Storage: HDD, SSD and RAID

Johan Montelius

KTH

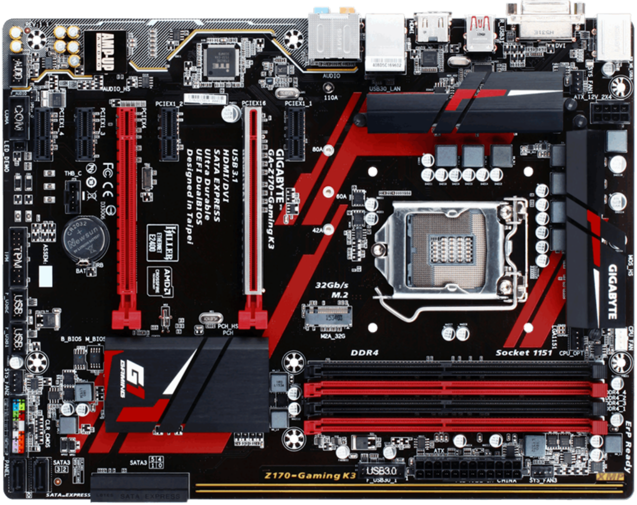
2021

Why?

Why?

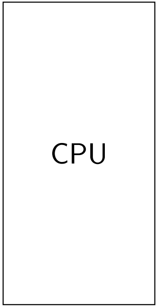
Give me two reasons why we would like to have secondary storage?

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



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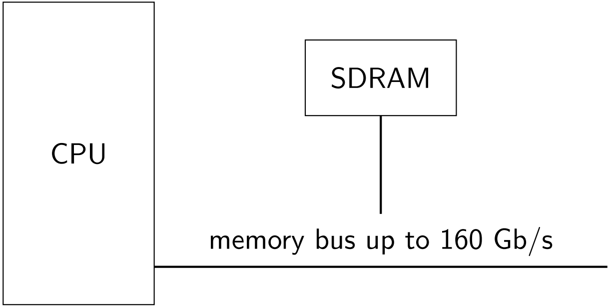

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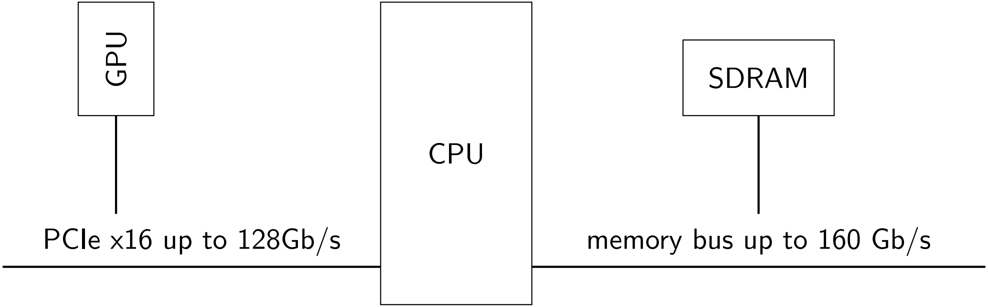

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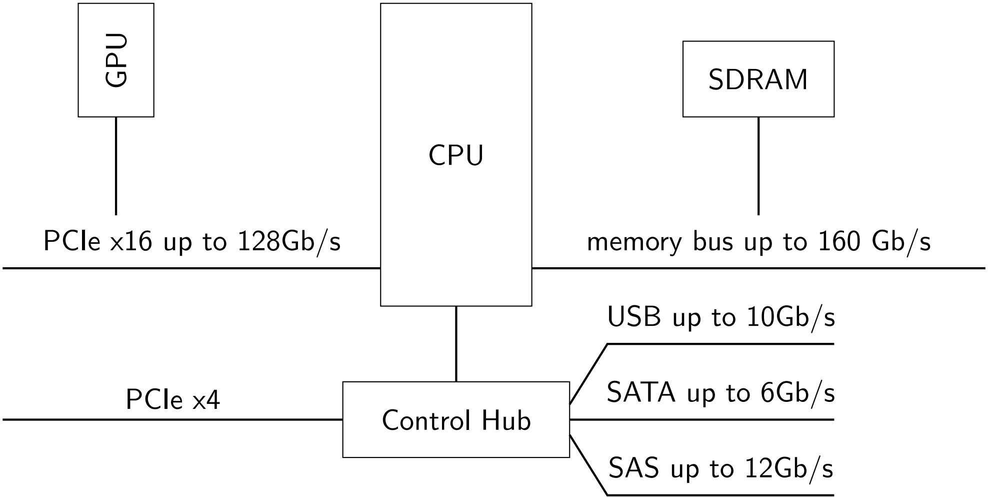

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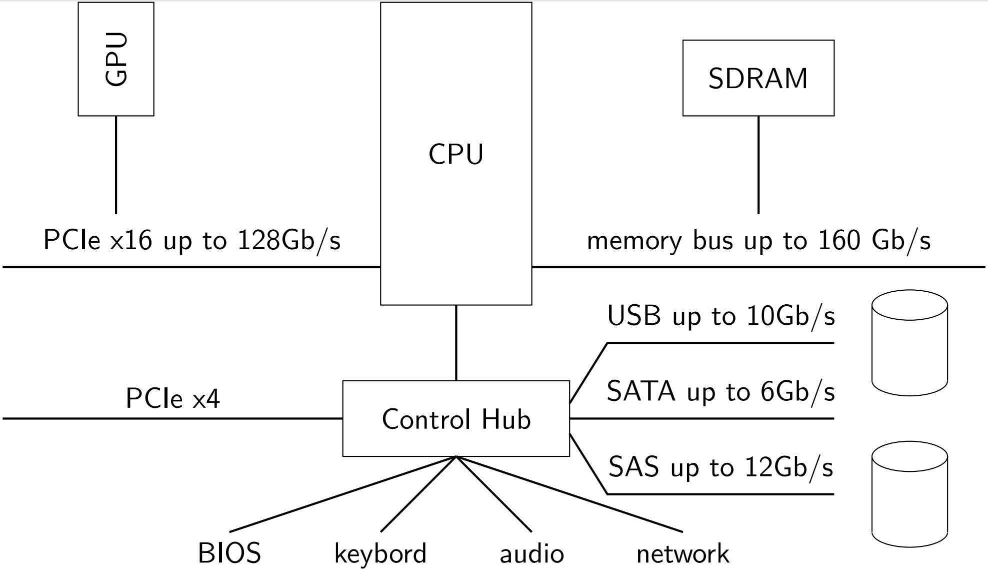

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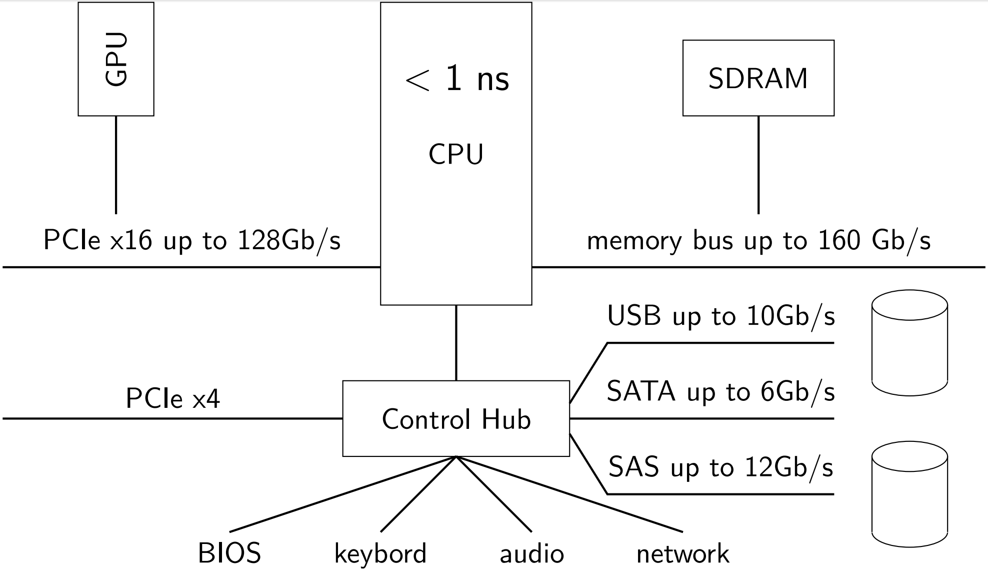

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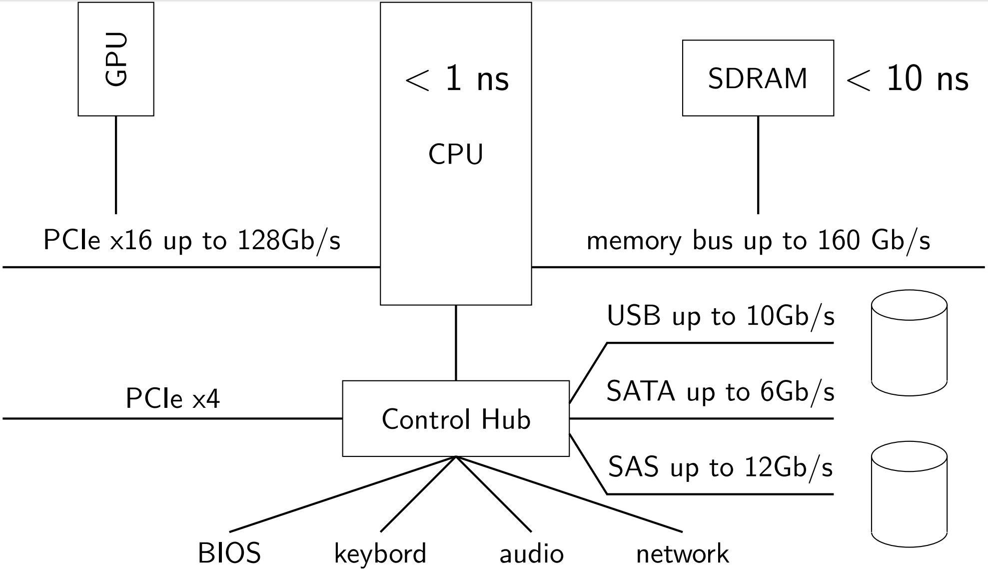

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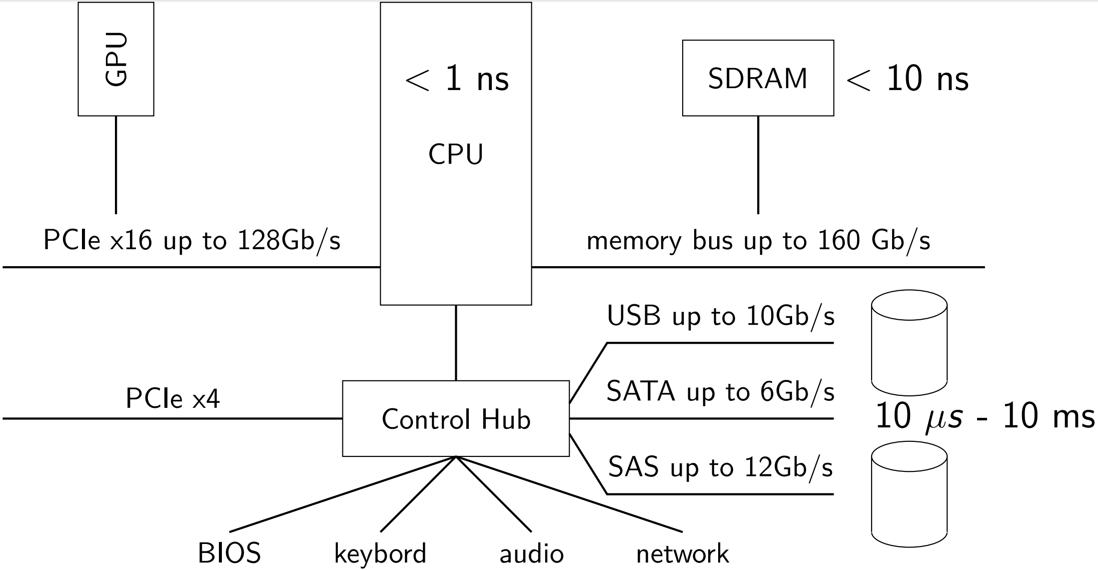

System architecture

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

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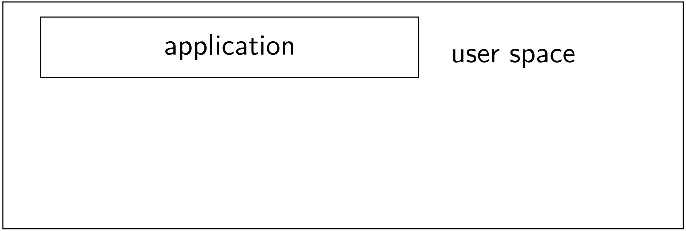

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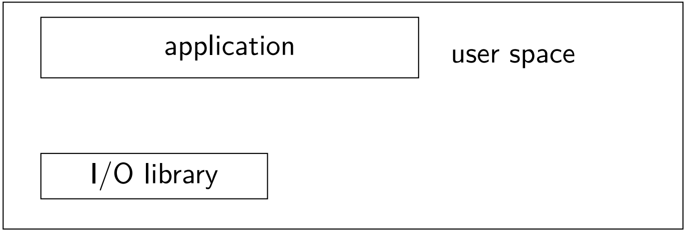

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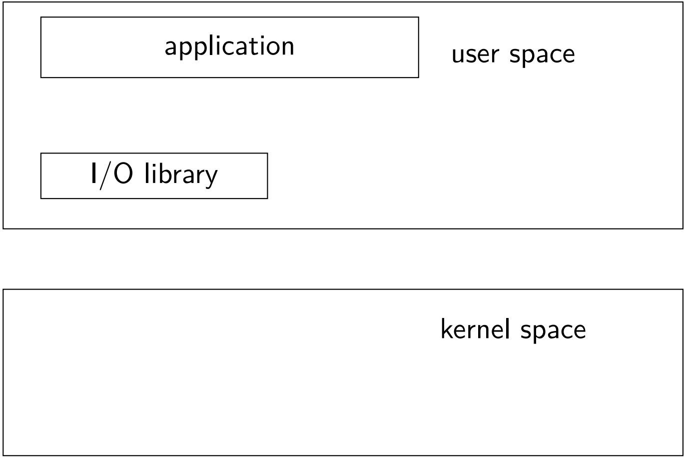

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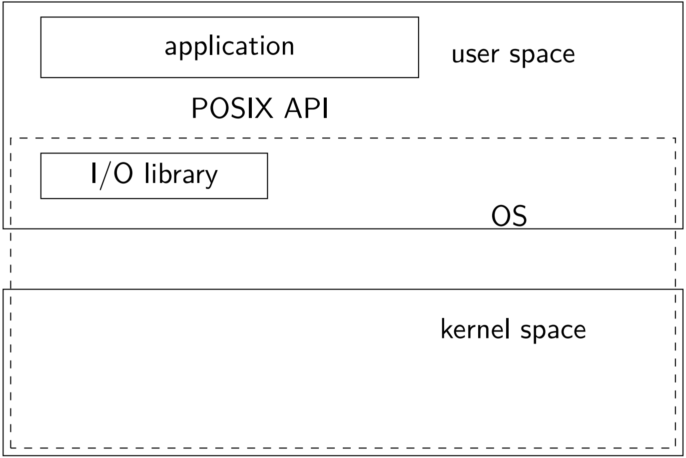

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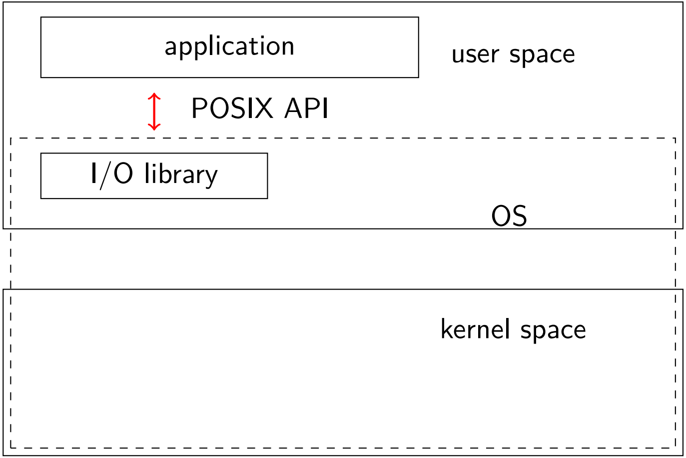

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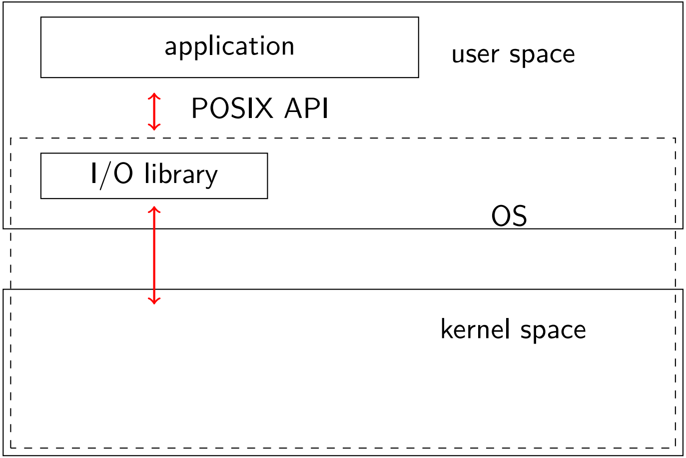

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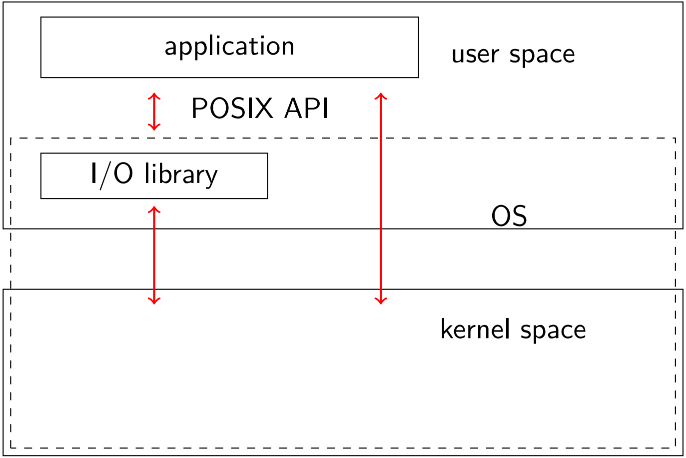

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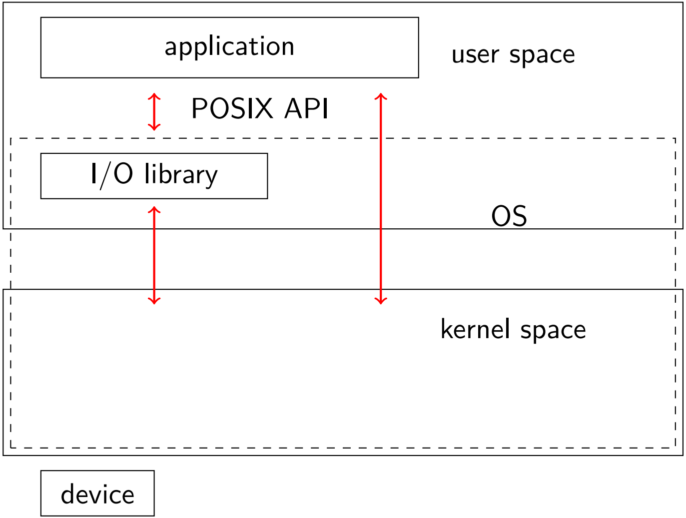

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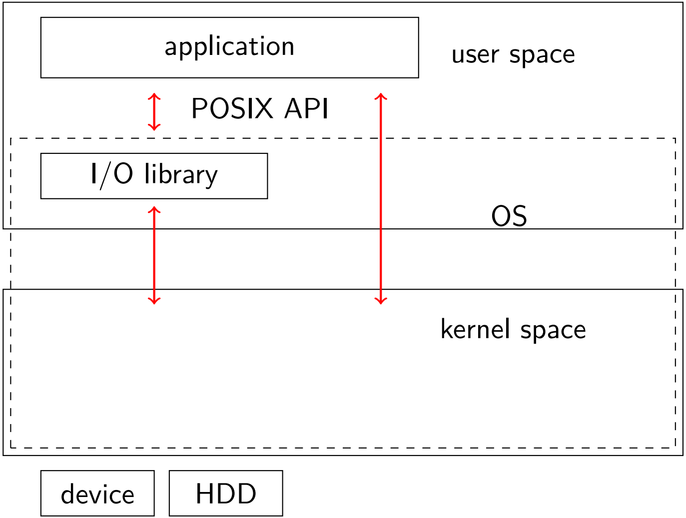

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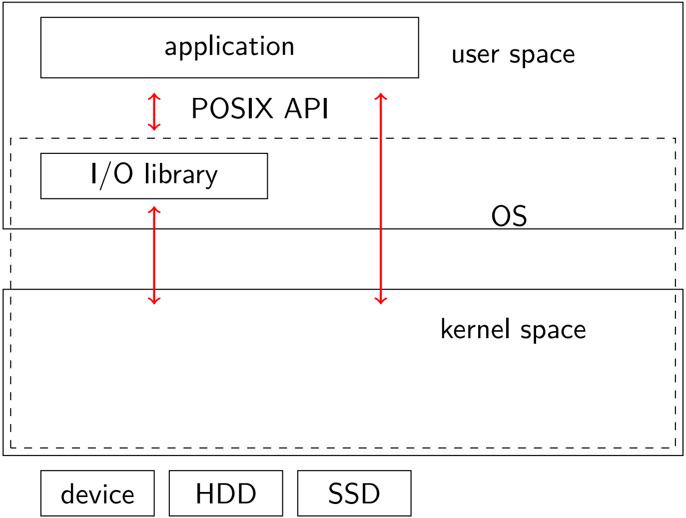

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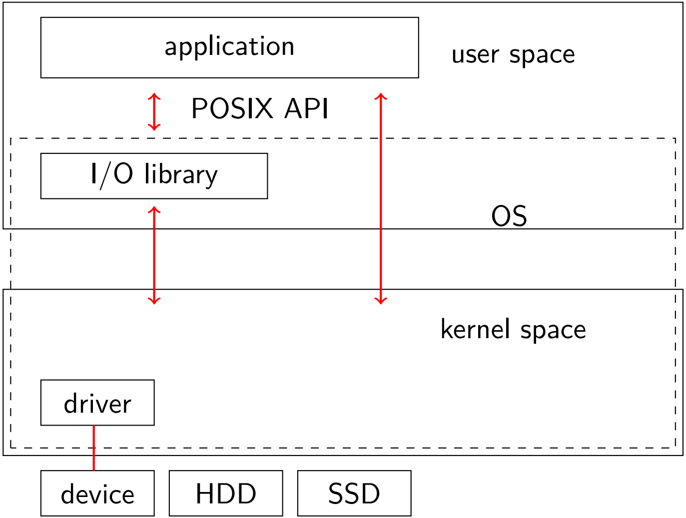

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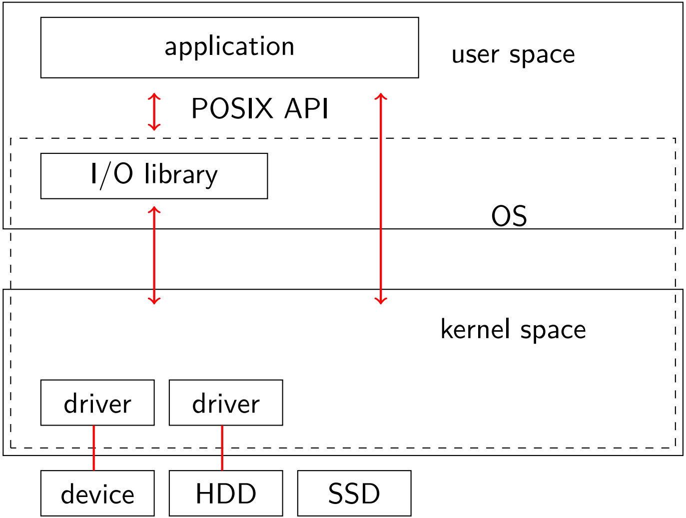

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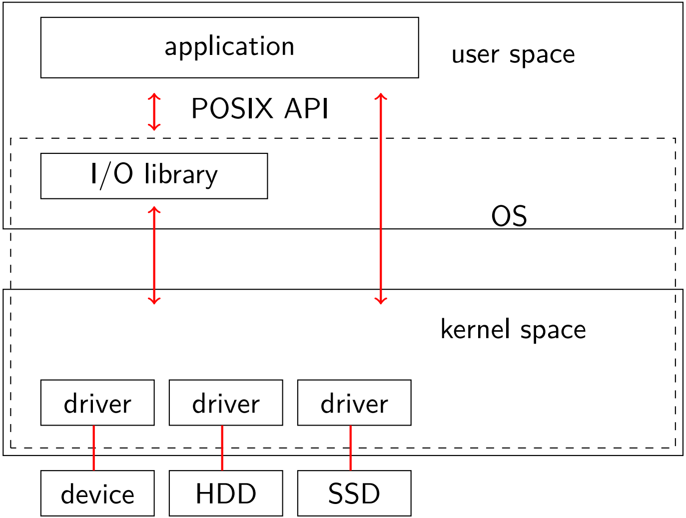

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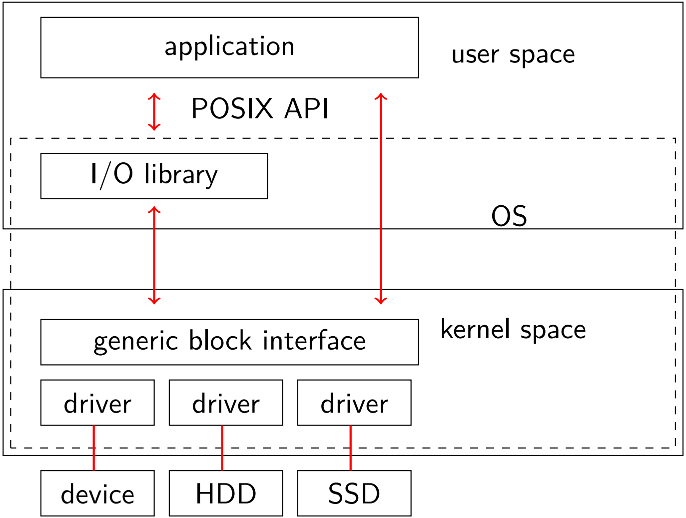

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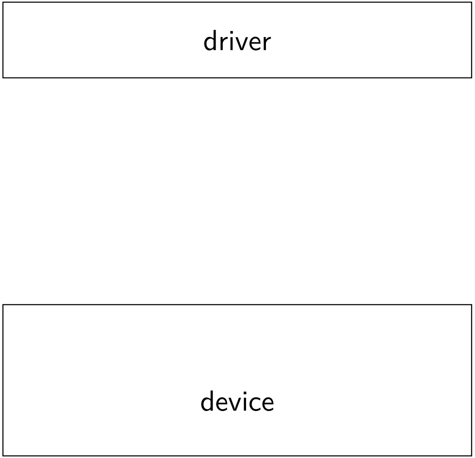
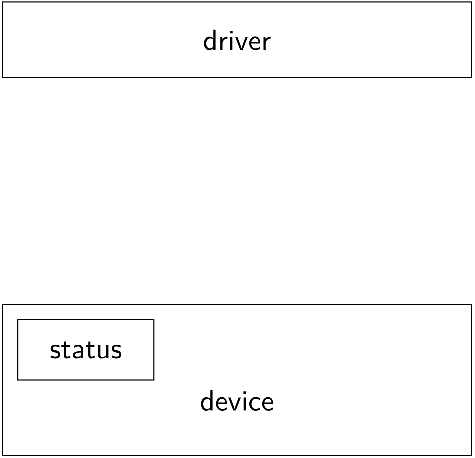
how to interact with a device





- A register to read the status of the device.

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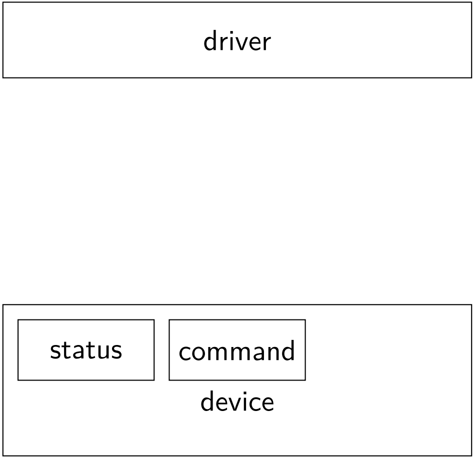

- A register to read the status of the device.
- A register to instruct the device to read or write.

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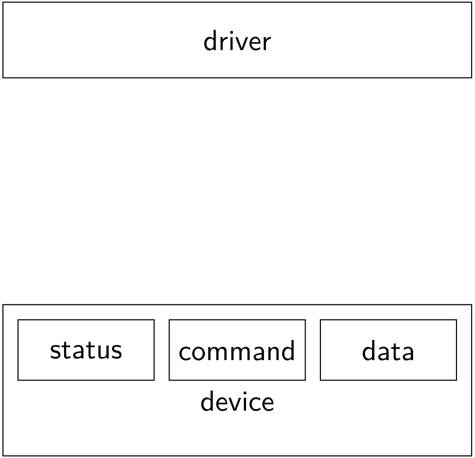

- A register to read the status of the device.
- A register to instruct the device to read or write.
- A register that holds the data.

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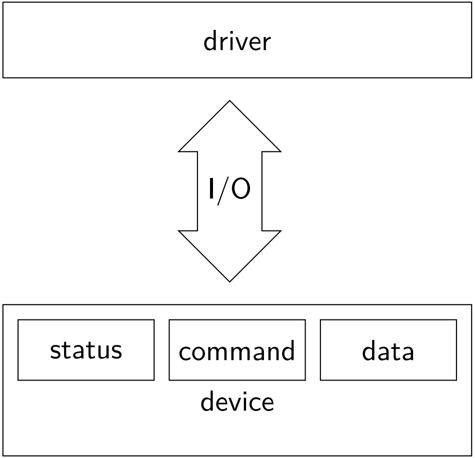

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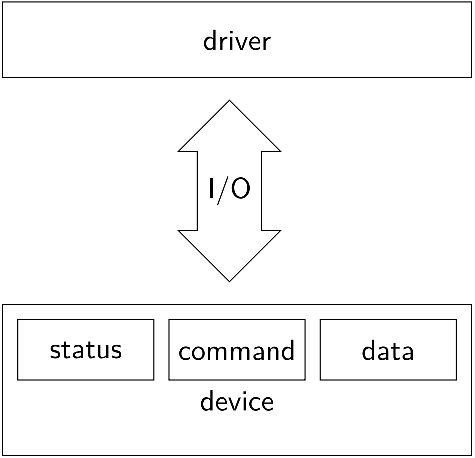

- A register to read the status of the device.
- A register to instruct the device to read or write.
- A register that holds the data.
- I/O-bus could be separate from memory bus (or the same).
- The driver will use either special I/O instructions or regular load/store instructions.

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);
}
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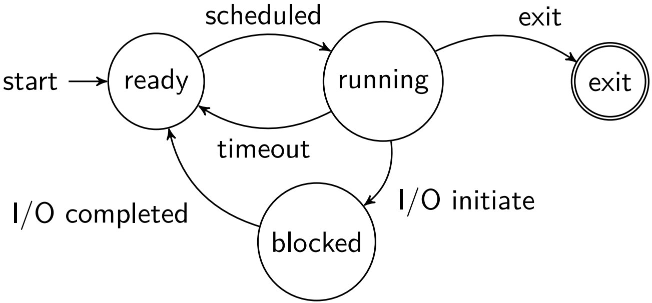
This is very schematic, more complicated in real life.

process state



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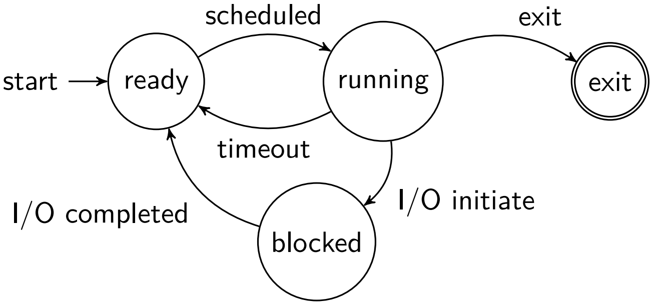

The kernel is interrupt driven.

Direct Memory Access

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

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```
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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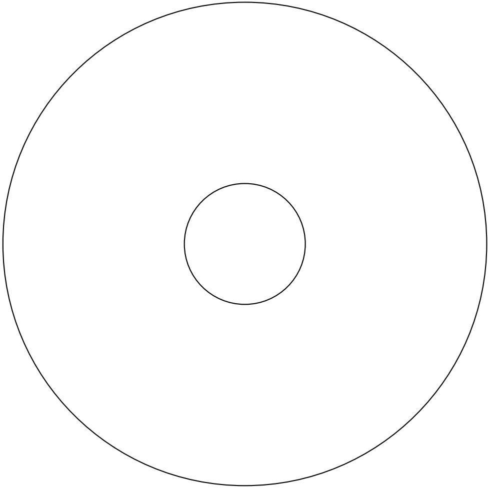
To understand the challenges and options of the operating system, you should know the basics of how storage devices work.

Anatomy of a HDD



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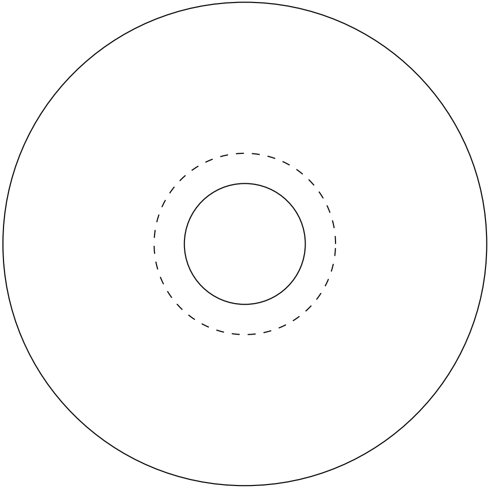

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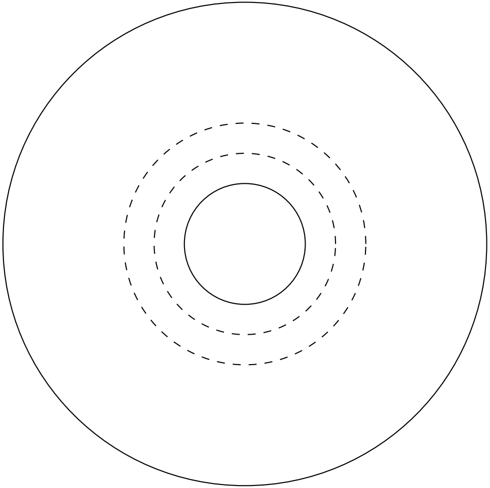

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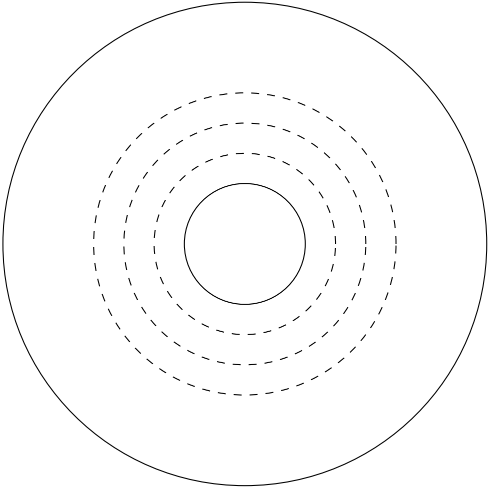

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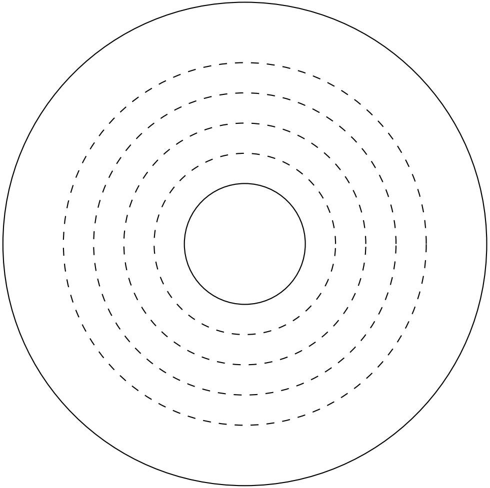

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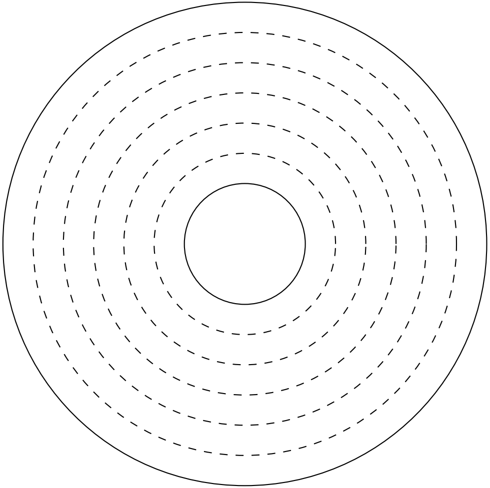

- track/cylinder

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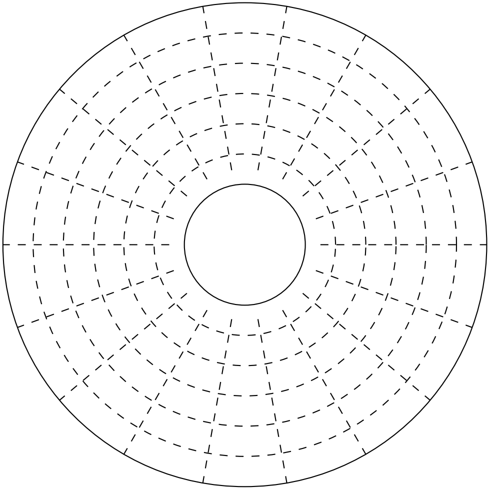

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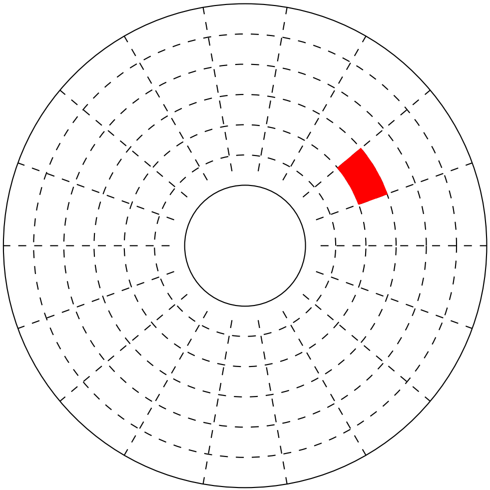

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- sectors per track varies
- sector size: 4K or 512 bytes

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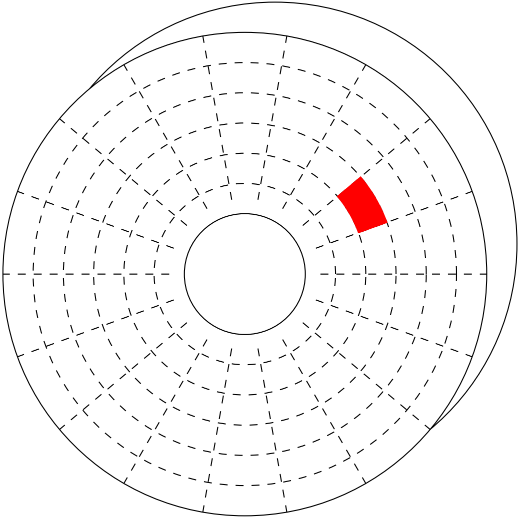

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- heads: one side or two sides

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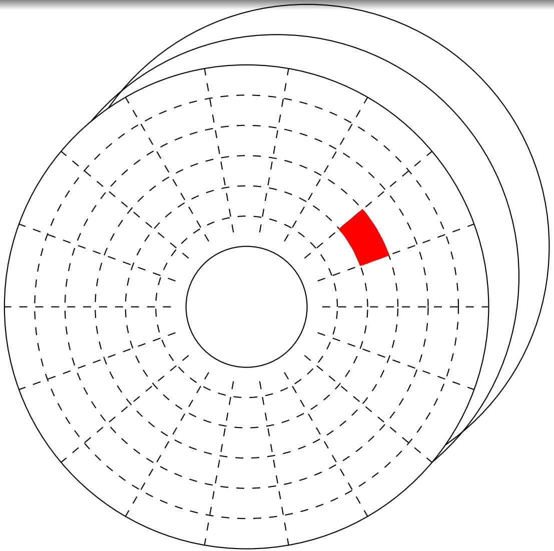

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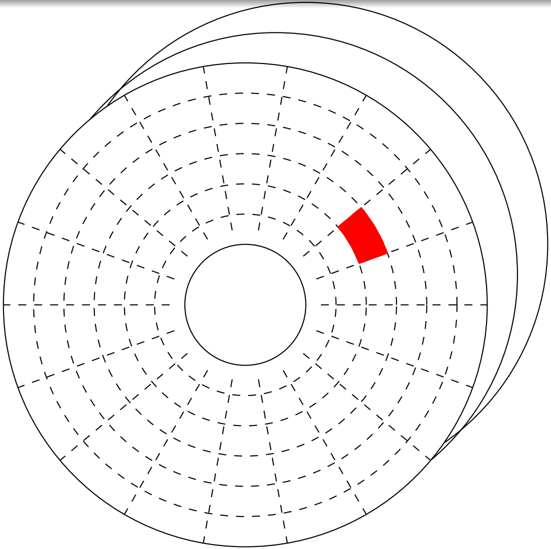

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Only one head at a time is used (no parallel read).

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  - 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

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aprx price, October 2016, 900:-

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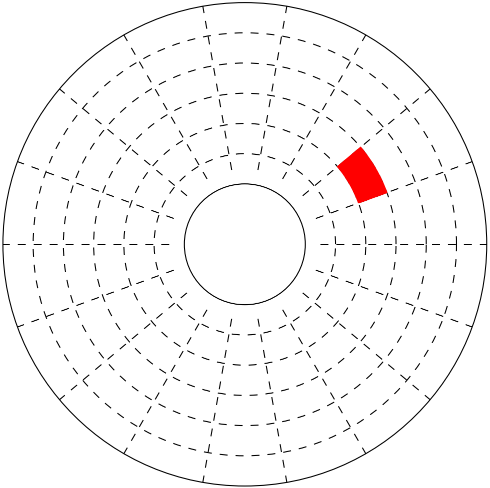
aprx price, October 2016, 2.200:-, no longer available

access time



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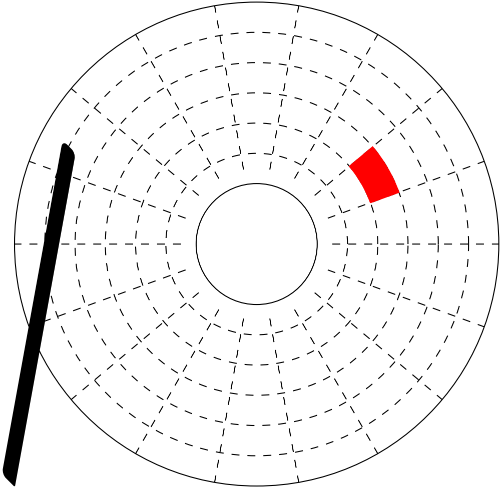
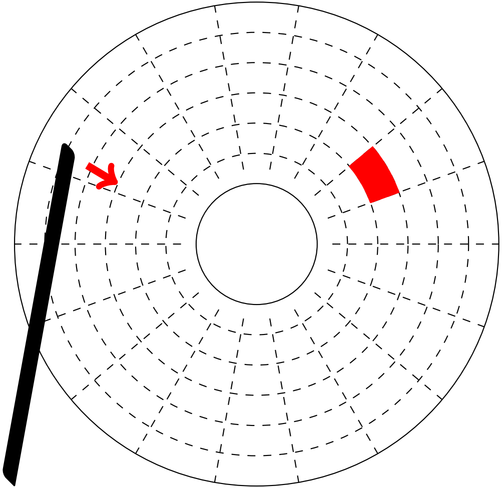


access time



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

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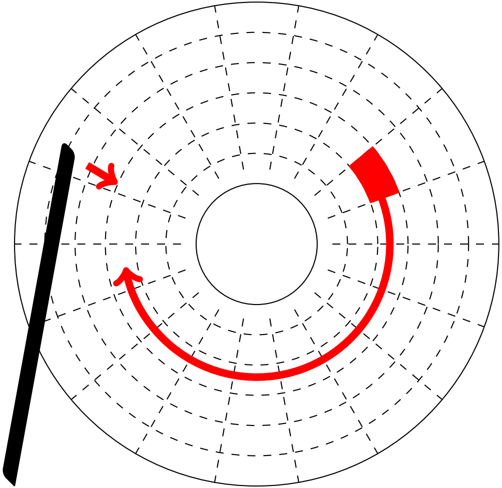
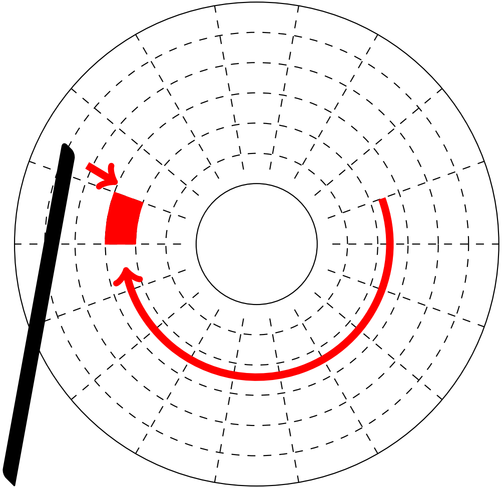


- seek time: time to move arm to the right cylinder
- rotation time: time to rotate the disk

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
- Seagate Cheeta 15K

HDD - shoot out

- Seagate Desktop
- rotation speed: 7200 rpm

- Seagate Cheeta 15K
- rotation speed: 15000 rpm

HDD - shoot out

- Seagate Desktop
- rotation speed: 7200 rpm
- average seek time: < 10 ms
- average rotation time: 4 ms

- Seagate Cheeta 15K
- rotation speed: 15000 rpm
- average seek time: < 4 ms
- average rotation time: 2 ms

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

- Seagate Cheeta 15K
- rotation speed: 15000 rpm
- average seek time: < 4 ms
- average rotation time: 2 ms

HDD - shoot out

- Seagate Desktop
- rotation speed: 7200 rpm
- average seek time: $<$ 10 ms
- average rotation time: 4 ms
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HDD - shoot out

- Seagate Desktop
- rotation speed: 7200 rpm
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- average rotation time: 4 ms
- average time to read a sector: $<$ 14ms
- capacity: 2 TiByte

- 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

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:-

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- average rotation time: 2 ms
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- 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

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- 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
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- 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),

who's in control

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There is a reason why MS-DOS is called MS-DOS.

Seagate Firecuda 120

- total capacity: 500 GiByte

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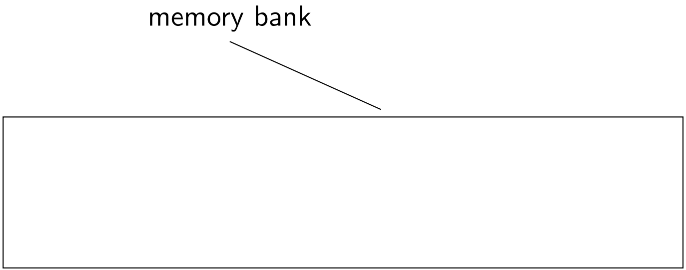
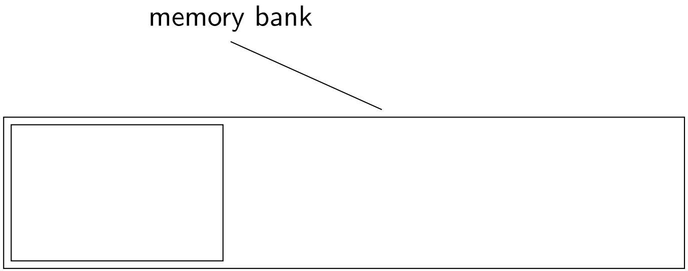
aprx price, November 2020, 1150:-

NAND - flash storage



NAND - flash storage



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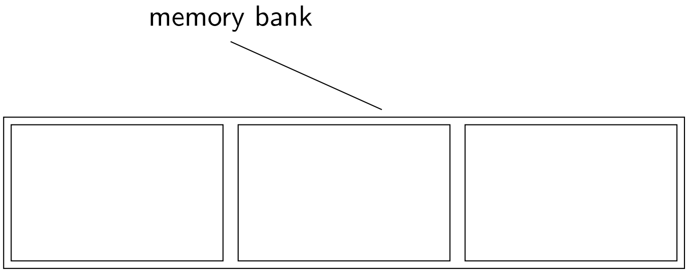

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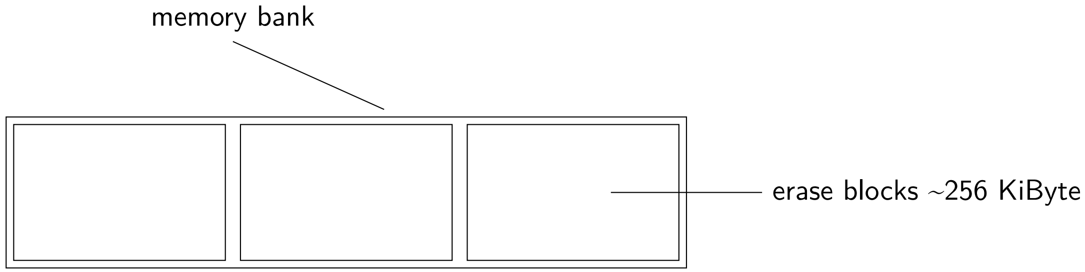

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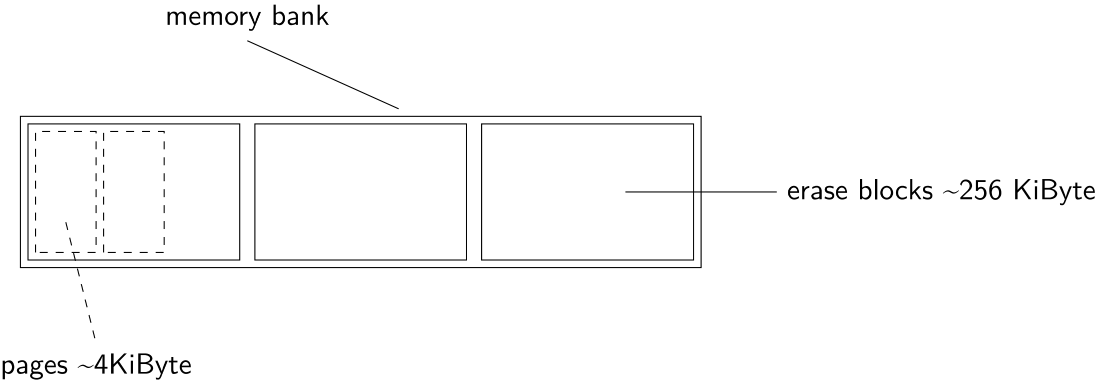

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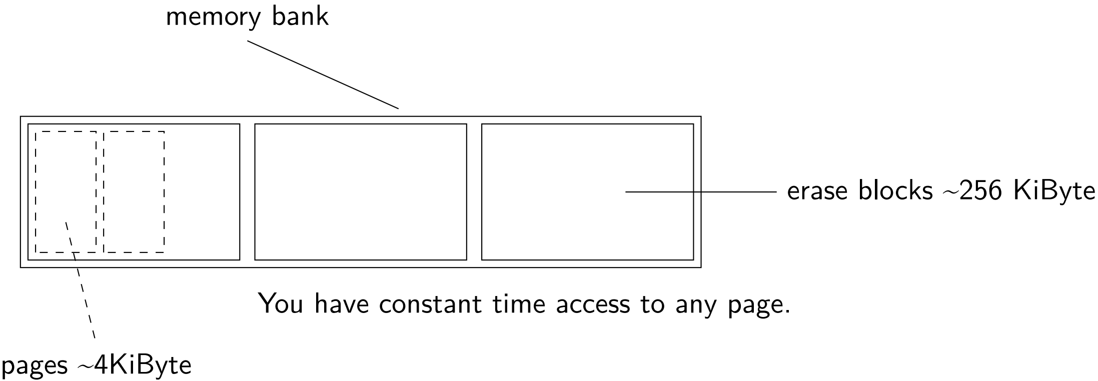
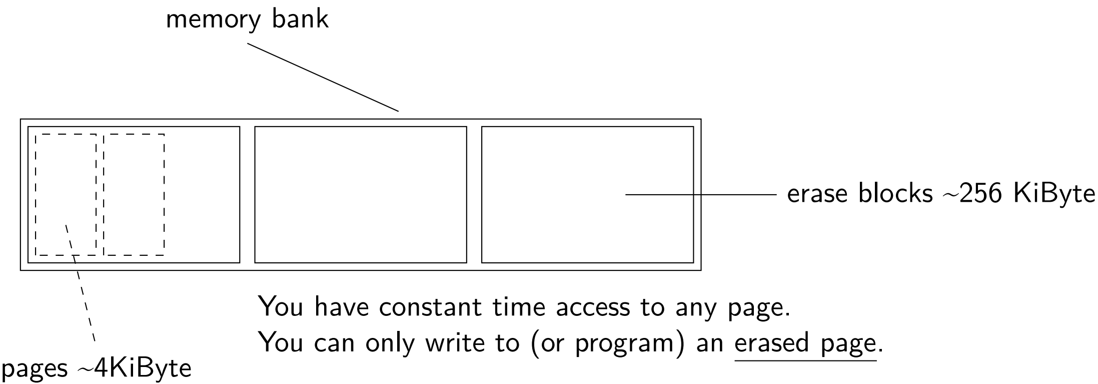


You have constant time access to any page.

NAND - flash storage



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

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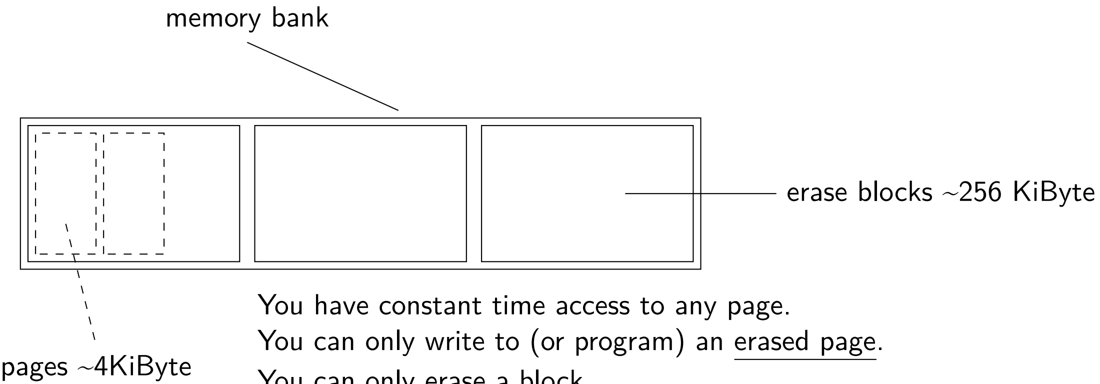

You have constant time access to any page.
You can only write to (or program) an erased page.
You can only erase a block.

price performance

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

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2018 figures: SSD 2.75:-/GiByte

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

Bus limitations

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- PCI Express 3.0 x16 - 128 Gb/s, what is it used for?

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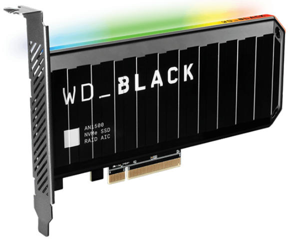
- USB3.1 - 10 Gb/s, everything
- PCI Express 3.0 x16 - 128 Gb/s, what is it used for?

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

SSD on the PCIe bus

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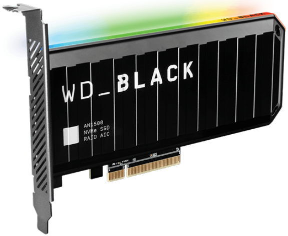

- total capacity: 1 TiByte
- connection: PCI Express 3.0 x8

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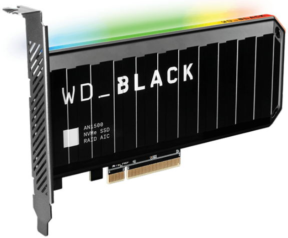

- total capacity: 1 TiByte
- connection: PCI Express 3.0 x8
- read performance: 6500 MByte/s

SSD on the PCIe bus

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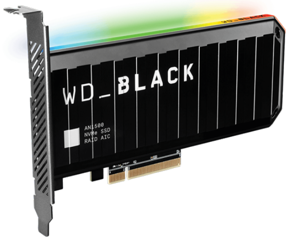

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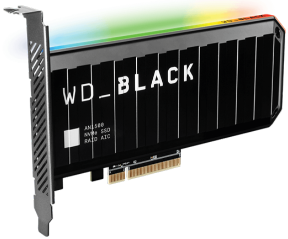

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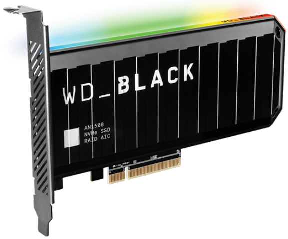

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2019 November, Corsair Neutron 400 GB, 3.399:-
2016 October, Intel SSD 400 GB, 4.599:-

The M.2 connector

Corsair MP 400 1TB

- total capacity: 1 TiB

The M.2 connector

Corsair MP 400 1TB

- total capacity: 1 TiB
- form factor: M.2-

The M.2 connector

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Corsair MP 400 1TB

- total capacity: 1 TiB
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- read performance: 3480 MByte/s

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Corsair MP 400 1TB

- total capacity: 1 TiB
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The M.2 connector

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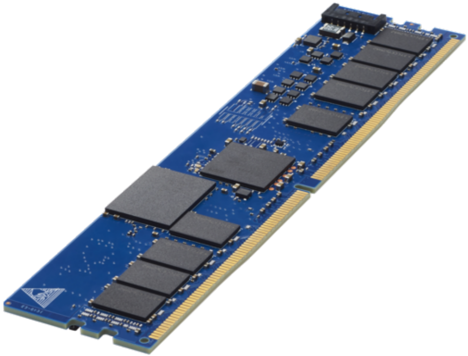
November 2019, Samsung 512 GB, 1.890:-
November 2018, Samsung 512 GB, 2.890:-

SSD on the memory bus

HP NVDIMM 16GB



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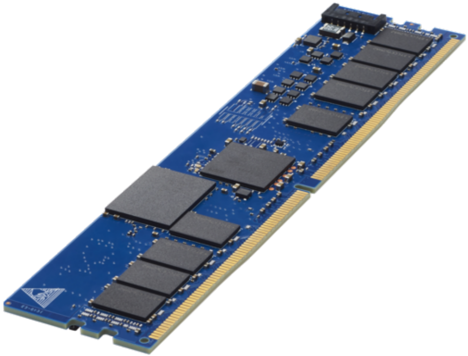

- regular DRAM backued up by Flash

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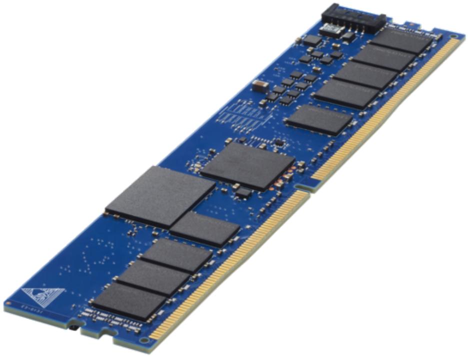

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- total capacity: 16 GiByte

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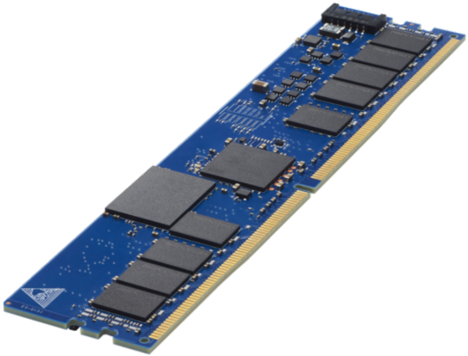

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- form factor: DDR4 SDIM

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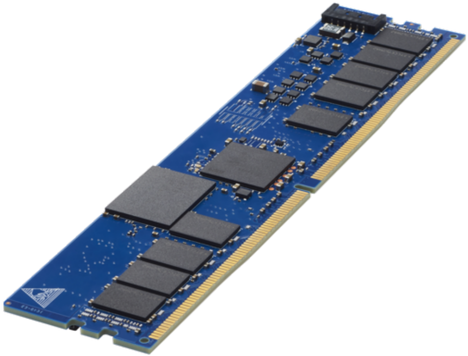

- regular DRAM backued up by Flash
- total capacity: 16 GiByte
- form factor: DDR4 SDIM
- bus speed: 2666 MT/s

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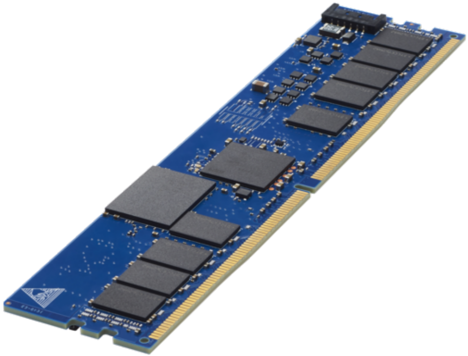

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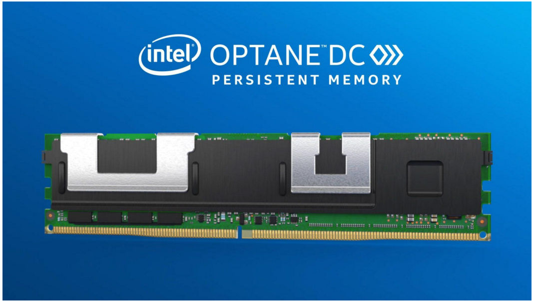
- bus speed: 2666 MT/s
- price: aprx 8000:-

Yes!

Intel Optane DC NVDIMM 512GB



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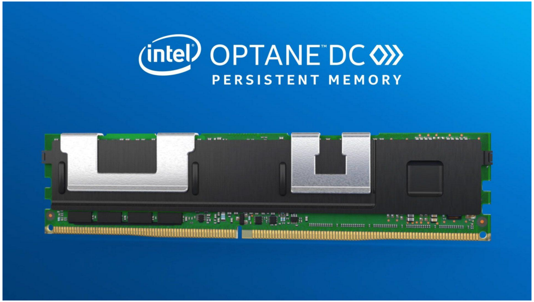

- total capacity: 512 GiByte

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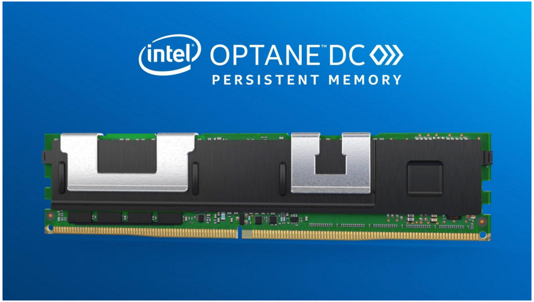

- total capacity: 512 GiByte
- price: 7.900 USD

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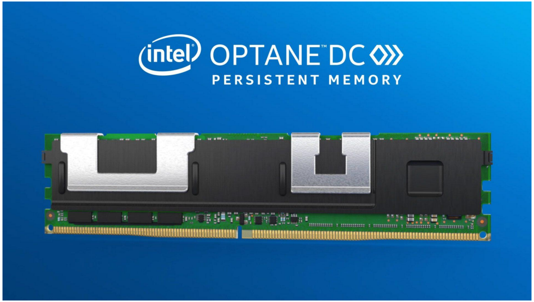
Intel Optane DC NVDIMM 512GB



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Redundant Array of Independet Disks
RAID

Increase capcity, performance and/or reliability

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RAID

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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

Alternatives:

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

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 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

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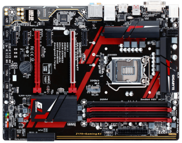
- RAID 1: keep a complete *mirror copy* of each file.
- RAID 2-6: spread a file plus parity information across several drives.

Summary

application layer, simple to understand

hardware - a complete mess

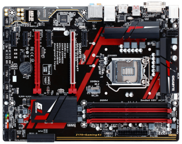


Summary

application layer, simple to understand

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

hardware - a complete mess





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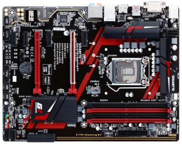

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device drivers that know what they are doing

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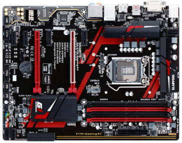



Summary

application layer, simple to understand

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all devices have a generic API

device drivers that know what they are doing

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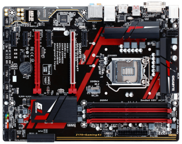

Summary

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