Central Processing Unit

Computer Components

- Central Processing Unit
- CPU Characteristics
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- Analogue vs. Digital
CPU

The brains

- **Central Processing Unit**: The “brains” of the computer, which performs the primary computations
- Some computations may be offloaded to other parts of the computer, but the CPU remains the central area of computation
- Each modern CPU consists of hundreds of millions of individual switches, each switch physically constructed as a transistor, with only two states: on or off
- Recent CPU’s in mainstream PC’s are multiple-core, which means two or more CPU units on the same chip
- Multiple core computers are most efficient when the software is able to support **parallel computing**, dividing tasks up to run separately on each core

x86 CPU’s

Based on the old classics

- PC CPU’s are organized around a very basic instruction set called x86 that dates all the way back to 1978
- Became the basis for the very first IBM PC in the early 80’s
- Intel dominant for PC (x86) CPU’s
- AMD in second place for PC’s, offers excellent value and full x86 compatibility, though does not match the high-end Intel CPU’s
- All major PC operating systems – Windows, Mac and Linux – run on the x86 instruction set

Intel PC CPU’s – Mainstream

Mainstream Chip Family: Core i series

- **Core**: Current family of Intel CPU’s from the Core family
  - i7: The high end, found in the most expensive PC’s
  - i5: Midrange, plenty of computing power for most
  - i3: The lower end, but still sufficient for most tasks
- Each new generation of Intel CPU’s in the Core family maintains the i7, i5 and i3 branding, even though there can be significant increases in performance across generations
- **Skylake** 6th generation Core CPU, end of 2015, a “tock”, a major upgrade, with the usual faster speed, graphics, and disk access, faster and more maximum memory
- Skylake also offers USB 3.1, wireless battery charging and wireless docking via **WiGig**, a standard allowing automatic wireless connections with keyboards, mice, and monitors
Other Intel PC CPU’s

Core mobile processors

- Parallel to the desktop series is the mobile series: m3, m5, m7
- Mobile chips are slower, but also consume less power

From the high end to the low end

- Xeon: High-end series of Intel chips for workstations/servers
- Pentium
  - Older, hotter, less efficient design, but still produced
  - Probably better to buy a used system at the same price or pay slightly more to move up in CPU power
- Celeron, which Intel calls “Affordable entry level computing”
  - CPU offered in only the cheapest systems
  - Probably better to buy a used system at the same price or pay slightly more to move up in CPU power

Need for Speed

When speed is of utmost importance, e.g., gaming

- People who want the most of the CPU’s over-clock them, leading to faster than normal processing and excessive heat
- Solution is to liquid cool the CPU and related components

CPU Rankings

From: http://www.cpubenchmark.net/

Figure: Top common desktop processors
CPU Rankings

From: http://www.tomshardware.com

- Photoshop processing in seconds (2015 CPU’s)

Figure: Fastest and slowest common desktop processors

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Smart Phones

Small general purpose computers

- **Smartphone**: Phone that is a small computer
- Dominant leader in smartphone and tablet CPU’s is ARM Limited, with over 90% of the market
- Examples of ARM products include Apple’s iPod, iPhone and iPad, Android phones and tablets, BlackBerry, most Windows Phone and most hand calculators
- ARM has been more energy efficient than Intel’s offerings
- The ARM architecture is licensed by chip manufacturers, and both ARM and its licensees develop the CPU
- Microsoft converted Windows to ARM, as a version of Surface, RT, which, however, has been discontinued due to disappointing sales

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Intel and Smart Phones

Missed the market

- Intel with its CPU’s and Microsoft with Windows and MS Office were the foundation of the dominant PC computing paradigm, both for business and for personal use
- Now PC sales are declining by more than 10% each year
  - Both companies failed to anticipate the importance of the smartphone and tablet markets
  - Intel cut over 12,000 jobs beginning in Spring of 2016
  - Microsoft cut around 25,000 jobs beginning in 2014, mostly related to cell phones from its acquisition of Nokia
- **Atom**: Intel’s smaller X86 processor to compete with ARM
- Intel never did get more than a minor adoption with phones, primarily with some models of Nokia, owned by Microsoft
- After losing billions of dollars on Atom, in April of 2016 Intel formally discontinued the Atom chip in mobile devices

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CPU Characteristics

CPU Clock

CPU runs in cycles

- The CPU does not compute continuously, but rather in a series of discrete cycles
- **CPU clock**: The master coordinator of the CPU cycles, a conductor that synchronizes the CPU and its communication with other components
- Each computer contains a clock in the form of a quartz crystal that vibrates at a specified frequency, each pulse or cycle is a beat, like a metronome

CPU Clock Speed

Number of cycles per second

- Each computer instruction requires a fixed number of cycles
- **Clock speed**: Number of cycles per second the CPU executes
- The clock speed is measured in cycles per second, or hertz, such as 2GHz, which is 2 billion cycles per second
- Overall amount of work accomplished by the CPU depends on both the clock speed and the amount of computing accomplished on each cycle, which varies from CPU type to CPU type
- More recent CPU’s run at a slower speed that CPU’s of even the 2006 era, but process more information per cycle
CPU Cache

- **Cache**: High-speed memory area as part of or directly connected to the CPU that keeps a copy of the most recently used data in main memory
- On modern CPU’s, 1MB or more, up to 6 or 8MB or so
- Purpose is to reduce the average time to access memory
- L1 cache is the fastest, is part of the CPU itself and is the first memory accessed by the CPU
- L2 cache is directly connected to the CPU, accessed after L1 cache, bigger and slower
- L3 is the next level, accessed after checking L1 and L2, bigger and slower

Other Components of a Computer

- **Motherboard**: The circuit board that contains many of the electrical components of a computer and provides the electrical connections to these components and the peripheral units

  ![Figure: A motherboard](image)

  The motherboard contains the socket that holds the CPU as well as the GPU, RAM, expansion slots and external communication interfaces such as USB connectors, and the connection to the power supply
**GPU**

Assists the CPU to render a graphic on the screen

- **GPU**: Graphics Processing Unit, specialized processor for computing the graphical displays that appear on the monitor
- Integrated GPU is typically included with the CPU and usually shares RAM with the CPU, usually just fine for most computing tasks
- Discrete GPU is a separate card required for higher end graphics intensive processing, though high-end integrated graphics are suitable for most uses
- Discrete GPU units include their own RAM called VRAM for video RAM
- Primary companies that provide discrete GPU’s are nVidia and AMD
- Recent trend is to also have the CPU offload some computing processing to the GPU

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**RAM**

Effective way to speed up computer

- **RAM**: Random Access Memory, the store of working memory on the computer
- The “random” means that any storage area can be accessed, without having to go in sequential order
- The amount of RAM is at least as important as the CPU in terms of the overall speed of processing
- Minimum recommended is 8GB, especially at around only $5/GB
- RAM chips come in different types and run at different speeds, so important to make sure to have the correct chip when upgrading

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**Hard Disk Drive (HDD)**

Larger and slower then RAM

- A **hard disk drive** is an electro-mechanical storage device that is non-volatile, which means that the information is retained even when power is shut off
- **Volatile memory**: The information is lost when the power is shut off
- The surface of the spinning disk is divided into small sectors, each of which is magnetized in one direction or the other, corresponding to the binary digits 1 and 0
- A bare minimum size for today’s PC’s is 256GB
- External hard disk works well for backing up the computer’s hard drive
Solid-State Disk Drive (SDD)

Much faster than a hard disk drive

- **Solid-state disk drive**: A non-volatile solid-state storage device, which means that the drive contains no moving parts and the information is retained even when power is shut off
- Currently much more expensive than a comparable HDD
- Particularly given cost considerations, entry level is about 256GB, but large drives are not so important now with cloud storage
- More reliable than a HDD, much more durable and much faster
- Same form factor as a HDD for internal drives, so can usually replace the internal HDD, particularly on more recent computers

External Connections: USB

Generic connector

- **USB**: Universal Serial Bus, a standard for connecting external devices to a computer such as a mouse or a storage device
- USB allows **hot swapping**, which means that it can be connected and disconnected while the computer is running
- Previous standard is USB 2.0, a peak (not sustained) data transfer rate of 480 Mbs
- Now becoming the mainstream is USB 3.1, with a data transfer rate of around 10 Gbs with the smaller USB-C connector

Analogue vs. Digital
Information Represented on a Computer

The electronic switch

- The physical state of a computer is as a set of switches, each switch at any point in time either on or off
  - CPU, RAM: each location is a transistor, an electrical switch that is off or on
  - DVD: each location has a pit or is smooth
  - Hard drive: each location has a + or - magnetic polarity
- The state of the switch is represented numerically by a binary numbering system with only two digits
- **Binary digit** or **bit**: 1 for on and 0 for off
- **Key Concept**: All data in a computer — numbers, characters, pictures, sound — are stored as a physical representation of binary digits, as a sequence of 1’s and 0’s

A Stream of Bits that Encodes the Reality of Your World

```
11101011101111000000011000100111110011000010011111
0111100101000100011011001001010000110100011111010
10010100110100010100110111100101101100101010010
010111110100011001010011100100100010000000001111010
00011001001001111101010000000000101001011011001
1010110011101011010110010101110010101100111111111
11110011011101111010101001101010110101101110000
100001101111101011011010101100000000010001011111
1110010001101111101010011010010101100111001000
11010100111000001110001011100100100011010001100
11111000110101011100101011100110010111010110111
110100111000101101001101100101010000100001111101
101011101011100001111100110001110110001101011011
11100010110101011100110111100100101101101101101
1111010011010011111011010110011010010110110110
11010100110110011010111010110011010010010001000
01110010111000011110110110110010110011100100001
100001001101011000011111001100011101000011011001
0000100000000101000000000000000000000000000000
000000000000000000000000000000000000000000000
```

The Analogue World

Continuous gradation

- **Reality**: Analogue, described by wave forms such as light waves and sound waves
- **Analogue map of reality**: Recording devices, such as the black, vinyl records for music, directly store a physical representation of the wave form with its continuous gradations

![Analogue representation of sound waves](image)
Digital recording

Binary digits only

- Digital map of reality: To store information digitally requires a conversion of the analogue world to a binary format
- **Sample rate**: A digital recording samples the waveform many times over a time interval
  - CD generates 44,100 samples per second, 44.1 kHz
  - DVD and Blu-ray Disc standards use 48 kHz
- **Sample size** or bit depth: Number of digits in each sample, such as 16 bits in the default CD recording, which results in $2^{16} = 65,536$ possible levels of gradation for each sample
- **Bit rate**: Amount of data per second the sample rate and sample size generate

Digital Playback

Create the sound waves

- A sensory experience of sound and/or video from a computer requires converting the binary digits or bits to the analogue world of sound waves and/or light waves
- **DAC**: Digital to analogue converter
  - The DAC in a default computer sound card for mass produced computers is usually of minimally acceptable quality
  - Even inexpensive upgrades can provide substantial improvement
  - **DragonFly**, $149: Extremely high value,
  - **EMM Labs DAC2X**, $15,500: Extremely high performance,

Music software

- The software source of music, the music player such as iTunes or Windows Media, can also be upgraded
  - **Mac – VOX**: [http://coppertino.com/vox/mac](http://coppertino.com/vox/mac)
  - **iPhone – VOX**: [http://coppertino.com](http://coppertino.com)
  - **Mac – Audirvana Plus**: [http://audirvana.com](http://audirvana.com)
  - **Windows – MusicBee**: [http://getmusicbee.com](http://getmusicbee.com)
Digital Images

The digital representation of visual reality

- A digital image consists of pixels (PICture ELement), the smallest element of the digital image, which form its dimensions, such as 165px wide by 250px tall.
- Each pixel displays as a color on an output device such as a screen or paper, a combination of the three primary colors for light: Red, Green and Blue.
- Each pixel contains the information for the amount of each primary color, usually one byte (8 bits) each, with decimal values from 0 (none) to 255 (maximum), for 24 bit color, 8*3=24 bits.
- 256 values for each primary color yields 256x256x256 = 16.7 million possible combinations or colors for 24 bit RGB color.
- The digital image is stored as a set of numbers, at least three numbers per pixel, for each pixel in the grid of rows and columns of pixels.