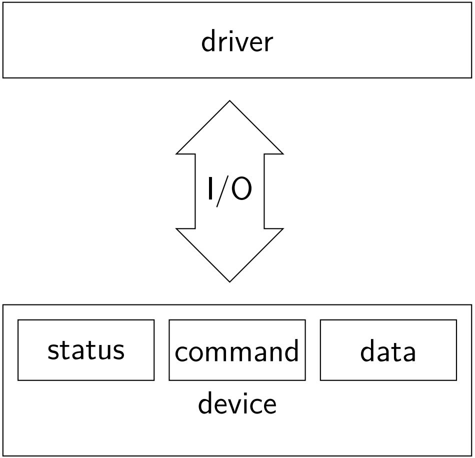


# System architecture




*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

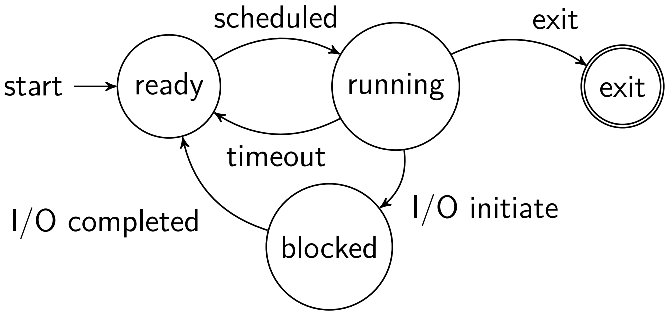
```
int interrupt_handler() {

  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

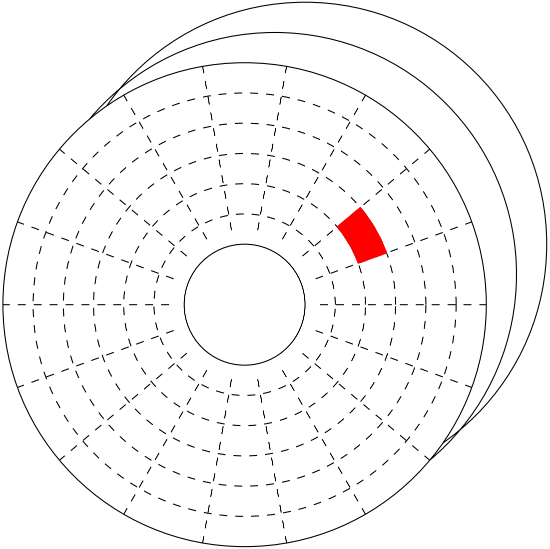
Each physical device is controlled by a *device driver* that provides the abstraction of a *character device* or *block device*.

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:-*

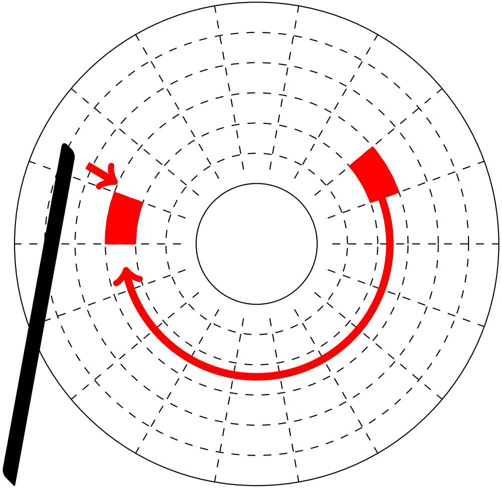
# HDD - Hard Disk Drive

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.*

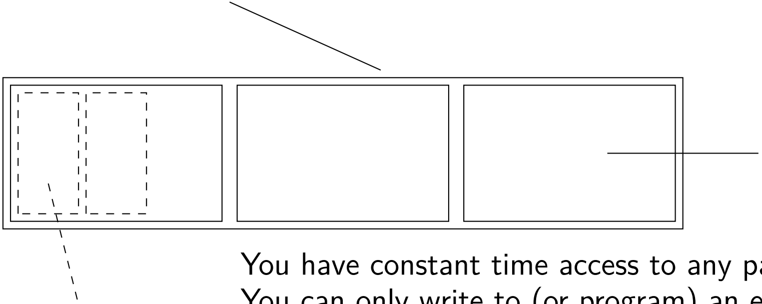
# SSD - Solid State Drive

Seagate Firecuda 120


- total capacity: 500 GiByte
- form factor: 2.5"
- connection: SATA III
- random access: 10 $\mu$ 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

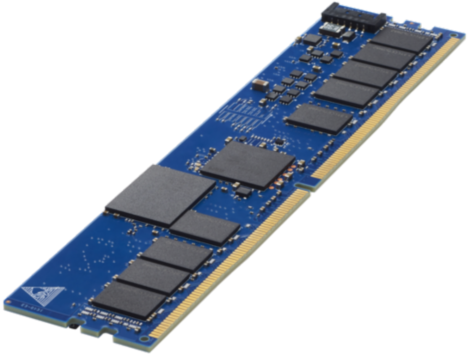
Corsair MP 400 1TB


- 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

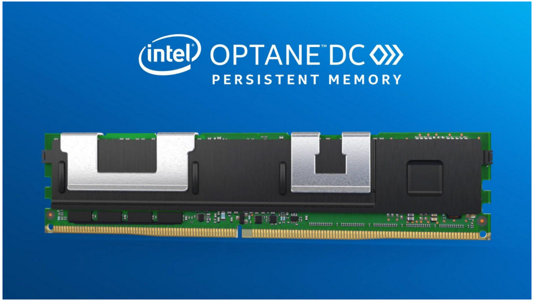
HP NVDIMM 16GB



- 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