Input/Output

Operating Systems
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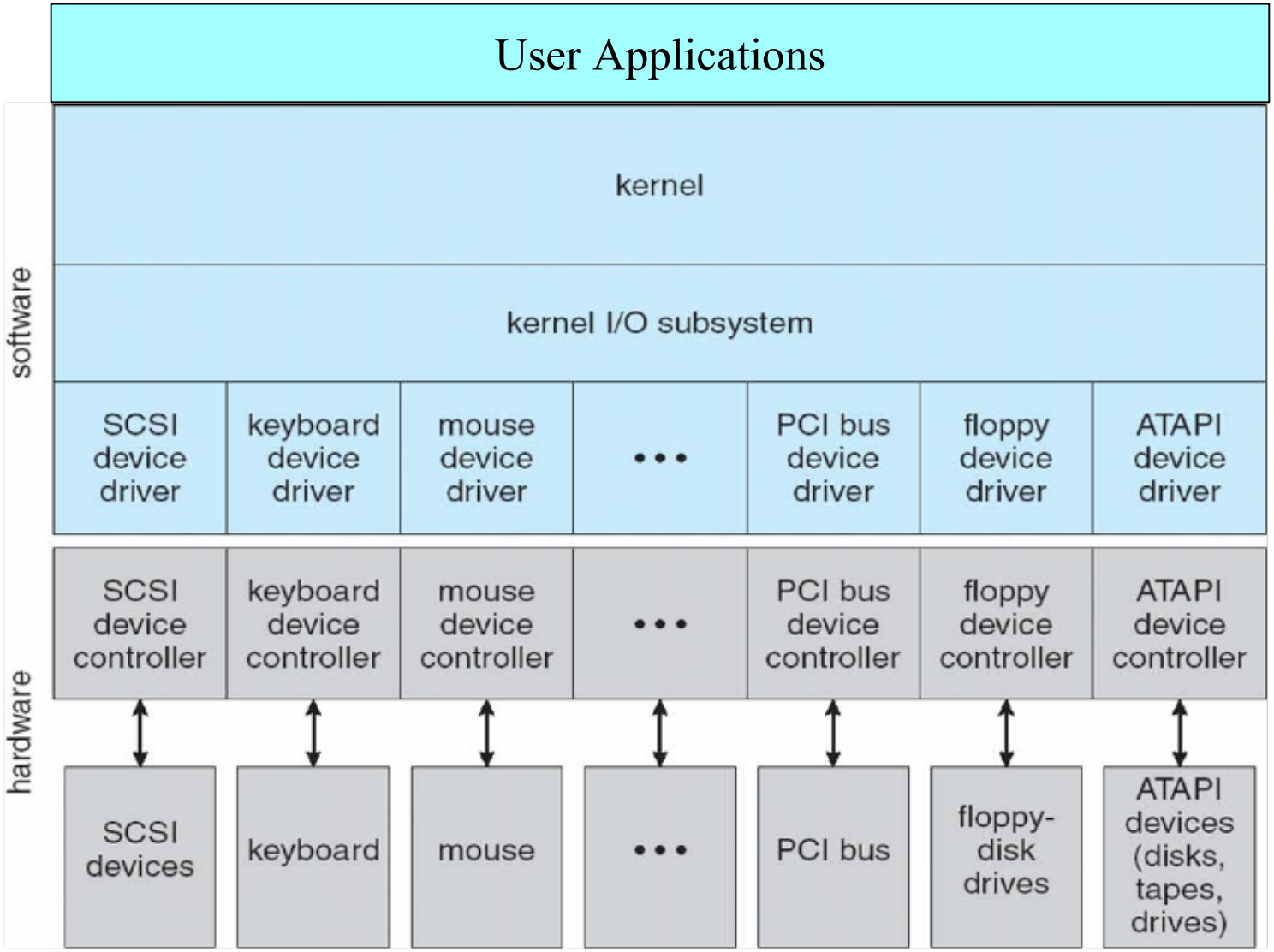
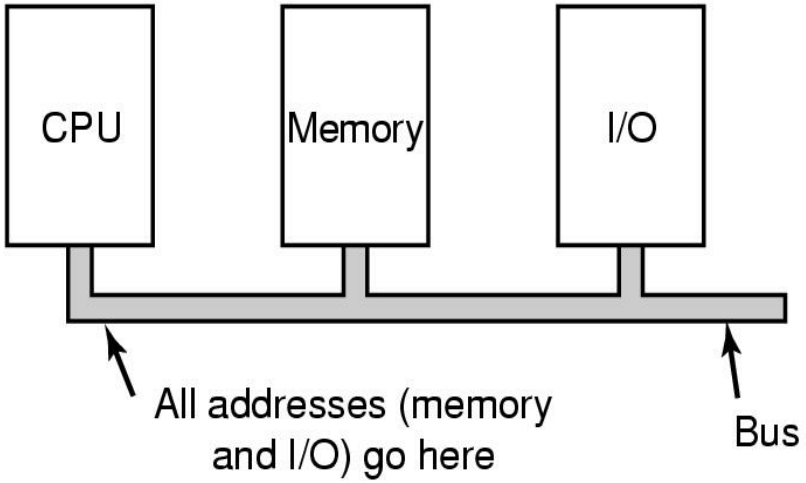
Chapter 5, Modern Operating Systems — Tanenbaum
Chapter 13, OS Concepts — Silberschatz (optional)

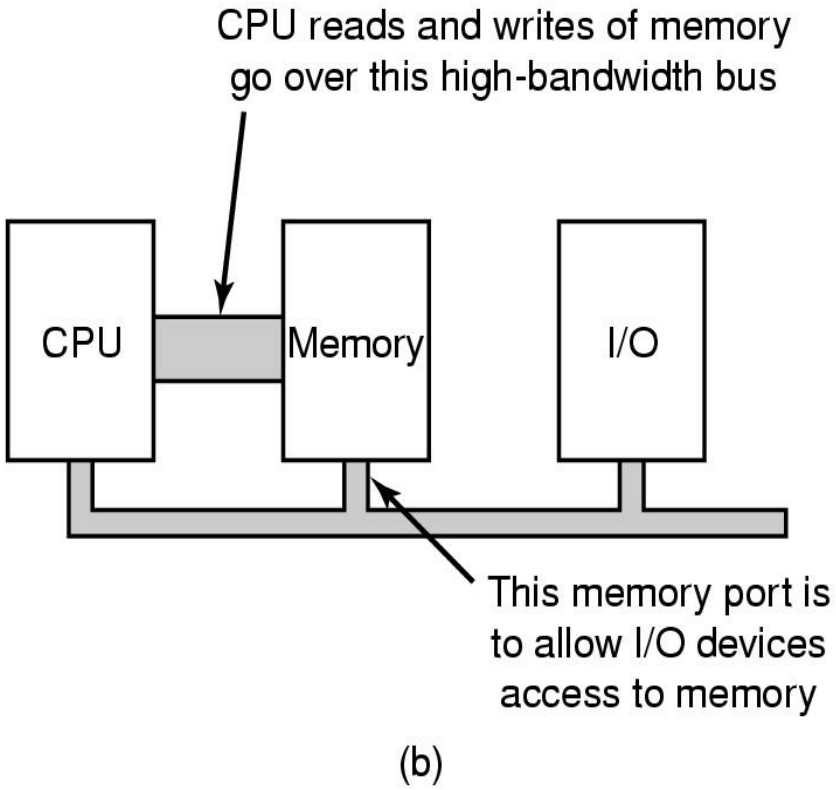
Layering in the I/O subsystem



How CPU and I/O devices communicate



A single-bus architecture

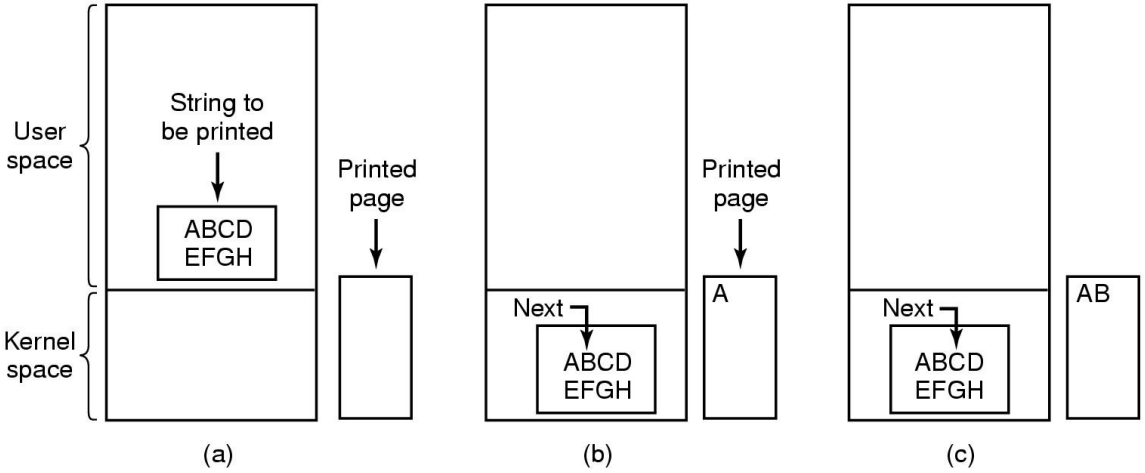


A dual-bus memory architecture

Device Controllers

- I/O devices may have
  - mechanical components
  - electronic components
- Device controller is the electronic component
  - may be able to handle multiple devices
- Controller's tasks
  - Intermediary between I/O devices, CPU, and memory
  - convert serial bit stream to block of bytes
  - perform error correction as necessary

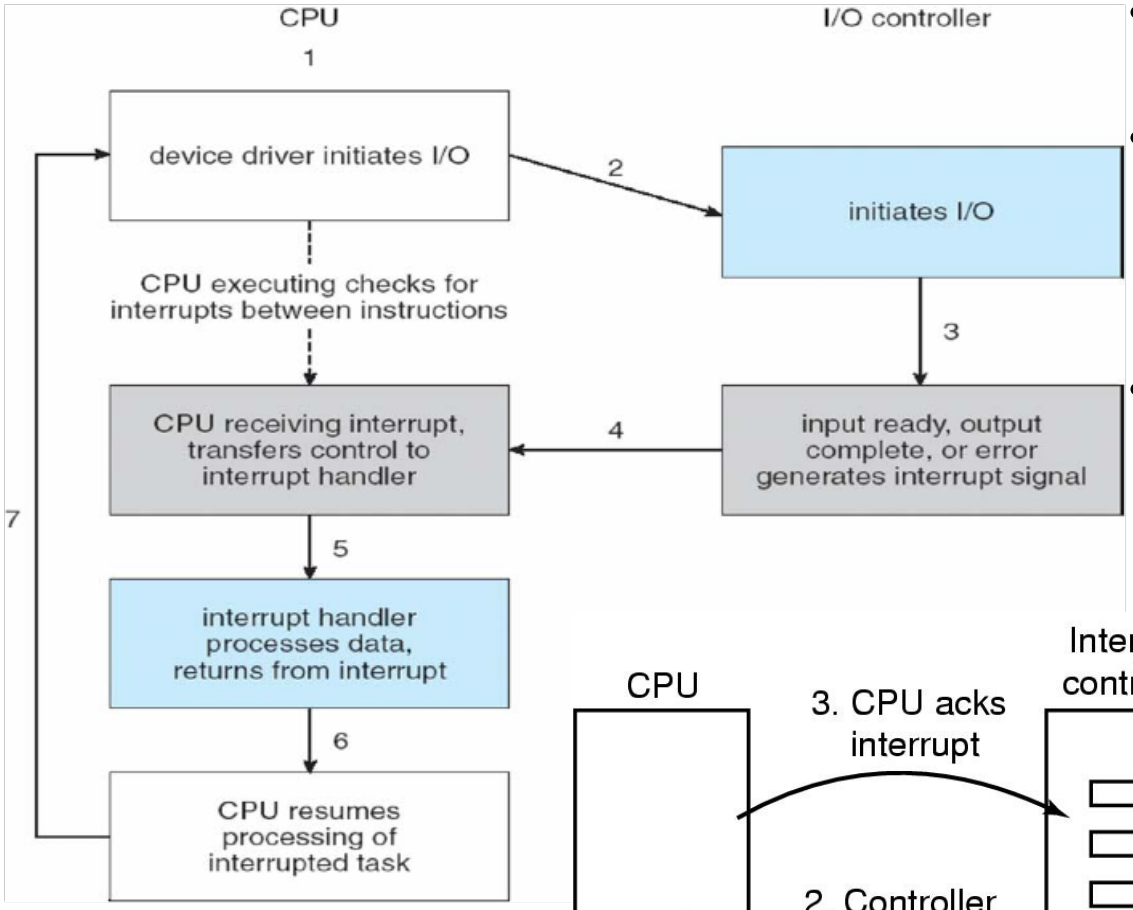
Programmed I/O



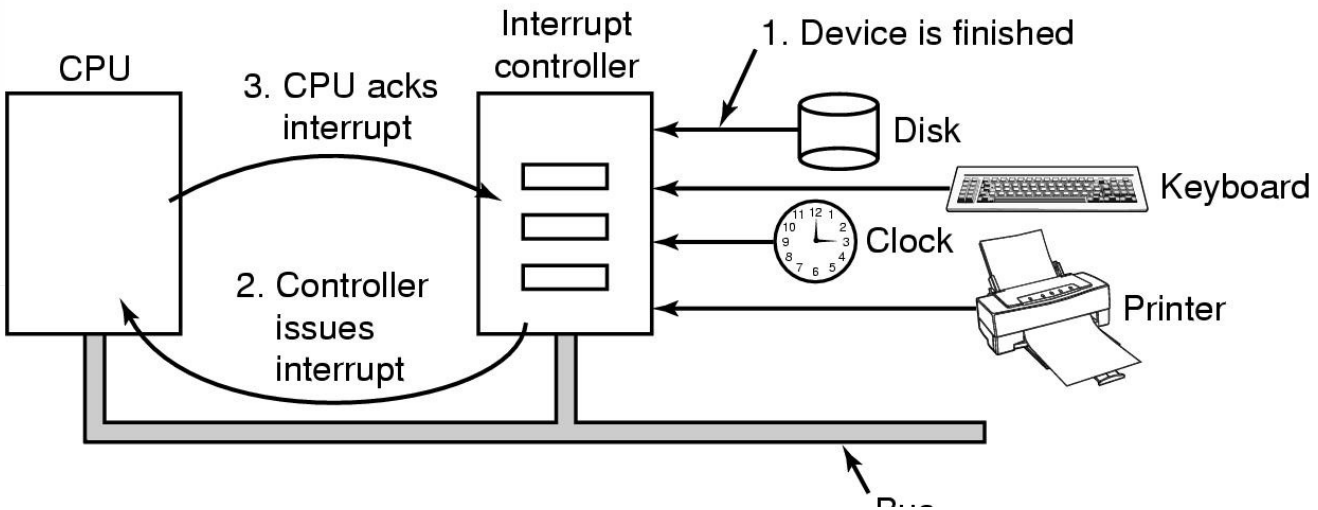
Printing a string: CPU transfers one byte at a time to device

```
copy_from_user(buffer, p, count);                /* p is the kernel bufer */
for (i = 0; i < count; i++) {                    /* loop on every character */
      while (*printer_status_reg != READY) ;     /* loop until ready */
      *printer_data_register = p[i];             /* output one character */
}
return_to_user( );
```

Interrupts



- I/O events signaled by device to CPU
- Interrupt-request (IRQ) line triggered by controller to CPU
  - Checked by CPU after each instruction
- Interrupt vector table used to invoke the correct interrupt handler



Example: Intel Pentium Interrupt Vector Table

vector number	description
0	divide error
1	debug exception
2	null interrupt
3	breakpoint
4	INTO-detected overflow
5	bound range exception
6	invalid opcode
7	device not available
8	double fault
9	coprocessor segment overrun (reserved)
10	invalid task state segment
11	segment not present
12	stack fault
13	general protection
14	page fault
15	(Intel reserved, do not use)
16	floating-point error
17	alignment check
18	machine check
19–31	(Intel reserved, do not use)
32–255	maskable interrupts

Interrupt-Driven I/O

```
copy_from_user(buffer, p, count);
enable_interrupts( );
while (*printer_status_reg != READY) ;
*printer_data_register = p[0];
scheduler( );
```

(a)

```
if (count == 0) {
    unblock_user( );
} else {
    *printer_data_register = p[i];
    count = count – 1;
     i = i + 1;
}
acknowledge_interrupt( );
return_from_interrupt( );
```

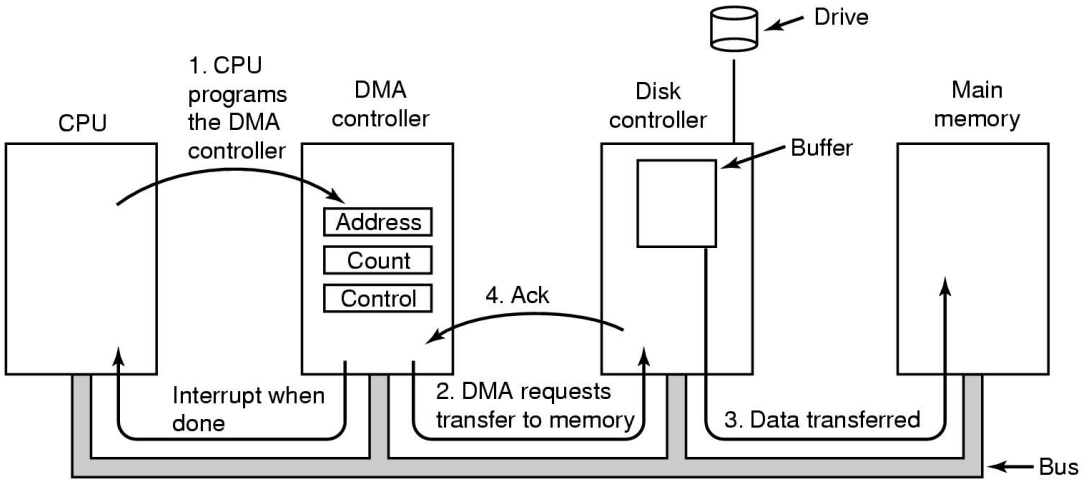
(b)

Writing a string to the printer using interrupt-driven I/O

(a) Code executed when print system call is made
- Starts off by printing the first character

(b) Interrupt service procedure
- called every time the printer completes printing one character and generates an interrupt

Direct Memory Access (DMA)



- DMA allows I/O controllers to directly transfer data to/from the main memory.
- Frees up the CPU for other tasks

```
copy_from_user(buffer, p, count);
set_up_DMA_controller( );
scheduler( );
```

(a)

Code executed by print system call

```
acknowledge_interrupt( );
unblock_user( );
return_from_interrupt( );
```

(b)

Interrupt service routine (ISR) called when the entire print job is completed

Device Classification

- Character (char) devices
  - byte-stream abstraction
  - E.g. keyboard, mouse

- block devices
  - reads/writes in fixed block granularity
  - E.g. hard disks, CD drives

- network devices
  - message abstraction
  - send/receive packets of varying sizes
  - E.g. network interface cards

- others
  - USB, SCSI, Firewire, I2O
  - Can (mostly) be used to implement one or more of the above three classes

Hard Disks

Hard disk organizes data in tracks and sectors

- Seeking: Disk head moves across tracks
- Rotation: Disk rotates to bring the correct sector under disk head

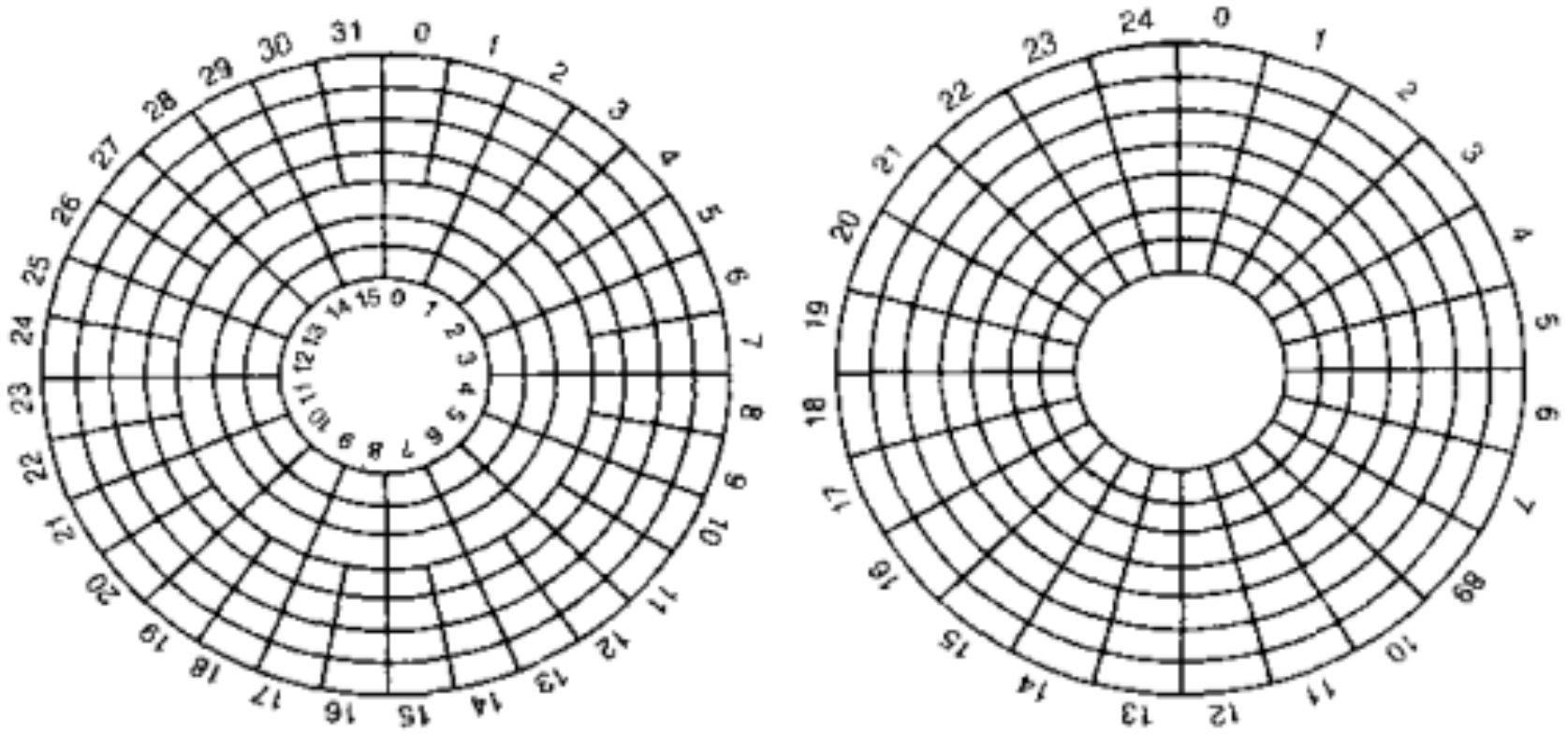


Figure 5-18. (a) Physical geometry of a disk with two zones. (b) A possible virtual geometry for this disk.

Factors affecting read/write latency

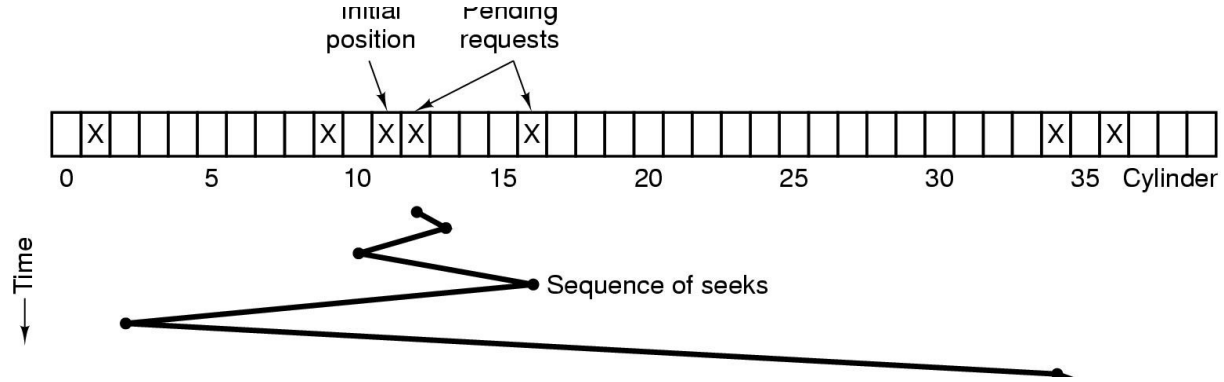
- Seek time
  - Time to move magnetic head from one track to next.
  - Average 5 to 10 milliseconds.

- Rotational delay
  - Time to rotate the disk to reach the sector containing the data
  - Depends on the rotational speed of the disk
  - E.g. A disk with 15,000 rotations per minute (rpm) will have 1 rotation every 4 milliseconds, or an average of 2 millisecond rotational latency (assuming that average latency is one-half of a rotational period).

- Actual transfer time
  - Time to transfer data from the disk sector to memory
  - In microseconds

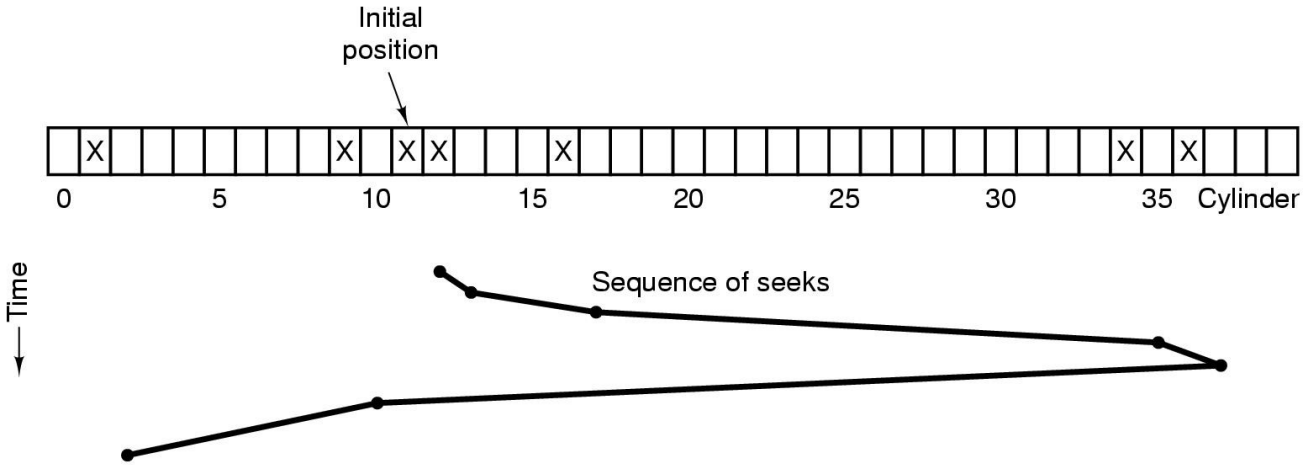
- Seek time dominates
  - For most practical purposes, rotational and transfer times are ignored.

Disk Arm Scheduling Algorithms



Shortest Seek First (SSF) disk scheduling algorithm

- High I/O throughput, but some I/O requests may starve



Elevator (SCAN) algorithm for scheduling disk requests

– Reasonable I/O throughput and No starvation

Disk I/O Throughput

- Seek Latency dominates

- Sequential I/O throughput is much higher than random I/O throughput
  - Sequential access involves fewer seeks

- I/O Operations per second (IOPS)
  - Better measure of disk throughput
  - Ignores the number of bytes in each I/O operation.

- https://en.wikipedia.org/wiki/IOPS

Disk Buffer

- Hard disk controllers have a small amount of buffer memory (RAM)
  - 8MB to 128MB

- Used to stage data moving between the physical disk and main memory

- Hides seek latency in two ways:
  - Read-ahead
    - Read extra data near the requested sector and store in disk buffer. Return from disk buffer when OS requests the extra data.

  - Write Acceleration:
    - When OS writes data, store data in disk buffer and return completion interrupt. Commit the data to physical disk “later”.
    - If power fails, data in disk buffer could be lost!

- https://en.wikipedia.org/wiki/Disk_buffer

Solid State Drives (SSD)

https://en.wikipedia.org/wiki/Solid-state_drive

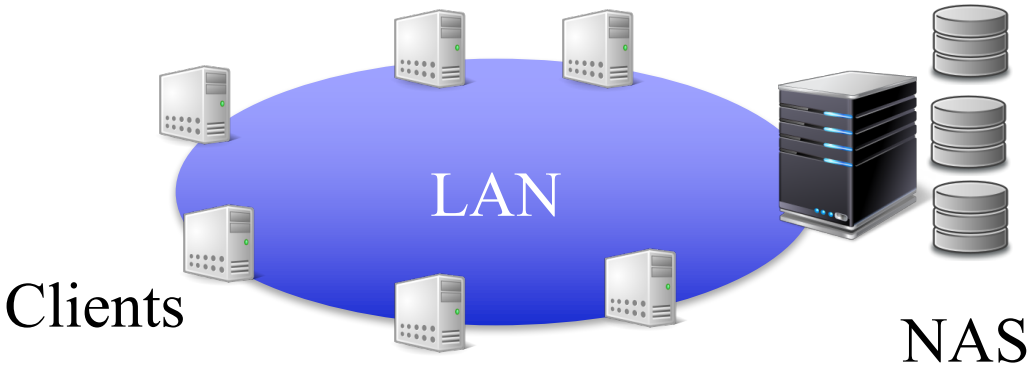
SSD

- NAND-based flash memory to store persistent data
  - Plus a controller performs Error Correction, Wear Leveling, Caching, etc.
- No mechanical components
- Works with various interfaces
  - SATA, SAS, PCI, USB, Fibre Channel, IDE
- Disks in various form factors
  - Regular, Thumb, embedded
- SSDs may also be used as buffer in Hard disks to improve reliability
- Or DRAM could be used as buffer to improve SSD access latencies

- SSD vs Hard Disks
  - Lower Access Latencies
    - Random access ~ 0.1ms
  - Higher throughput
  - Reliability
    - No moving parts
    - But repeated writes to the same cell makes the cell unreliable.
    - Wear leveling: write to a different cell each time
  - Silent operation
  - Low power consumption
  - Smaller capacities
  - More expensive

Network Attached Storage (NAS)

- A storage server accessed over a Local Area Network (LAN)



Storage Area Network (SAN)

- A dedicated network to access a collection of storage media
  - High speed network interconnect
    - Fiber Channel, iSCSI, AoE etc
  - Virtualized storage
    - Consolidated block-level access