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Topic 4: The Modern Computer

ICT170: Foundations of Computer Systems

Overview

- Memory
- Primary Memory
- Secondary Memory
- Secondary Memory Storage Technologies
- Input
- Output
- Buses

Objectives

In order to achieve the unit learning objectives, on successful completion of this topic, you should be able to:

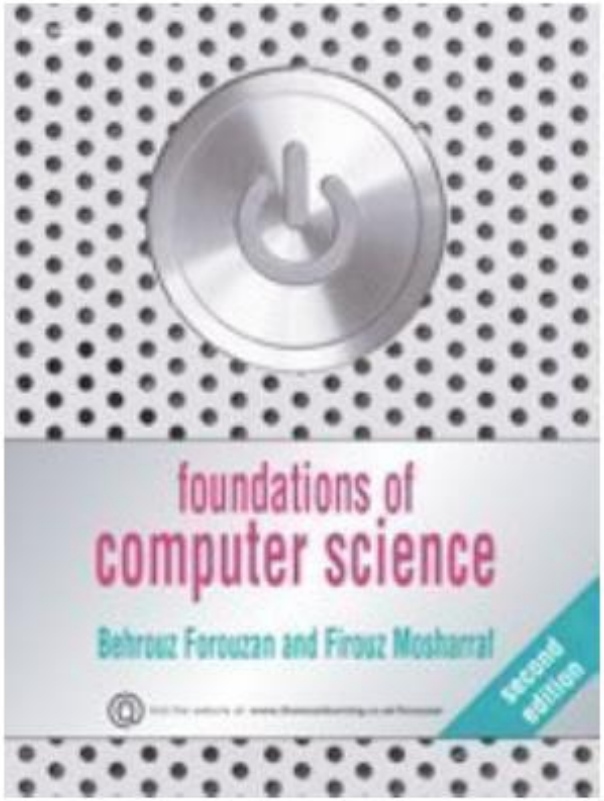
- Understand primary memory addressing including byte ordering.
- Understand the role of secondary memory in a computer.
- Explain the variety and differences of secondary memory options.
- Describe the range of I/O possibilities for computers and how each connects to the computer
- Describe the general operation of a computer bus.

Reading

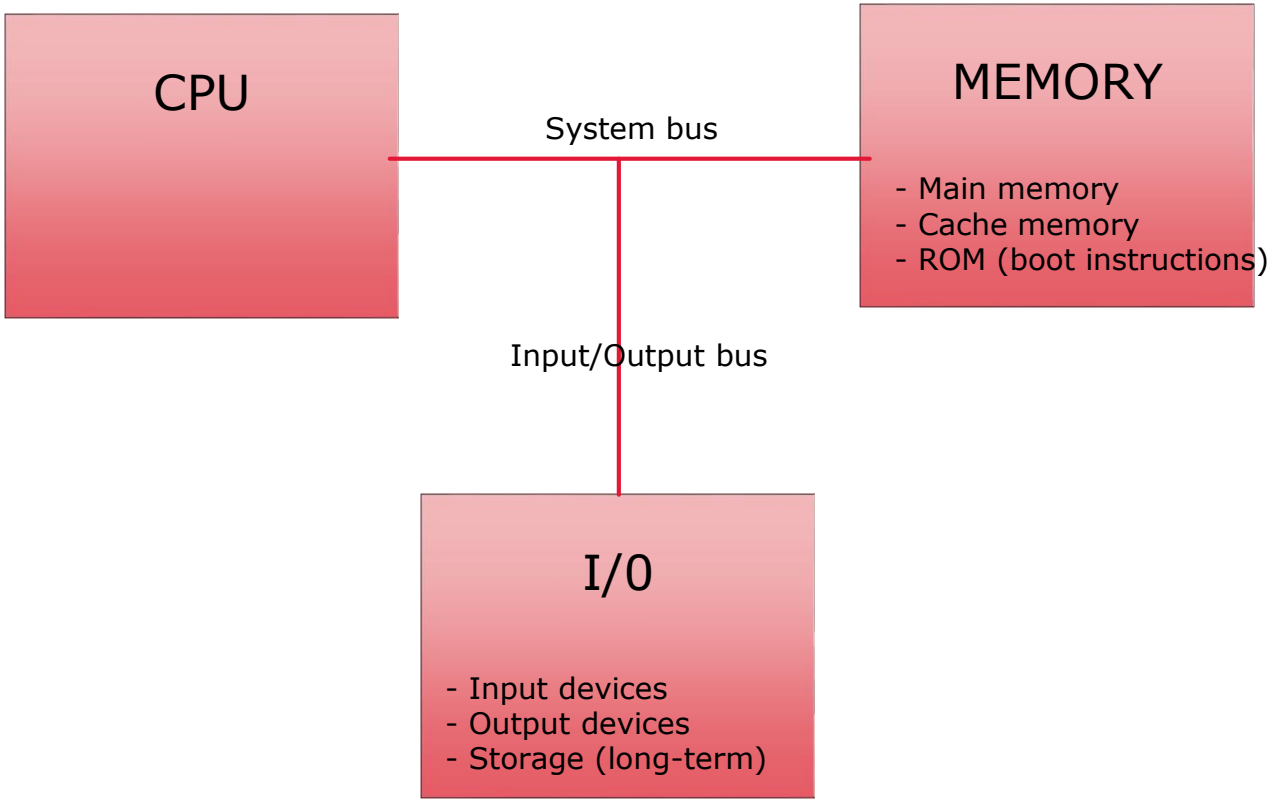
Title: **Foundations Of Computer Science (2nd Edition)**
Author: Behrouz A. Forouzan, Firouz Mosharraf,
Publisher: Cengage Learning Business Press
Keywords: science, computer, foundations
Pages: 640
Published: 2007-12-05
Language: English
ISBN-10: 1844807002 ISBN-13: 9781844807000
Binding: Paperback (2)
Reading: Chapter 5 "Computer Organization"

Resources:

- The recorded lectures available on LMS.
- The lecture slides available on LMS.



The Computer System

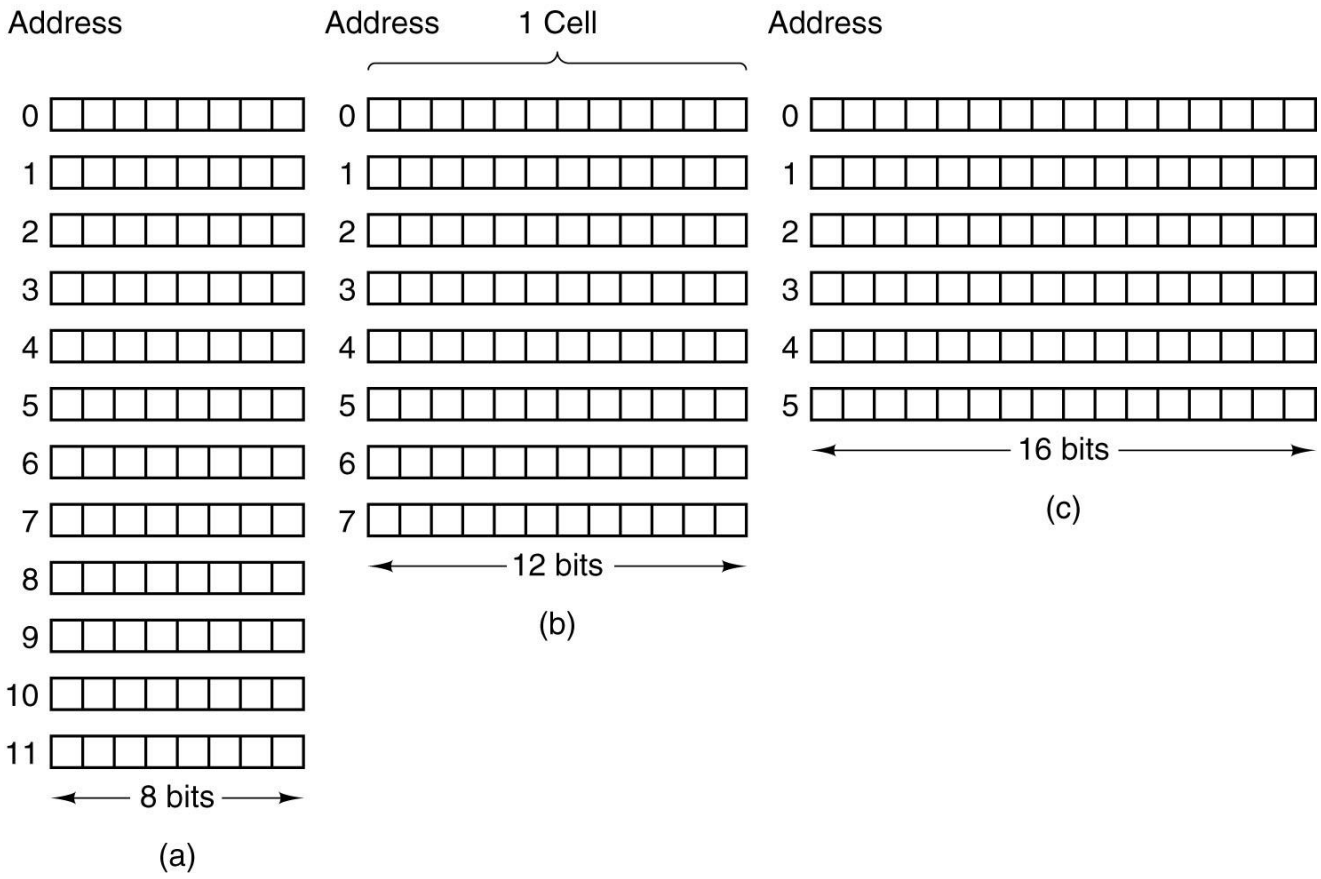


What is Memory?

- The part of the Computer where programs and data are stored.
- Without memory from which processors read and write – there would be no stored-program digital computers
- Basic Unit: The bit. ‘0’ or ‘1’
- A number can be stored in Binary

  E.g. 17 in decimal is 00010001
- You just need to know now that we need to store stuff!

Memory Addresses



Three ways of organizing a 96-bit memory.

Memory Addresses (2)

- Main memory consists of a number of storage locations, each of which is identified by a **unique address**
- The ability of the CPU to identify each location is known as its **addressability**
- Each location stores a **word** i.e. the number of bits that can be processed by the CPU in a single operation. **Word length** may be typically 16, 24, 32 or as many as 64 bits.
- A large word length **improves system performance**, though may be less efficient on occasions when the full word length is not used

Byte Ordering

We want to write a 32 bit number: $90AB12CD_{16}$

Address	Value
1000	90
1001	AB
1002	12
1003	CD

(a) Big endian memory

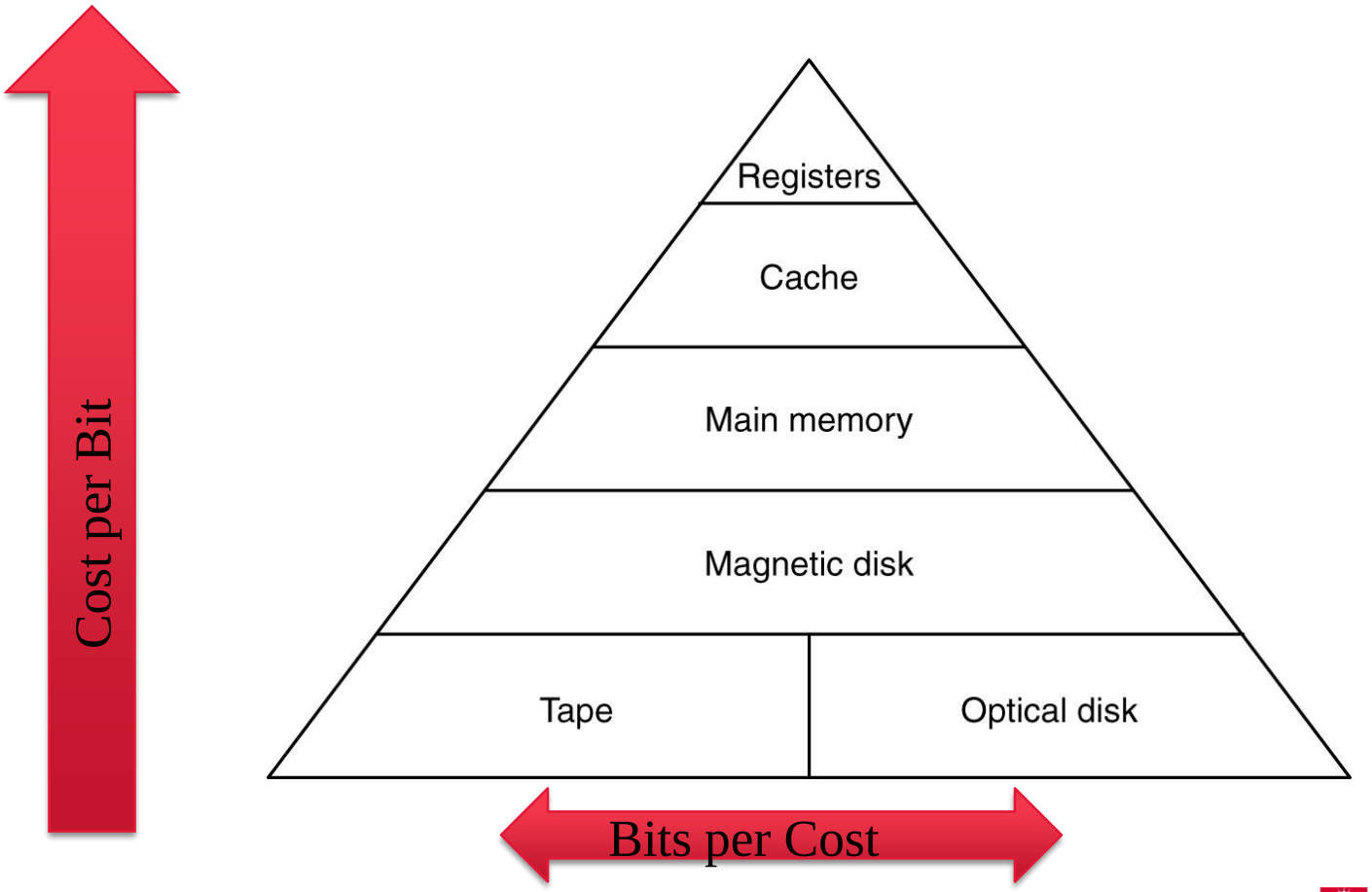
Address	Value
1000	CD
1001	12
1002	AB
1003	90

(b) Little endian memory

Primary and Secondary Memory

- Primary Memory
  - Connected to processor through memory bus
  - Relatively fast access
  - Typically volatile (lost on power-off)
- Secondary memory (called storage)
  - Typically external memory such as memory sticks or hard drives
  - VERY slow access
  - Very cheap

Memory Hierarchies

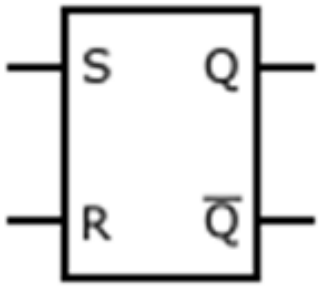


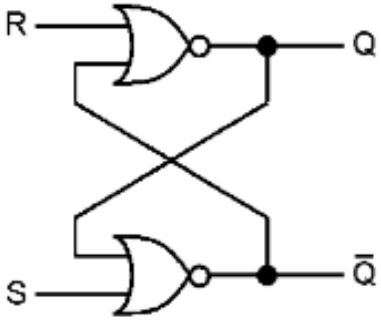
Primary Memory: ROM and RAM

- ROM: Read-Only Memory
  - Non-volatile memory
  - Typically impossible or very time-consuming to write/rewrite
  - Used to hold, e.g., firmware for hardware, BIOS for PC systems
- RAM: Random Access Memory
  - Volatile memory
  - Constant access time for any memory cell
  - Read- and writeable

RAM

- Static Random Access Memory (SRAM)
  - Implemented using *latches (flip-flops)* SR(Set/Reset)latches
  - Does not need to be refreshed
  - Complex implementation
    - Expensive compared to DRAM
    - Large size: a latch requires 6 transistors
  - Faster access, uses less power than DRAM
    - Typically used for caches
      - Processors, hard drives, etc





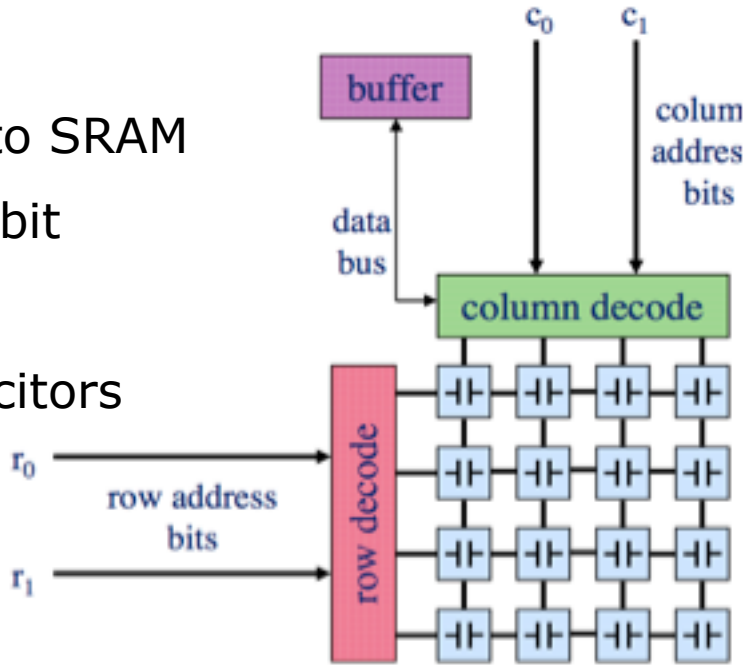
RAM

Dynamic RAM (DRAM)

- Cheap & dense but slow compared to SRAM
- Uses one capacitor + transistor per bit

Works like a "leaky bucket"

- Based on constantly refreshed capacitors
- Organized in a grid
- Addressed by column + row



Entire row refreshed on access

Periodical refresh implemented in hardware

Embedded DRAM (eDRAM)

DRAM integrated in processor circuit

SDRAM – Synchronous with the clock

RAM – Cache Memory

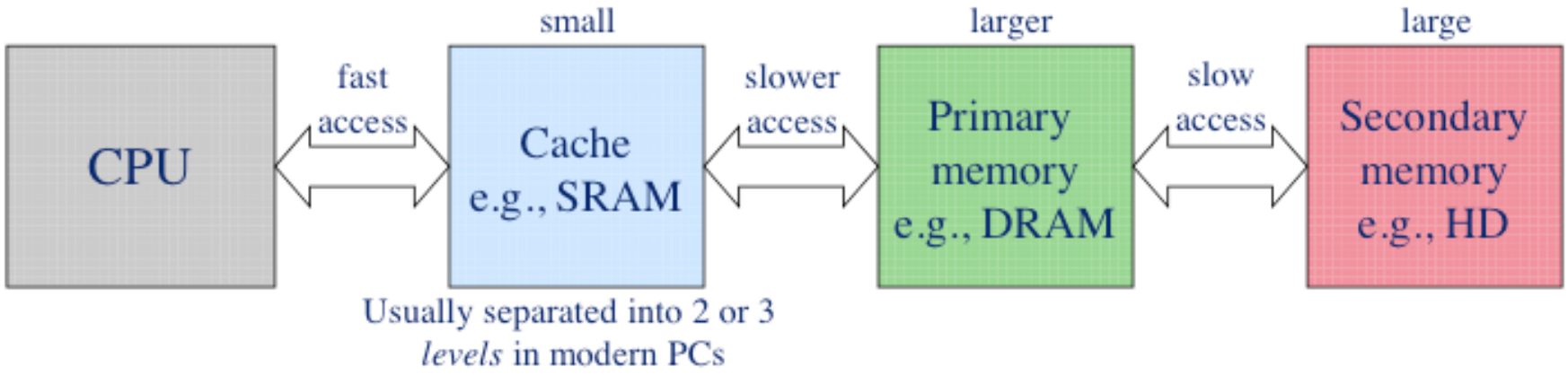
- Small amount of memory typically 256 or 512 kilobytes
- Temporary store for often used instructions
- **Level 1** cache is built within the CPU (internal)
- **Level 2** cache may be on chip or nearby (external)
- Faster for CPU to access than main memory

Memory Evaluation

- Two main memory metrics: *cost* and *access* time
  - Cost: cost per bit
  - Access time: time between addressing and data available on the data lines (number of CPU *wait states)*
  - Also relevant: physical *size*
- Goal : lowest access time that meets cost requirements
  - SRAM: fast (5-10 times faster than DRAM) but expensive – DRAM: slow but cheap and compact
  - Best of both worlds: fast access time, cheap bulk storage

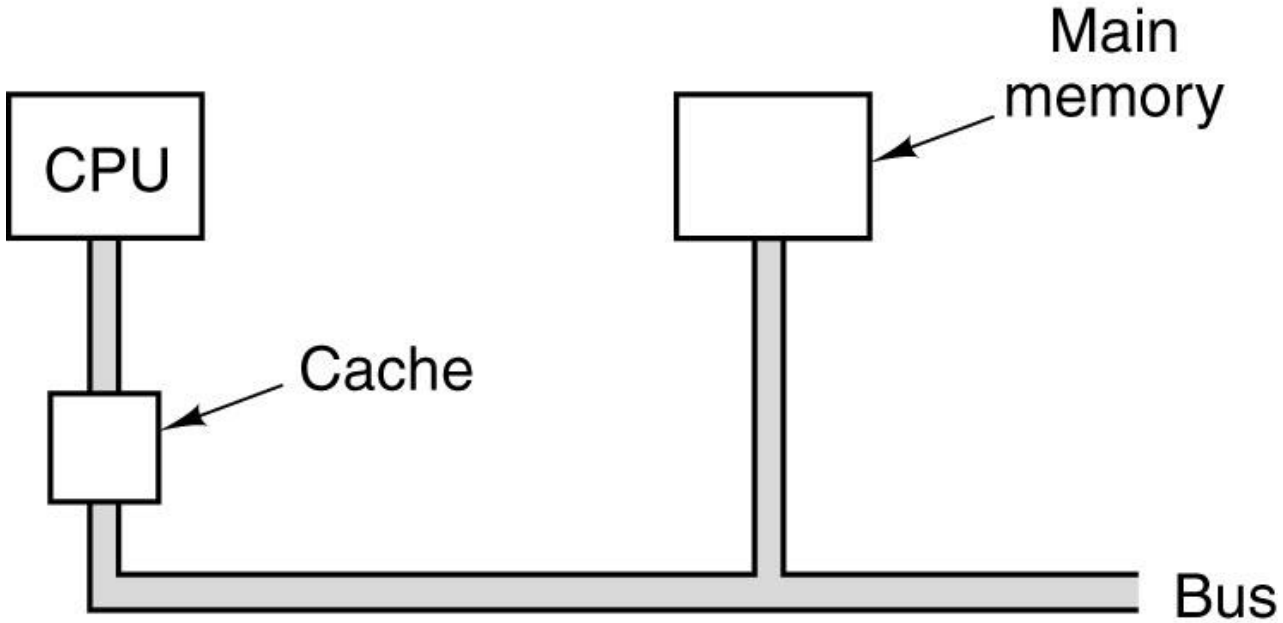
So how do we use these memory types?

- Memory Hierarchies
- Caching: fundamental technique in Computer Science
  - Provide fast access to data that is likely to be used
  - Probabilistic approach
- Basic memory architecture: three-level hierarchy



Cache Memory

- The cache is logically between the CPU and main memory. Physically, there are several possible places it could be located.



Caching

- Provides illusion of a large memory space
  - Programs execute as if memory size = size of lowest level
    - Compare to: virtual memory in operating systems
  - But programmers should not get lazy
    - Write memory-efficient and cache-aware code
- Provides faster access to data in high levels
- Specialized caches possible

  E.g., *instruction* and *data* cache
- Required: technique for finding cached data
- Required: policy for replacing cached data

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Secondary Memory

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Secondary Memory/Storage

- **Memory (RAM) versus storage**
  - Secondary storage is used for long term storage of software and data outside the CPU
  - Secondary storage is non-volatile and retains data even when power is turned off
  - Recall that data stored in memory (RAM) will be lost
  - Storage devices are less expensive than memory
  - Common storage technologies for reading and writing data; magnetic, optical, and electronic

Secondary storage

- Secondary storage devices are used to:
  - Store/save
  - Back-up
  - Transport files
- Unlike primary storage like RAM (Random Access Memory), secondary storage is non-volatile/permanent,
  - i.e. it stays available even after the device has been turned off and on again.
- Often simply called “storage”

Technologies

- Magnetic storage
  - Floppy, Zip disk, Hard drives, Tapes
- Optical storage
  - CD, DVD, Blue-Ray, etc…
- Solid state memory
  - USB key, Memory cards for mobile phones/digital cameras, Solid State Drives, MP3 players

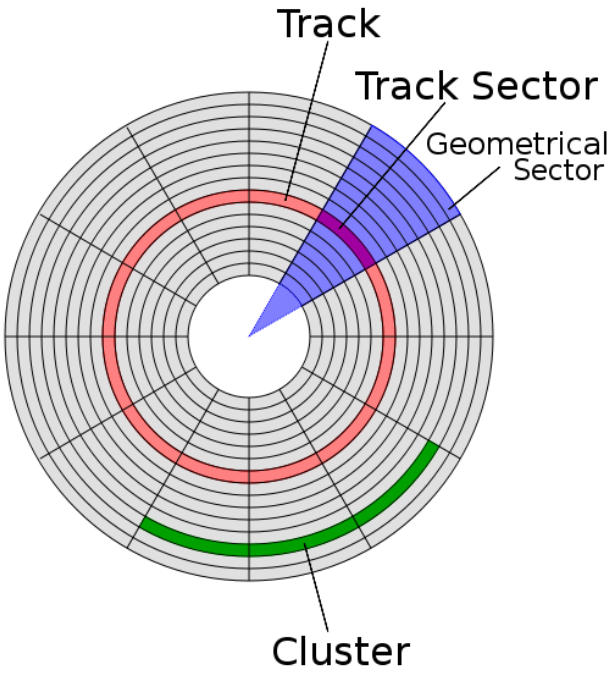
Secondary Memory Characteristics

1. Medium
2. Capacity
3. Writing ability
4. Performance
    - Transfer rate/Access speed
5. Reliability

A combination of these informs choice…

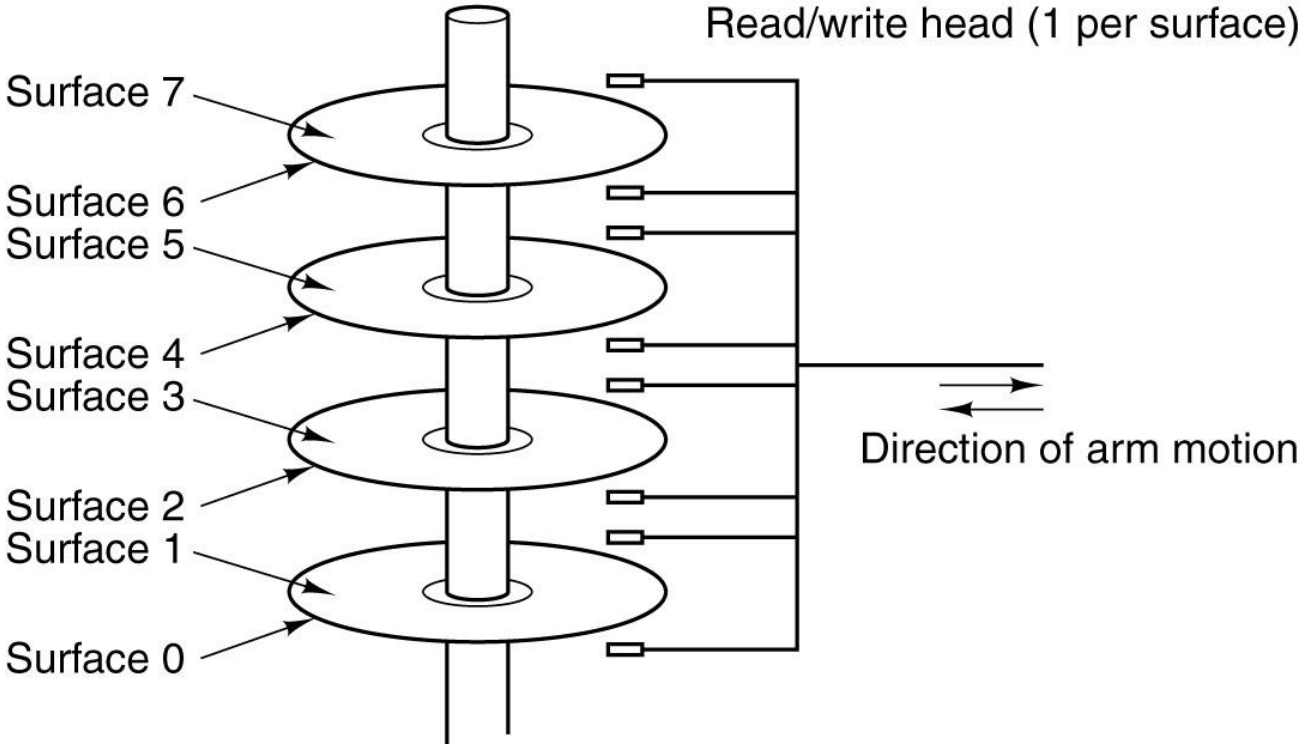
Magnetic storage: floppy disks

1. Capacity
   - 360kB (DD), 720kB (DD), 1.44MB (HD)
   - 100MB, 250MB, 750MB (Zip)
2. Writing ability: can protect writing
3. Performance
   - Transfer rate: 250/500/1000 kB/s
   - Access time: 90 msec/ 30 msec
4. Reliability
   - Avoid
     - Magnetic sources (speakers)
     - Cold/Heat
     - Water/Dirt
   - Long lifetime if kept in a safe environment
   - Very noisy



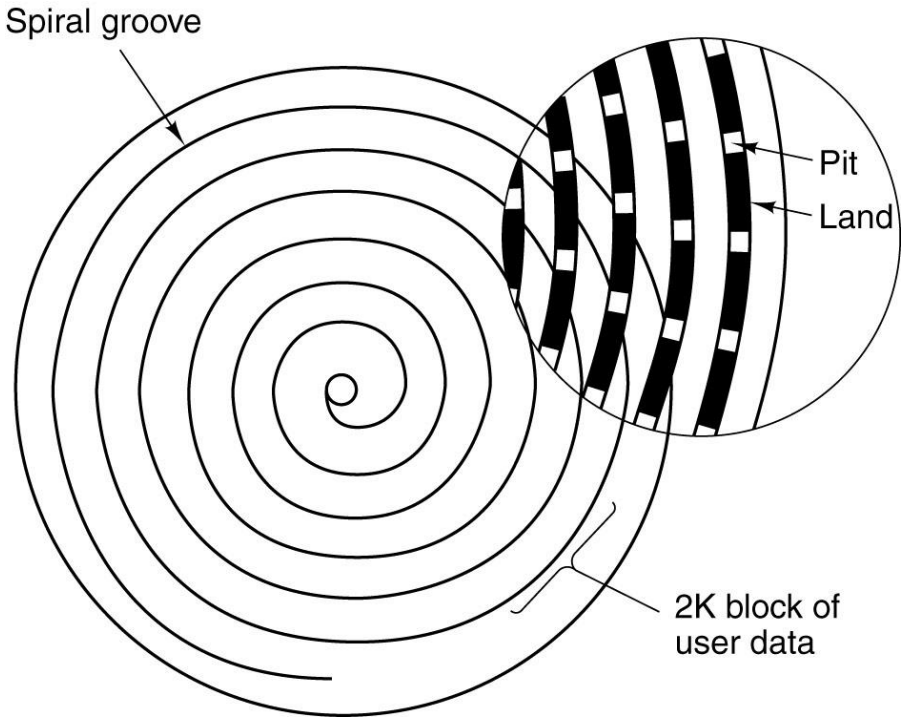
Magnetic storage: Magnetic Disks

A disk with four platters.



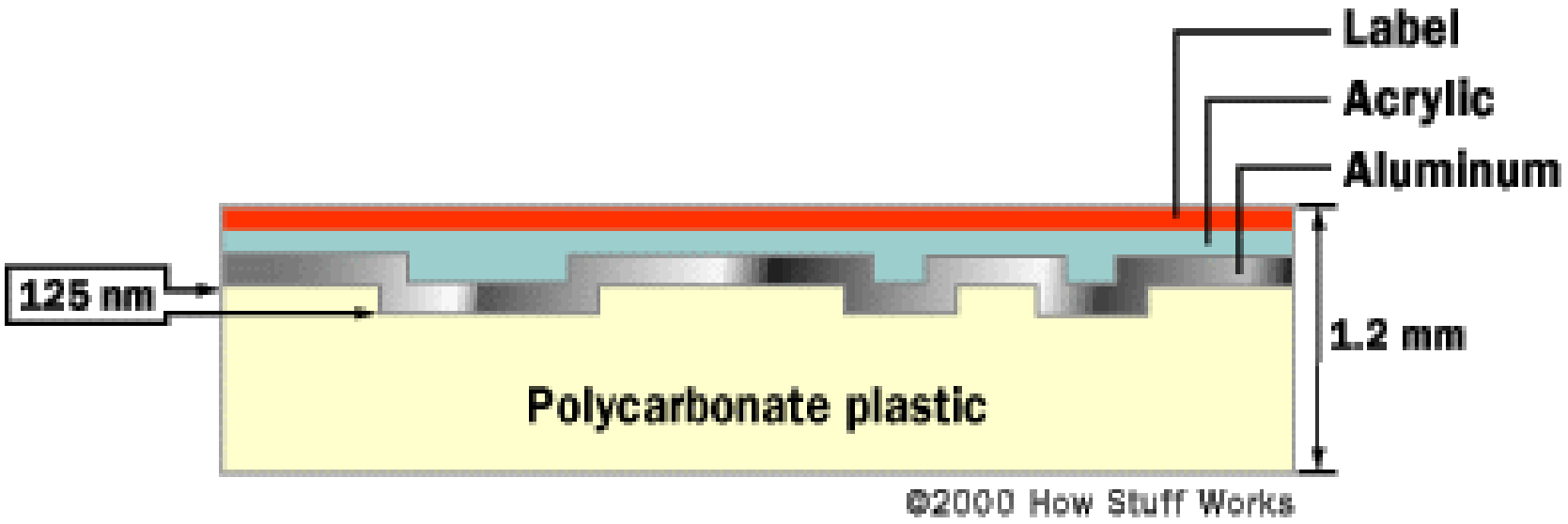
Optical Storage: CD-ROMs

Recording structure of a Compact Disk or CD-ROM.



Optical Storage: CD-ROMs

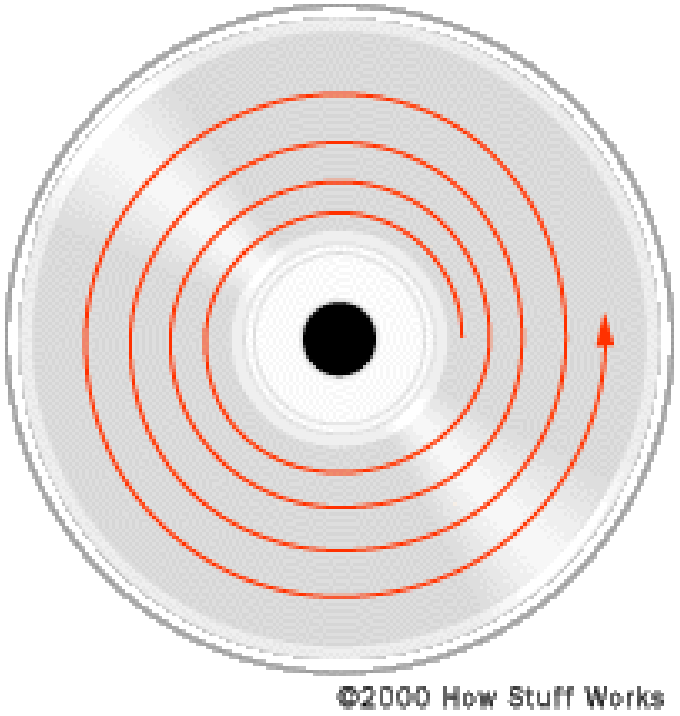
- Data: pits and lands
  - Bit 1: transition between pit and land
  - Bit 0: flat



Optical Storage: CD-ROMs

Laser reads the data from the bottom

CD= Compact Disc

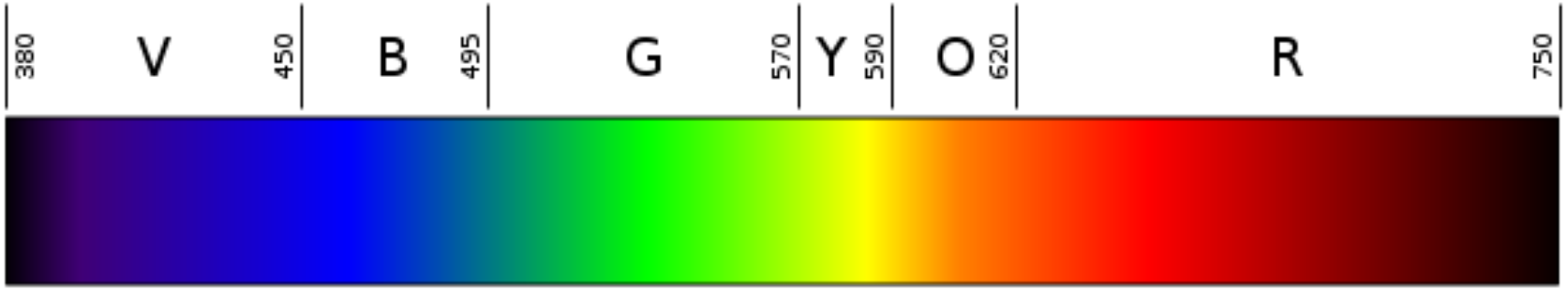


Optical Storage: DVD/BD

CD vs DVD vs HD-DVD/BD

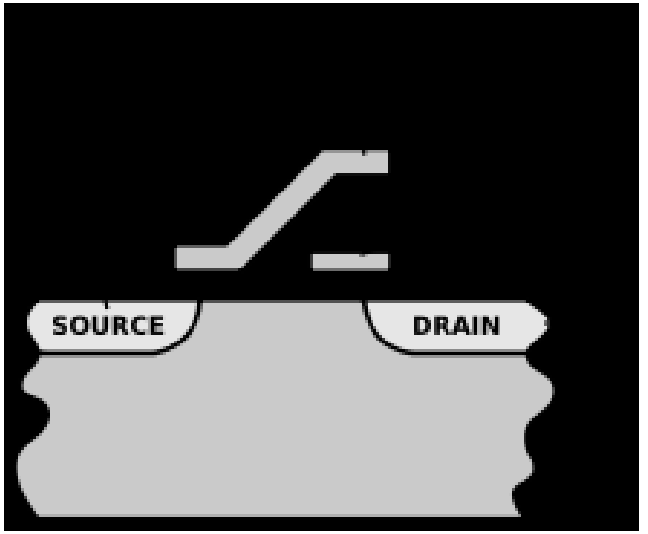
Type of laser

- CD: 780nm (infrared)
- DVD: 635nm or 650nm (visible red)
- HD-DVD/Blu-ray Disc: 405nm (visible blue)



Solid state storage

- Memory cards
  - For Digital cameras, mobile phones, MP3 players...
  - Many types: Compact flash, Smart Media, Memory Stick, Secure Digital card...
- USB flash drives
  - Replace floppies/CD-RW
- Solid State Drives
  - Replace traditional hard disks



Solid state storage

- Uses flash memory
  - Type of EEPROM
    - Electrically erasable programmable read only memory
  - Grid of cells (1 cell = 1 bit)
  - Write/erase cells by blocks
- Cell=two transistors
  - Bit 1: no electrons in between
  - Bit 0: many electrons in between

Solid state storage

- Many SSD devices combine flash (non-volatile) memory with DRAM (volatile) memory to improve performance
  - DRAM cache
  - May have energy storage (capacitor) built in to allow flushing DRAM cache to flash memory in case of power loss.
- Size
  - Very small: 1cm² for some memory cards
- Capacity
  - Memory cards: up to 32 GB
  - USB flash drives: up to 32 GB
  - Solid State Drives: up to 16 TB (SAMSUNG)

Storage: Holding Data for Future Use

Hybrid hard drives (HHDs or SSHD)

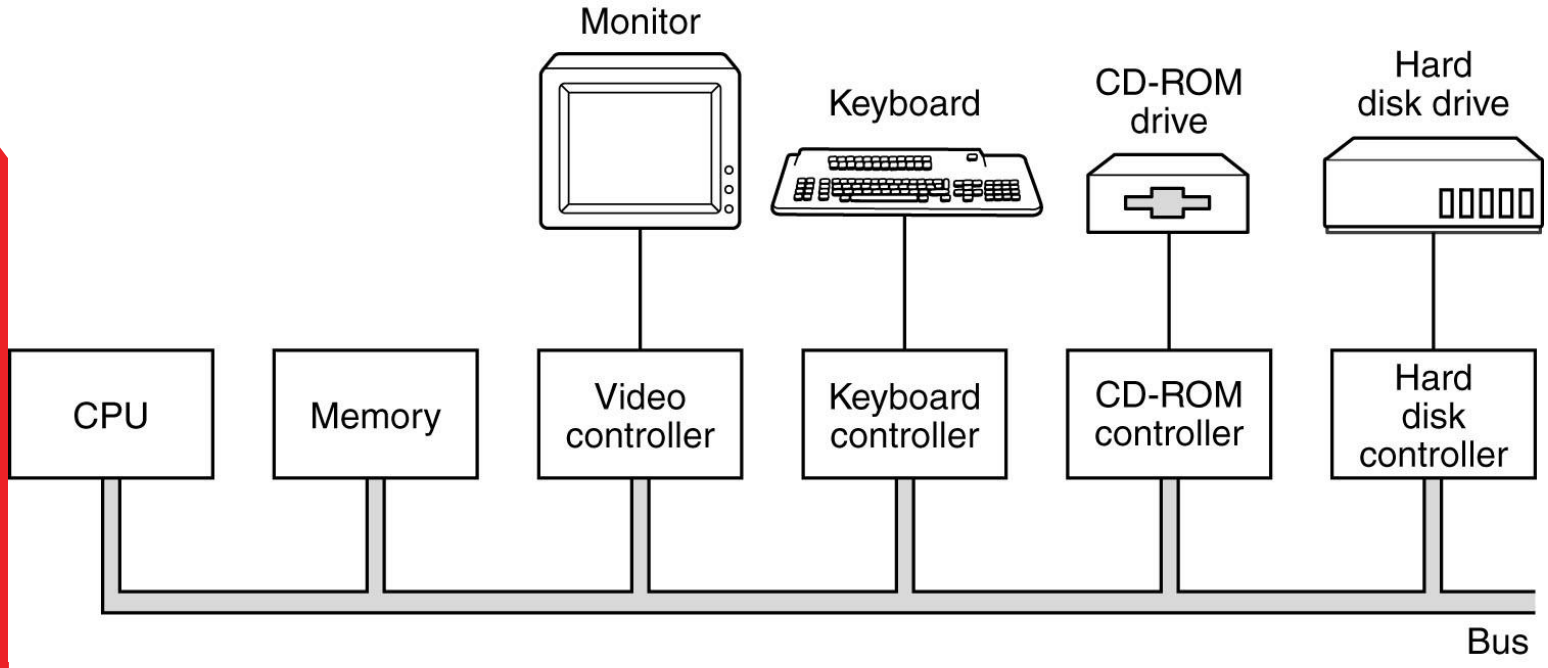
- Incorporate flash technology to speed up the boot process
- Affordability, performance with a high storage capacity

USB flash drives

- Popular **portable** or **removable storage devices**
- Replace legacy technology of floppy disks and Zip disks
- Should be removed only when not actively in use

Recap: Personal Computer

Logical structure of a simple personal computer.



Computer Input Devices

- Any Device that is used to provide data or control to a computer
- Different types, based on:
  - Type of input mechanism – keys, wheel etc.
  - Continuous or discrete input
  - Degree of input, 2D-3D etc.
- Classification
  - Keyboards
  - Pointing devices: Mouse, joystick...
  - Audio: Microphone, MIDI
  - Imaging and Video: Webcam, scanner, Fingerprint scanner...
  - Other: game controller, remote control
  - Haptic devices (Tactile feedback)

Input Devices: Giving Commands

Principal input devices include

Keyboard

- Most common input device—enables data and instruction entry through the use of a variety of keys
- Alternate keyboards such as virtual keyboards

Pointing devices such as the computer mouse

- Optical—most popular pointing device – does not work in the air
- Alternate Mice such as Trackball, Pointing stick, Touchpad (also called a trackpad), Joystick, Stylus, Touch screen

Input Devices: Giving Commands

Alternative input devices include:

Microphones for speech or voice recognition

Scanner for optical character recognition (OCR)

Bar code reader – hand-held or desktop

Radio frequency identification (RFID reader)

Magnetic stripe card reader e.g. reads credit card info

Biometric input device

Digital cameras and digital video cameras

Webcams

Pointing Devices

Audio Input

Microphones:

- Used to record sound
- Can be used with speech recognition software

MIDI input devices

MIDI data consists of notes characterized by:

- Pitch (height of the note: e.g. C#)
- Start
- Sustain
- Release

Instruments defines the timbre

Others: Games Controllers

Mostly button based + pointing device

Joystick, Joypad

Specialised game controllers

- Wheel + pedals, Yoke (aircraft), light gun
- Wii: motion sensor (3D accelerometer), position (infrared)

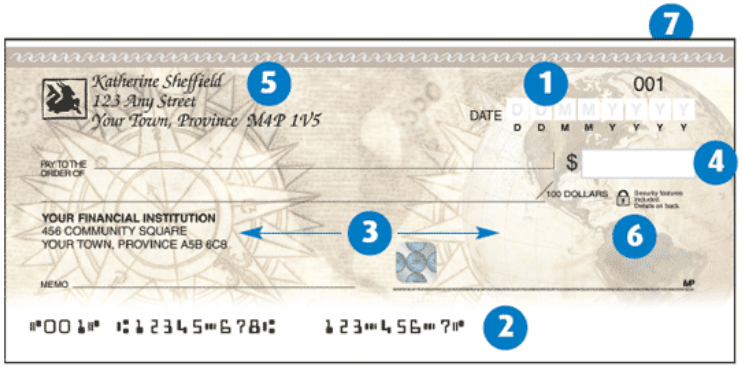
Force feedback information

- Mostly rumble

- Gloves

Source Data Automation

- Data entered into a computer without key entry
- Two types of scanner used: Contact and Laser
  - Both types depend on bouncing a light beam off an image, then measuring the reflected light to interpret the image
  - Contact scanners must make contact (with the paper); laser scanners can read data passed near the scanning area



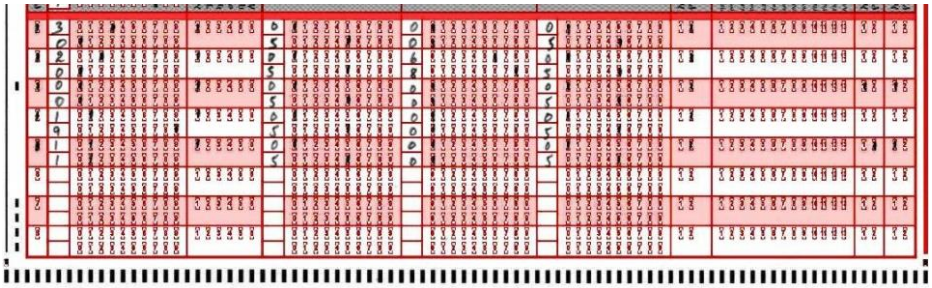
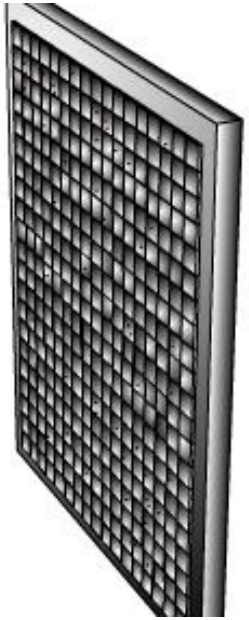


Image Entry

Wide variety of devices to record and process images/video

- Scanners
- Digital Cameras
- Web Cams



- charge coupled device (CCD)
- complementary metal oxide semiconductor (CMOS) array

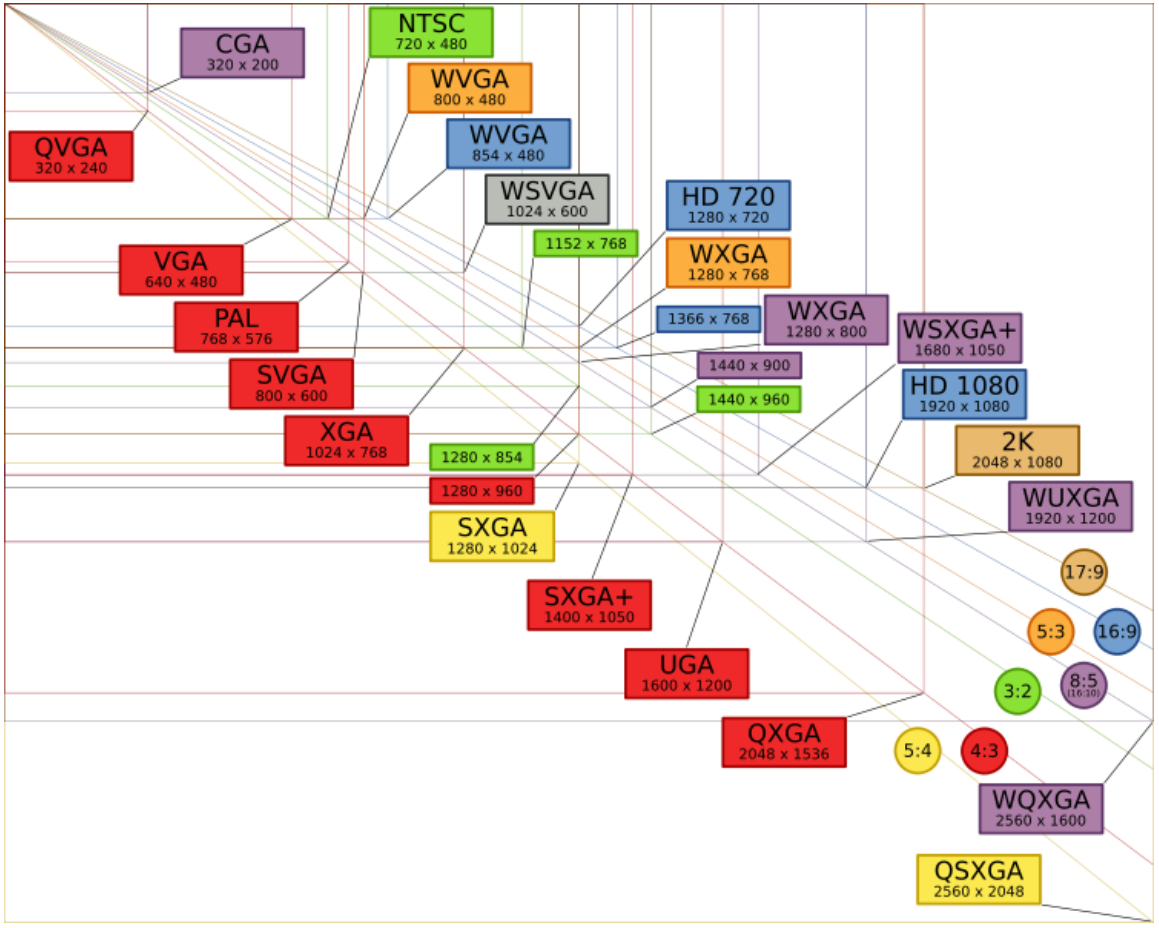
Output Devices: Engaging Our Senses

- Principal output devices
- Enable users to see, hear, or feel the end result of processing operations
- Most commonly used output devices
  - Monitors (and other types of display terminals)
  - Printers
  - Audio output devices (such as speakers and headphones)

Computer Output Devices

- Any Device that a computer uses to output data to a user
- Main types of devices
  - Monitors
  - Touchscreens
  - Tablet PC
  - Interactive whiteboards
  - Projectors
  - E-Readers
  - Printers

Computer Output Devices



Output Devices: Engaging Our Senses

Printers

Supply a **hard copy** of output displayed on a computer's monitor. Types include:

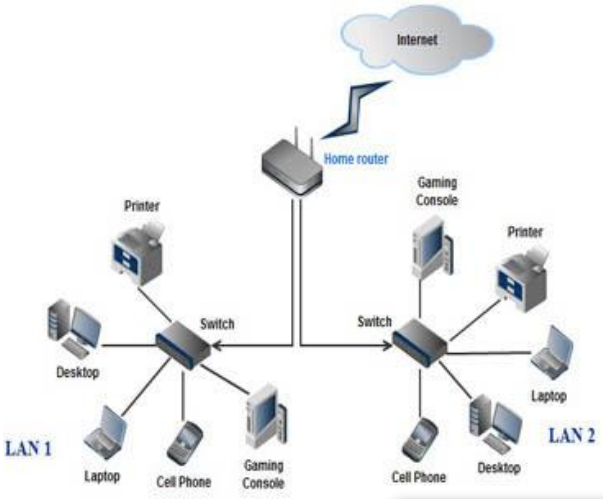
- Inkjet; Laser
- Dot-matrix
- Thermal-transfer (sometimes called dye sublimation printers)
- Photo; Plotters

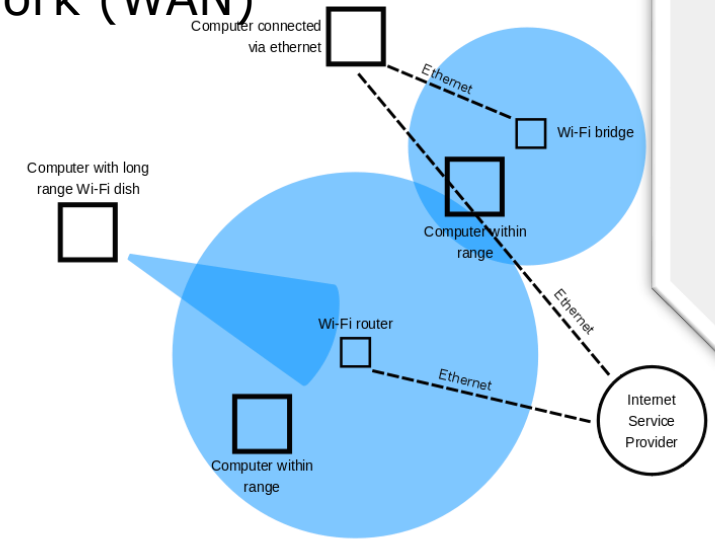
Inkjet (nonimpact)—popular with home users. Provide excellent images—made up of small dots

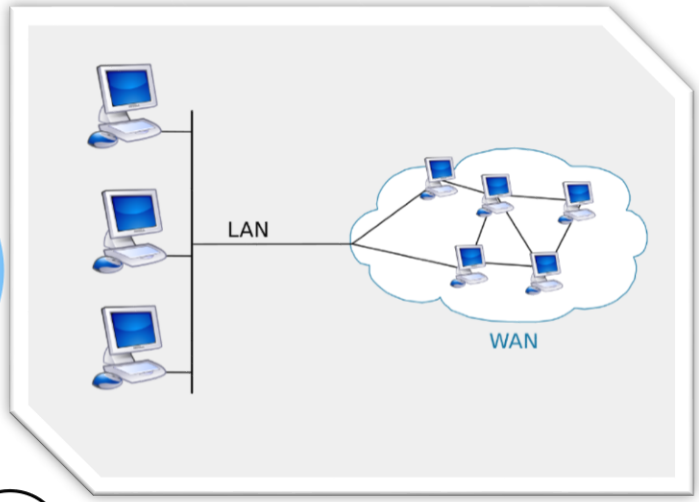
Laser (nonimpact) —Use electrostatic reproductive technology to produce high-quality output

Communications and Networking

- Radio
- Bluetooth
- WiFi
- Local Area Network (LAN)
- Wide Area Network (WAN)
- Cloud







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Busses

Buses

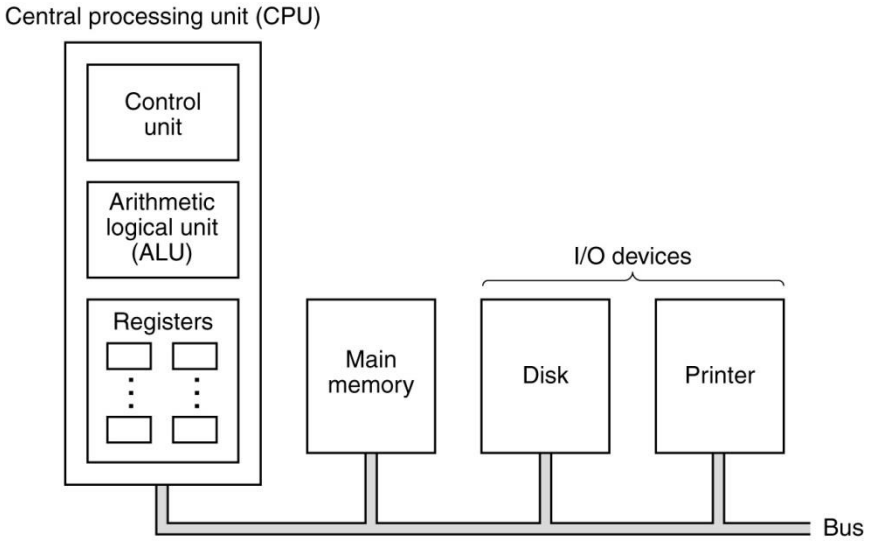
- What is a Bus?
  - A bus is a data communications connection between two or more communicating devices.
- What does a Bus carry?
  - Electrical Power.
  - Control Signals.
  - Memory Address.
  - Data.

Different Buses

- Buses that work in sync with CPU and system clock are called the local buses or system buses
- Buses that work asynchronously with the CPU are called the expansion buses.
- Example: The Memory bus is a local bus while the PCI bus is an expansion bus.

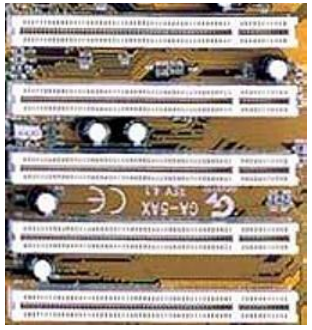
Bus Arrangement

- All components attached to bus (STD bus)
- Due to Moore's law, more and more functionality exists on a single board, so major components are now on the same board or even the same chip



Bus Physical Implementations

- Parallel lines on circuit boards (ISA or PCI)
- Ribbon cables (IDE)
- Strip connectors on mother boards (PC104)
- External cabling (USB, Firewire, thunderbolt, etc)



Bus evolution

USB – Universal Serial Bus

- Allows 3 speeds 1.5 Mbit/s, 12 Mbit/s and 10Gbit/s
- Replaces the slow serial and parallel ports.

Firewire

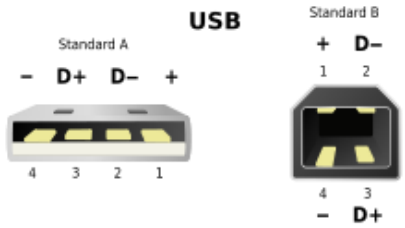
- Data Speeds as high as 400 Mbit/s.
- Replacing the High speed, High volume peripheral devices like network cards, DVD etc.

AGP – Accelerated Graphical Port

- Has 32 Bit Data path and Run at Memory Bus Speed.
- Designed to provide fast access to video. Has replaced VESA & PCI Buses for Video output.

More – PCI-Express, USB 3.0, Bluetooth, Thunderbolt!

Bus evolution

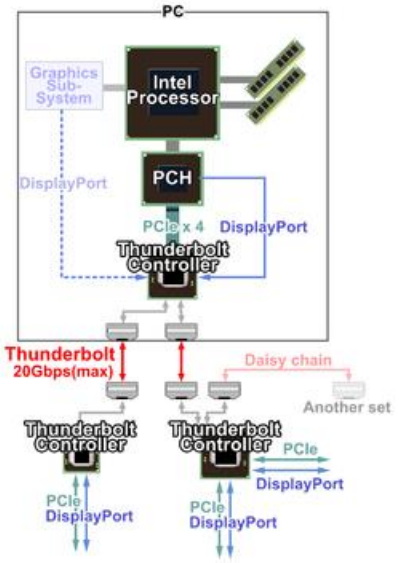


USB – Universal Serial Bus

Design goals.?

- Users must not have to set switches or jumpers on boards or devices
- Users must not have to open the case to install new I/O devices
- There should be only one kind of cable, good for connecting all devices
- I/O devices should get their power from the cable
- Up to 127 devices should be attachable to a single computer
- The system should support real-time devices (e.g., sound, telephone)
- Devices should be installable while the computer is running
- No reboot should be needed after installing a new device
- The new bus and its I/O devices should be inexpensive to manufacture

Bus evolution



Thunderbolt

- Code name Light Peak – developed by Intel
- Introduced by Apple in 2011 – using DisplayPort connector
- Combines PCI Express with Displayport – as a serial data interface
- Initially optical, then copper to save costs
- Currently used for Graphics, mass-storage, displays etc.
- Future directions will emerge.

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Single Bus Problems

- Lots of devices on one bus leads to:
- Physically long buses
  - Propagation delays – Long data paths mean that co-ordination of bus use can adversely affect performance
  - Reflections/termination problems
- Aggregate data transfer approaches bus capacity
- Slower devices dictate the maximum bus speed

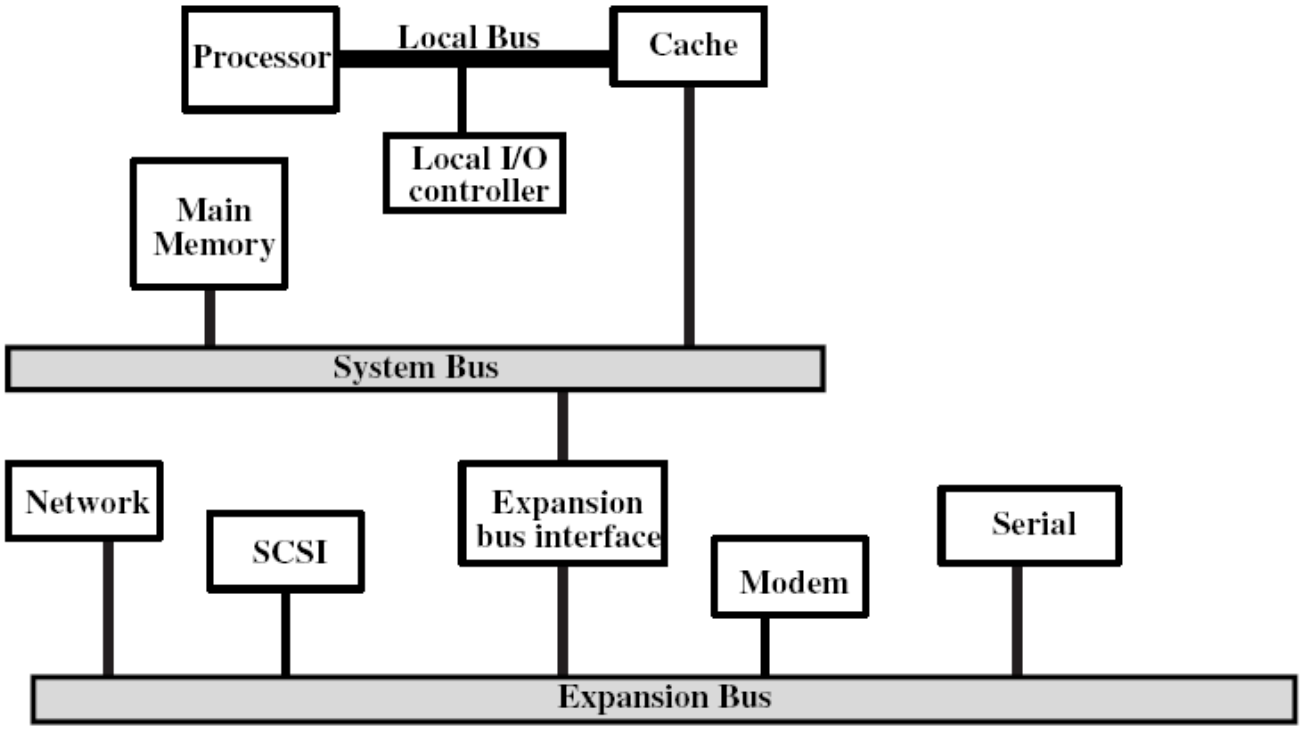
Multiple Buses

- Most systems use multiple buses to overcome these problems
- Requires bridge to buffer (FIFO) data due to differences in bus speeds
- Sometimes I/O devices also contain buffering (FIFO)

Benefits:

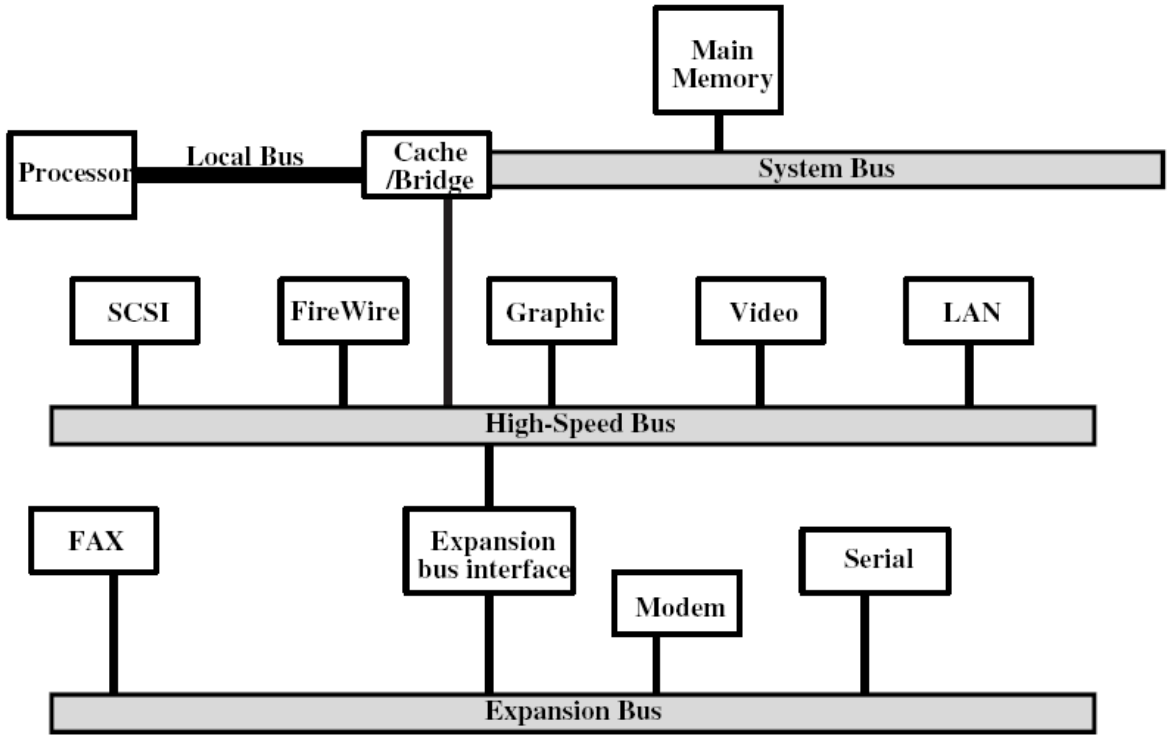
- Isolate processor-to-memory traffic from I/O traffic
- Support wider variety of interfaces
- Processor has bus that connects as direct interface to chip, then an expansion bus interface interfaces it to external devices (ISA)
- Cache (if it exists) may act as the interface to system bus

Expansion Bus Example



(a) Traditional Bus Architecture

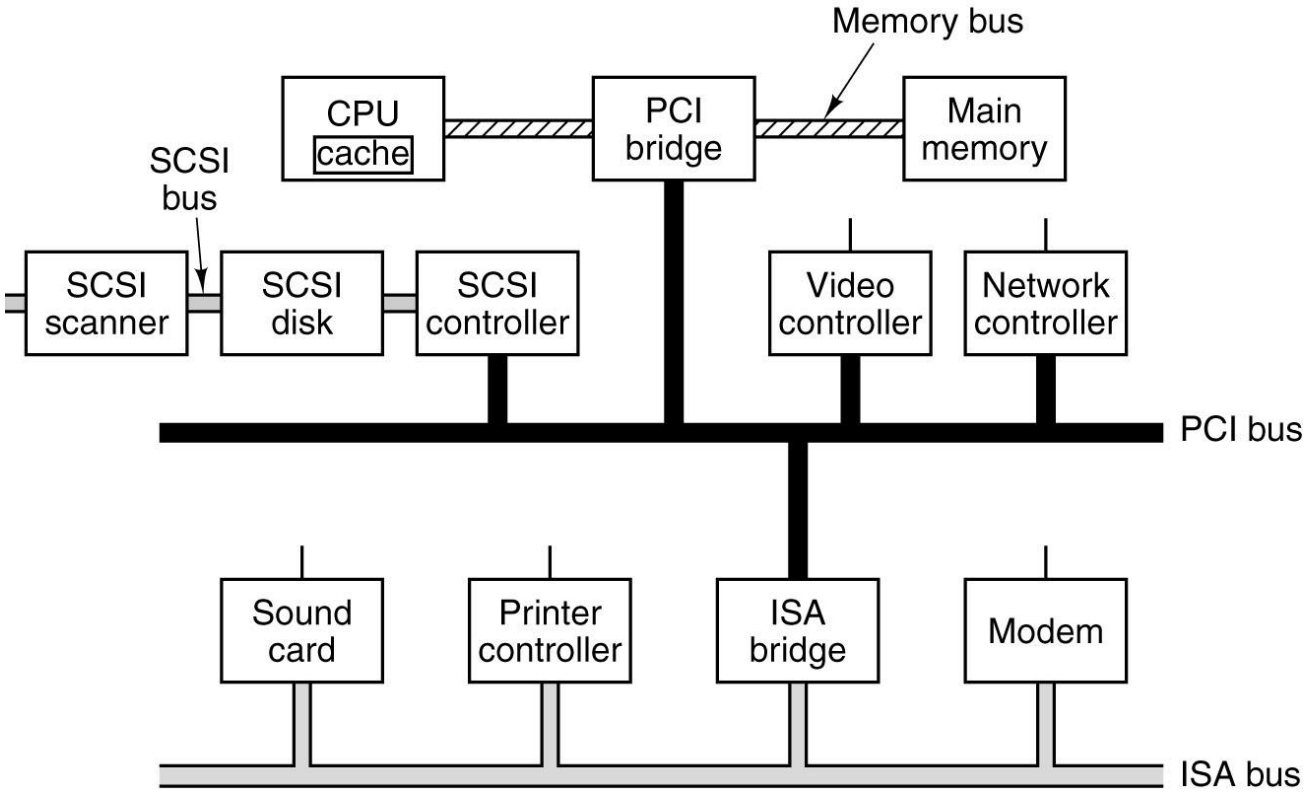
Mezzanine Approach



- Differences in I/O speeds demands separating devices.
- Separate items that are high-speed and those that are not
- An additional high-speed bus is added to communicate with the faster devices and also the slower expansion bus
- Advantage is that high-speed devices are brought closer to processor

Typical Modern PC

A typical modern PC with a PCI bus and an ISA bus.



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Summary

Summary

- Memory
- Primary Memory
- Secondary Memory
- Secondary Memory Storage Technologies
- Input
- Output
- Buses


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Storage Technologies

Three Broad types:

1. Magnetic storage
   - Floppy, Zip disk, Hard drives, Tapes
2. Optical storage
   - CD, DVD, Blue-Ray, HD-DVD
3. Solid state memory
   - USB key, Memory cards for mobile phones/digital cameras, Solid State Drives, MP3 players