

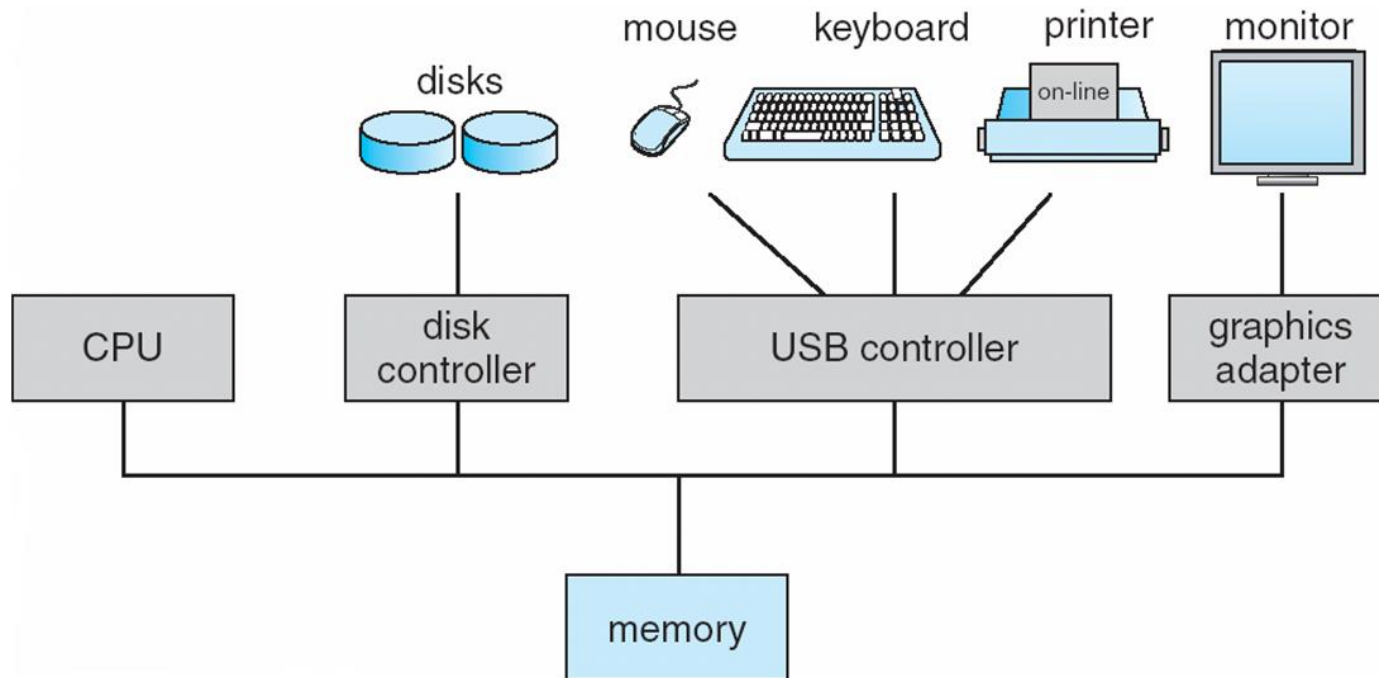
I/O

Disclaimer: some slides are adopted from book authors' slides with permission

Concepts to Learn

- I/O subsystems
- Blocking, non-blocking, asynchronous I/O
- Memory-mapped I/O
- Programmed I/O vs. DMA
- Disk

Input/output (I/O) Subsystems



I/O Subsystems: the Goal

- Provide easy to use **standardized** interfaces

- This code works for many different devices

```
int fd = open("/dev/somedev", O_RDWR);
char buf[80];
for (int i = 0; i < 10; i++) {
    sprintf(buf, "i: %d\n", i);
    write(fd, buf, 80);
}
close(fd);
```

- Hide the details of each device to users

Standard Device Types

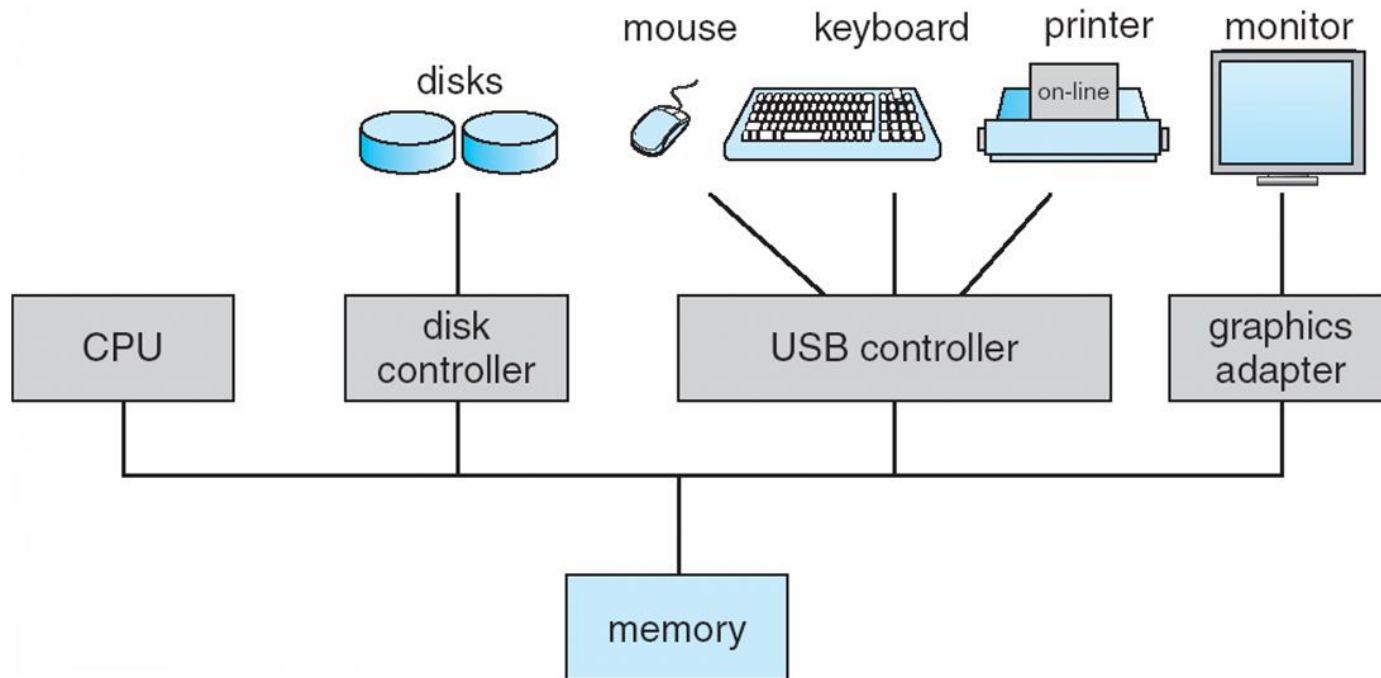
- Block devices
 - E.g., disk, cd-rom, USB stick
 - High speed, block (sector) level accesses
- Character devices
 - E.g., keyboard, mouse, joystick
 - Low speed, character level accesses
- Network devices
 - E.g., ethernet, wifi, bluetooth
 - Socket interface

Types of I/O Operations

- Blocking I/O
 - Wait (i.e., the calling process is put to sleep) until the data is ready
- Non-blocking I/O
 - Immediately return to the caller no matter what.
 - I/O may not be completed
- Asynchronous I/O
 - Notify later when the I/O is completed (via callback or interrupts)

How Does CPU Talk to Devices?

- CPU talks to device controllers
 - Via I/O instructions or **memory mapped I/O**



Memory Mapped I/O

Base Address	Limit Address	Size	Description
0x0000_0000	0x0001_0000	64 KB	iROM
0x0200_0000	0x0201_0000	64 KB	iROM (mirror of 0x0 to 0x10000)
0x0202_0000	0x0206_0000	256 KB	iRAM
0x0300_0000	0x0302_0000	128 KB	Data memory or general purpose of Samsung Reconfigurable Processor SRP.
0x0302_0000	0x0303_0000	64 KB	I-cache or general purpose of SRP.
0x0303_0000	0x0303_9000	36 KB	Configuration memory (write only) of SRP
0x0381_0000	0x0383_0000	–	AudioSS's SFR region
0x0400_0000	0x0500_0000	16 MB	Bank0 of Static Read Only Memory Controller (SMC) (16-bit only)
0x0500_0000	0x0600_0000	16 MB	Bank1 of SMC
0x0600_0000	0x0700_0000	16 MB	Bank2 of SMC
0x0700_0000	0x0800_0000	16 MB	Bank3 of SMC
0x0800_0000	0x0C00_0000	64 MB	Reserved
0x0C00_0000	0x0CD0_0000	–	Reserved
0x0CE0_0000	0x0D00_0000	–	SFR region of Nand Flash Controller (NFCN)
0x1000_0000	0x1400_0000	–	SFR region
USB, SD/MMC, Timer, ...			
0x4000_0000	0xA000_0000	1.5 GB	Memory of Dynamic Memory Controller (DMC)-0
0xA000_0000	0x0000_0000	1.5 GB	Memory of DMC-1
DRAM			

Samsung Exynos 4412 (ARM) Processor **Physical** Address Map

Memory Mapped I/O

- Parts of physical memory space are mapped to hardware controllers
 - Mapped to control registers and buffers
- Reading/writing from/to the memory mapped regions in device specific ways
 - Device drivers' job

Example

```
#define CTRL_BASE_ADDR 0xCE000000
```

```
int *io_base = (int *)ioremap_nocache(CTRL_BASE_ADDR, 4096);
```

```
// initialize the device (by writing some values to h/w regs)
```

```
*io_base = 0x1;
```

```
*(io_base + 1) = 0x2;
```

```
*(io_base + 2) = 0x3;
```

```
...
```

```
// wait until the device is ready (bit31 = 0)
```

```
while (*io_base & 0x80000000);
```

```
// send data to the device
```

```
for (i = 0; i < sizeof(buffer); i++) {
```

```
    *(io_base + 0x10) = buffer[i];
```

```
    while (*io_base & 0x80000000);
```

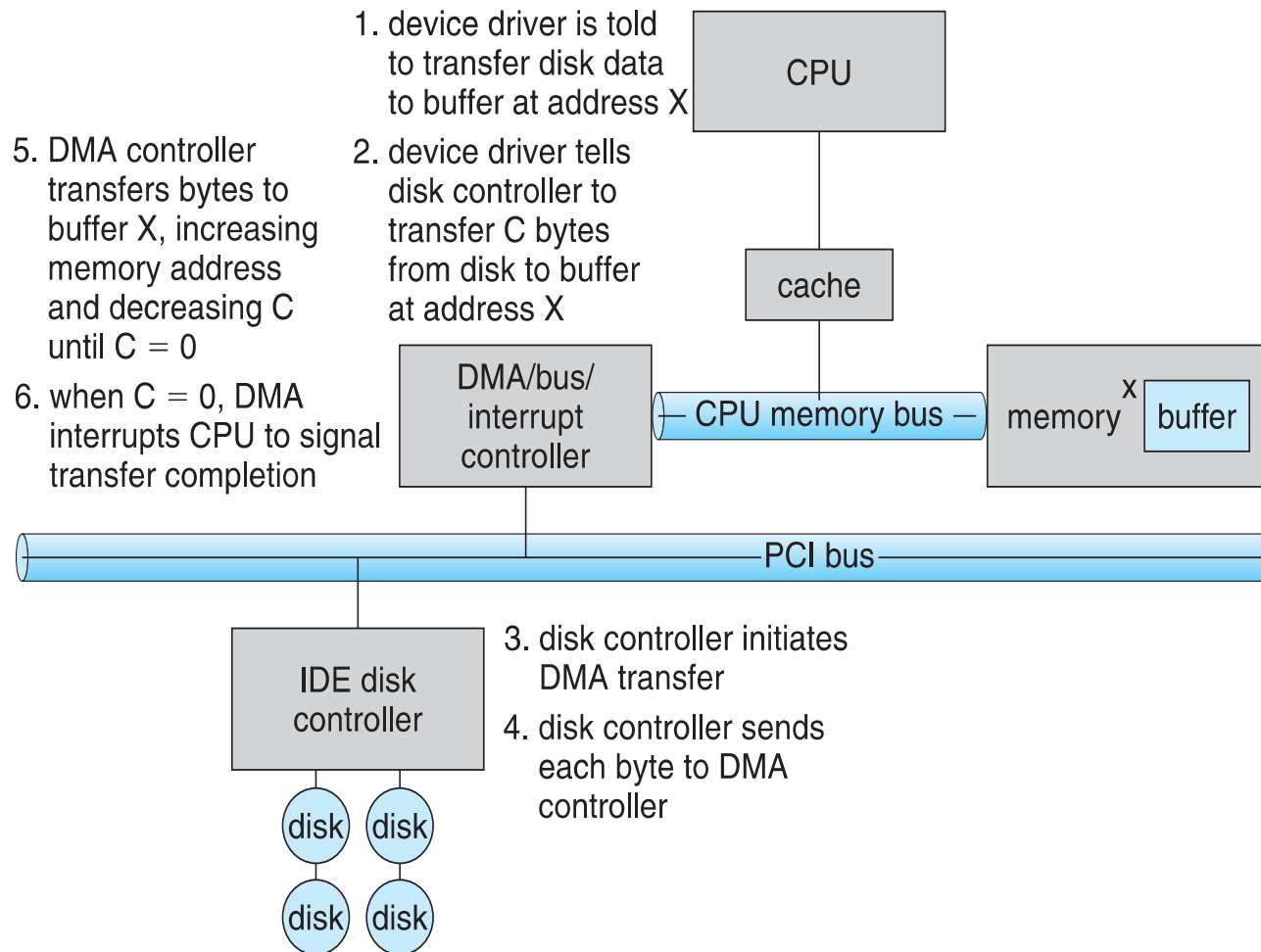
```
}
```



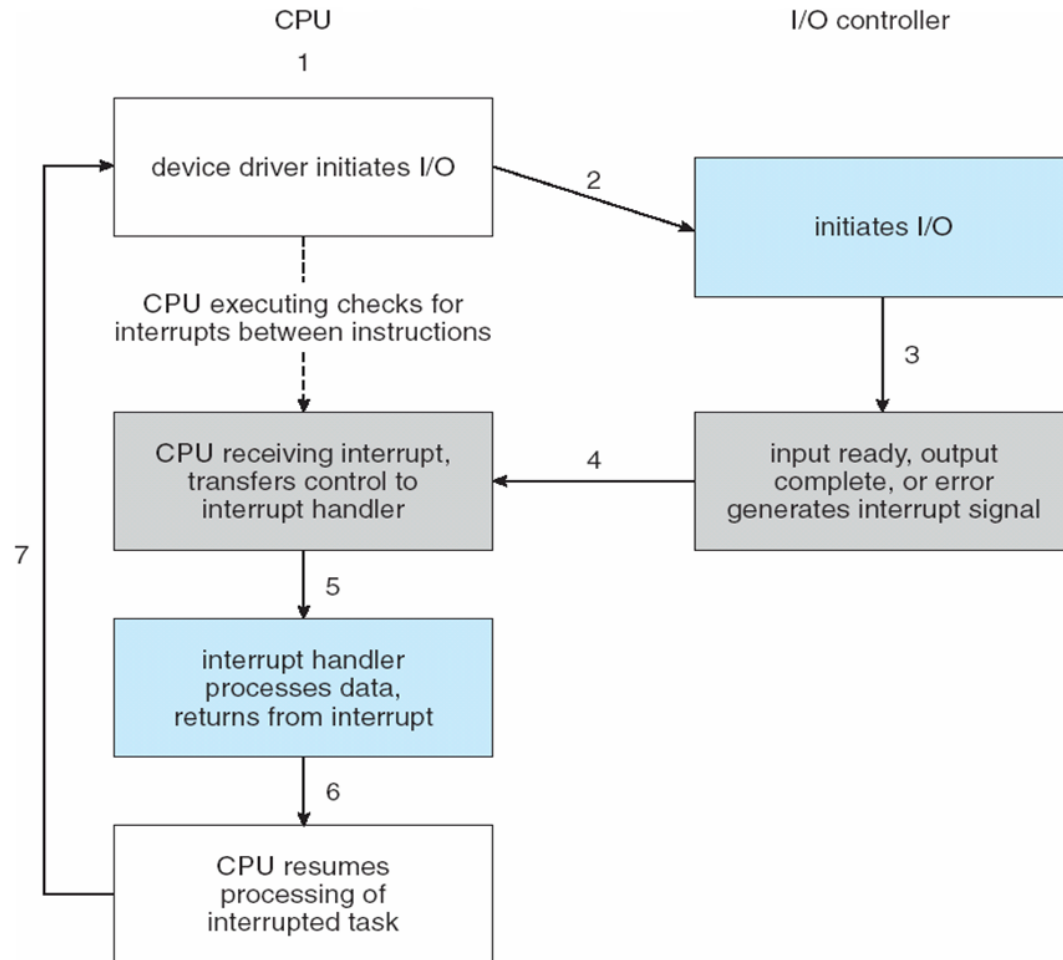
Data Transfer Methods

- Programmed I/O
 - Via CPU's load/store instructions
 - Simple h/w, but high CPU load
- Direct Memory Access
 - Controllers directly read/write from/to DRAM
 - Interrupts the CPU on the completion of I/O ops.
 - Complex h/w, but low CPU overhead

Direct Memory Access



Interrupt Driven I/O Cycle



Disk

- Magnetic disks (HDD)
 - Still used as the main storage device on many computers
 - Mechanical device (moving parts)
 - Cheap but slow
- Solid-state disks (SSD)
 - All smartphones and tables, many notebooks
 - No moving parts, use NAND flash chips
 - Still a bit expensive but faster

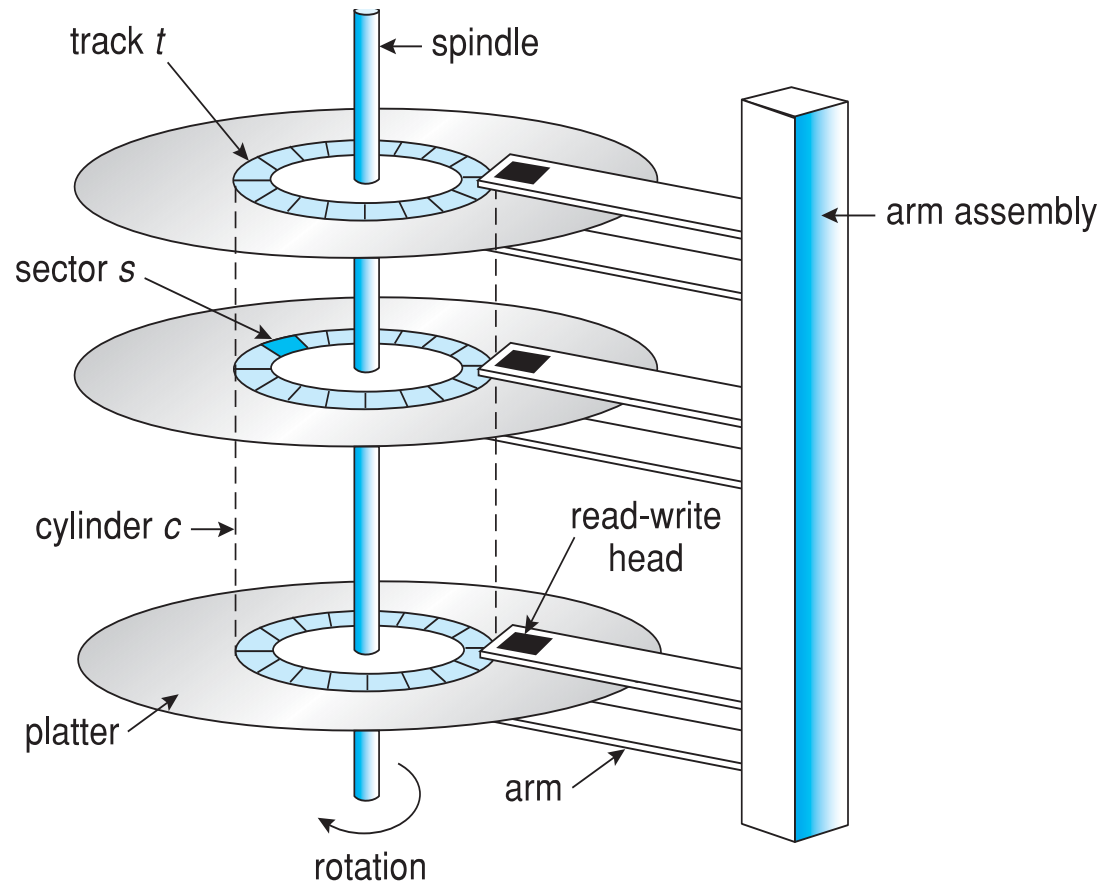
The First Commercial Disk Drive



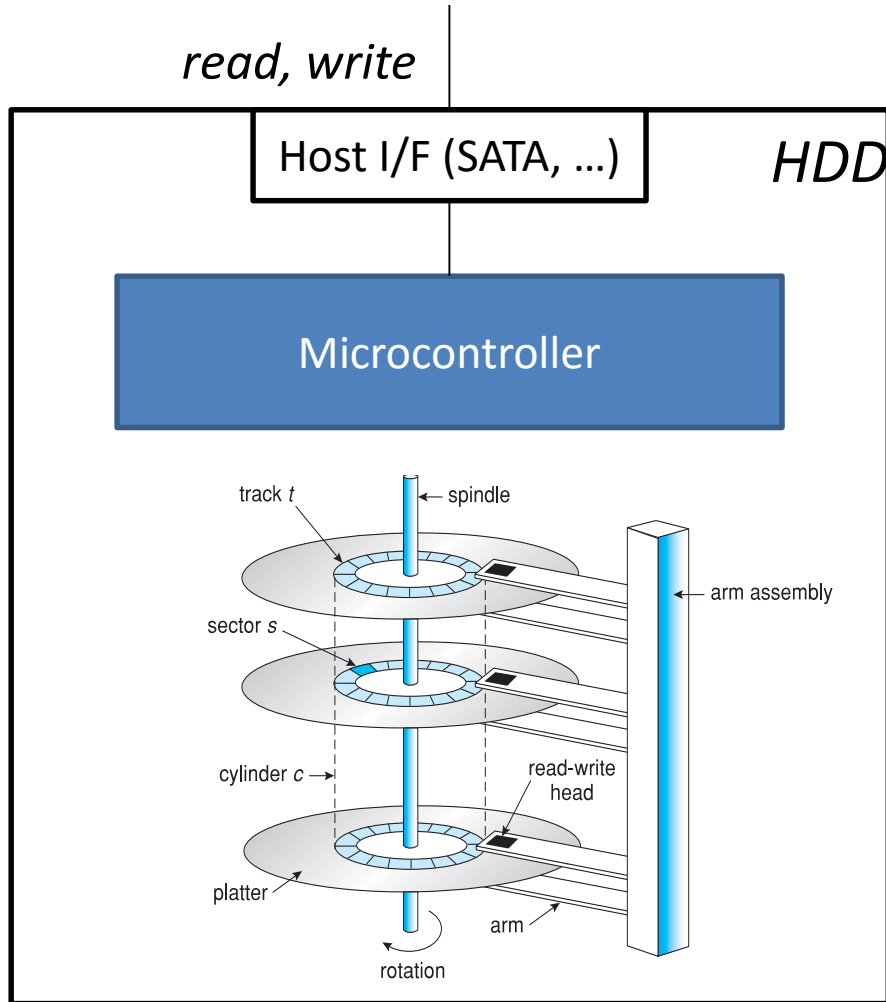
1956
IBM RAMDAC computer
included the IBM Model
350 disk storage system

5M (7 bit) characters
50 x 24" platters
Access time = < 1 second

Magnetic Disk



Hard Disk Drive (HDD)

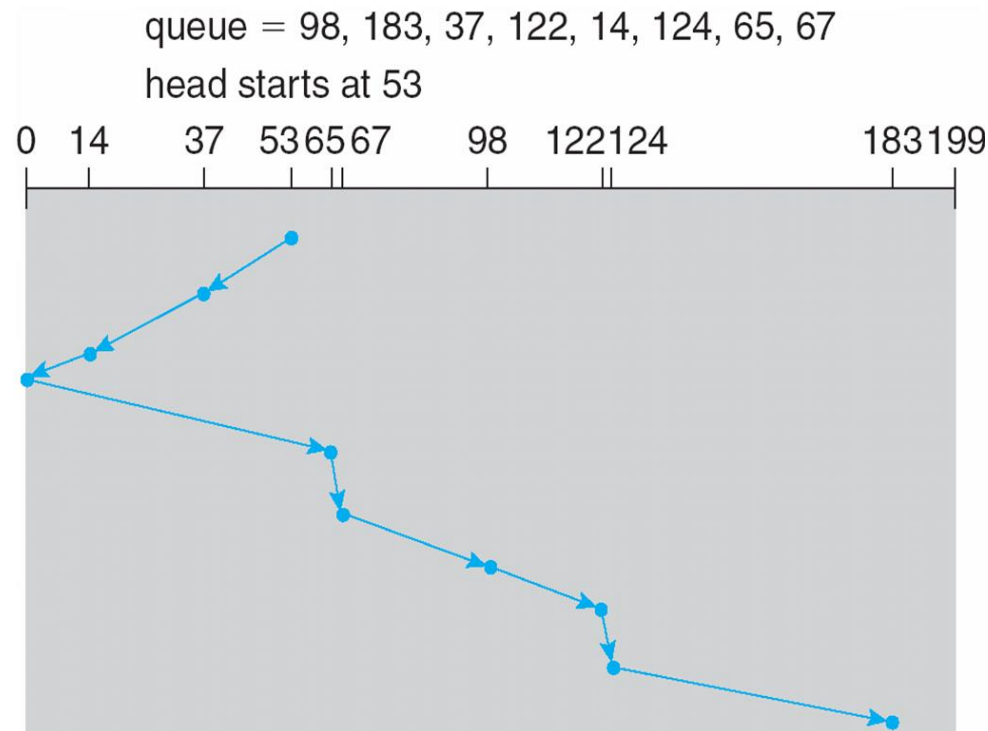


- Storage size
 - $\sim 3\text{TB}$
- Performance
 - B/W: $\sim 1\text{Gb/s}$
 - Seek time: 3-12ms



Disk Scheduling

- Goal: minimize seek time
- FCFS, SSTF (shortest seek time first), SCAN



SCAN scheduling

NAND Flash Memory Chip

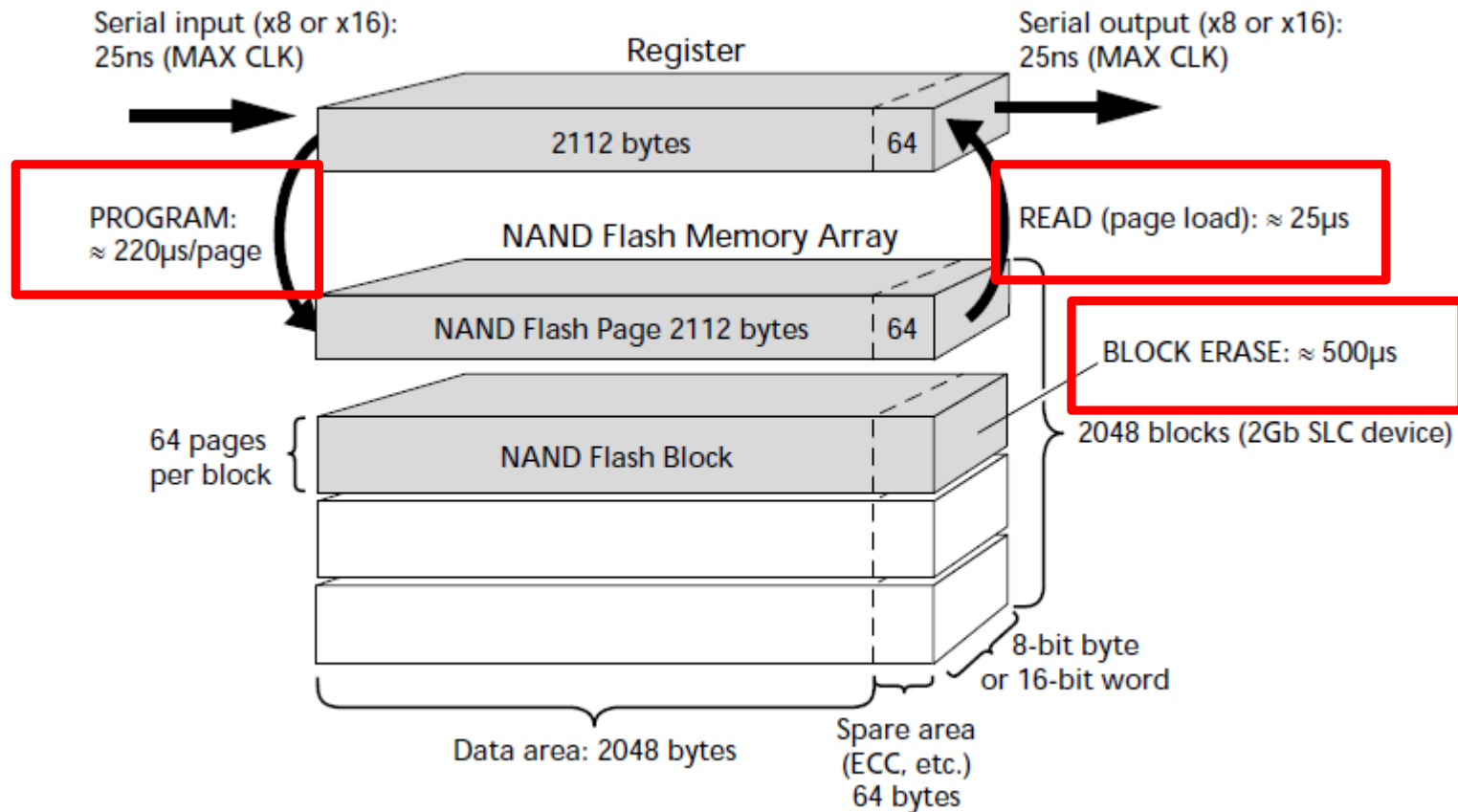
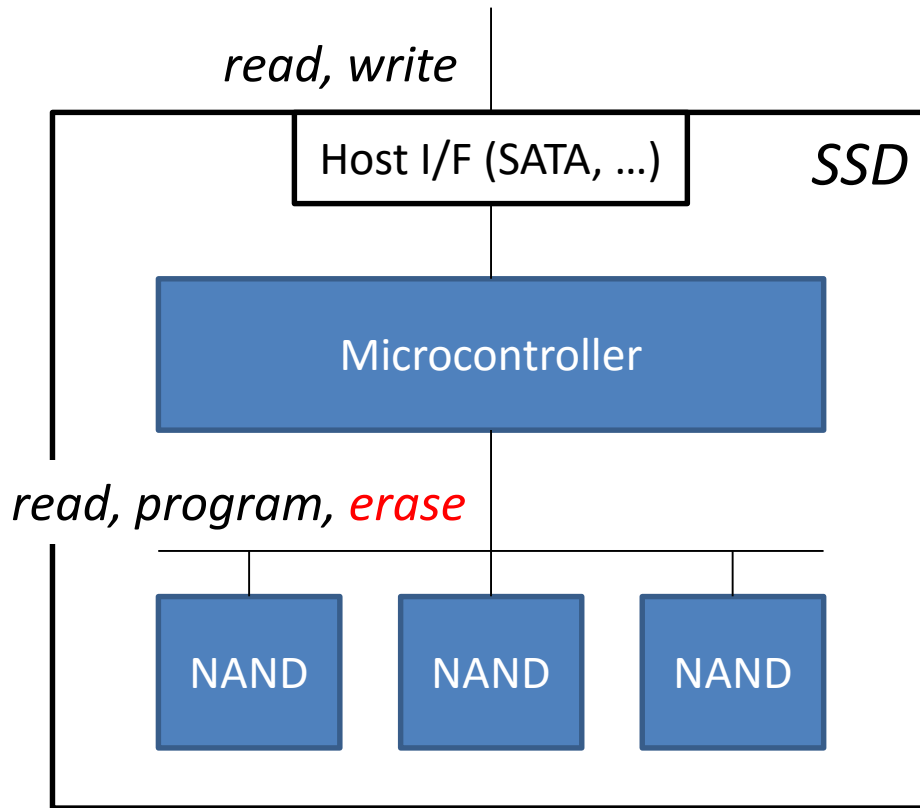


Figure source: Micron, [“TN-29-19: NAND Flash 101”](#), 2010

Solid-State Disk (SSD)



- Same I/f as HDD
 - SATA.
- Flash Translation Layer (FTL)
 - S/W running on the controller
 - Provides **disk abstraction**
- Storage size
 - ~1TB
- No seek time
- Bandwidth
 - SATA (6Gbps) is the bottleneck
 - Some use PCIe I/F



Summary

- I/O subsystems
 - Standardized interfaces to access various i/o devices
- I/O device types
 - Block, characters, network devices
- I/O mechanisms
 - Memory-mapped I/O, I/O instructions
 - Programmed I/O vs. DMA
- Disk
 - HDD vs. SDD