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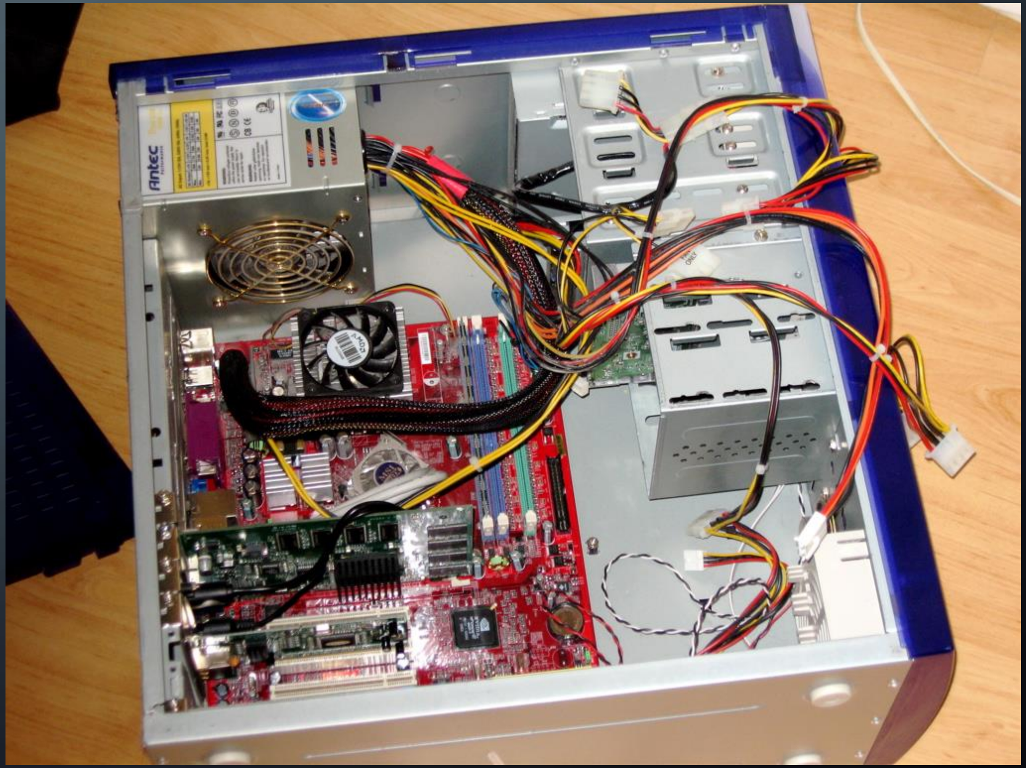
COMPUTER ARCHITECTURE & TECHNOLOGY CONVERGENCE

Lecture 2

A Brief History of Computing

and System Hardware

What's inside your computer?:



PRINCIPAL COMPUTER COMPONENTS

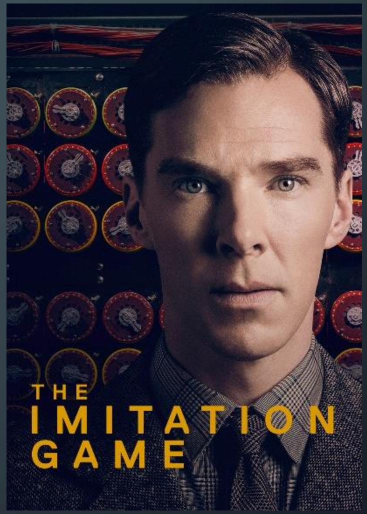
- CPU – Central Processing Unit - coordinates all system actions, executes program instructions.
- Motherboard - connects all components together
- Memory (RAM) – used to store information.
- Hard disk drive (HDD)
- Graphical Processing Unit (GPU) – Converts computer data into content suitable for a monitor.

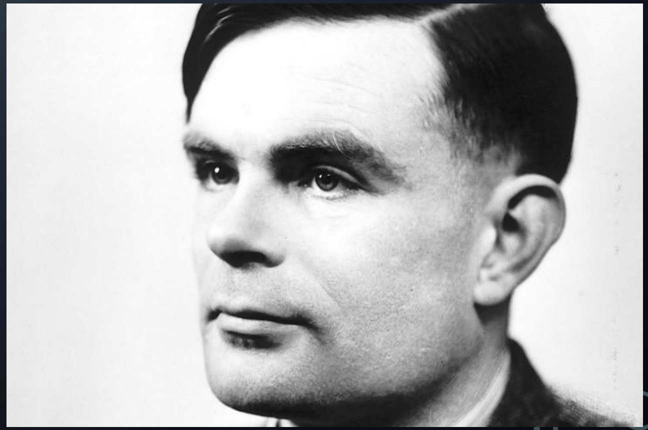
PRINCIPAL COMPUTER COMPONENTS

- Computer case and power supply
- I/O Devices – Input/Output devices, which allow you to receive or display data.
  - Monitor
  - Mouse/Keyboard controller
  - USB ports
  - Ethernet controller

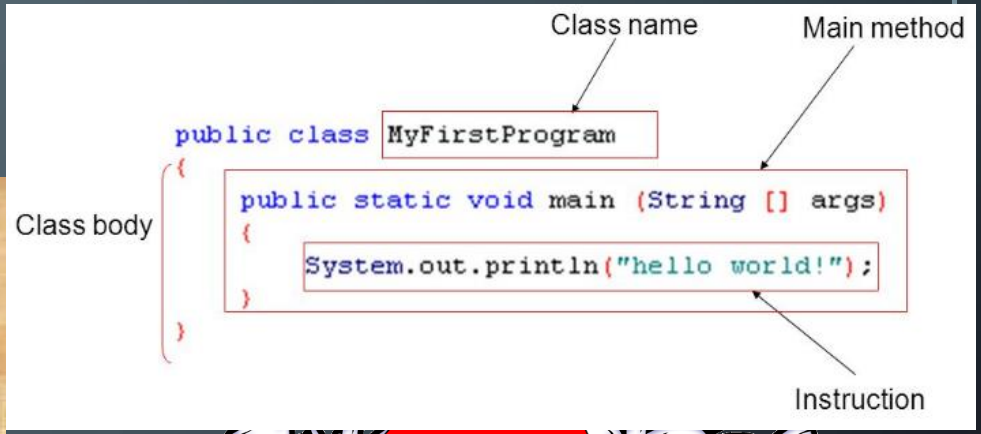
WHERE DID THIS COMPUTER ARCHITECTURE EMERGE FROM?

- Early computing - War-time research
  - WW1 - WW2
- Alan Turing
  - Proposed a universal computational device in 1937
  - Developed Bombe computer to break Enigma Code
  - Estimated to have shortened war by more than 2 years and saved 14 million lives





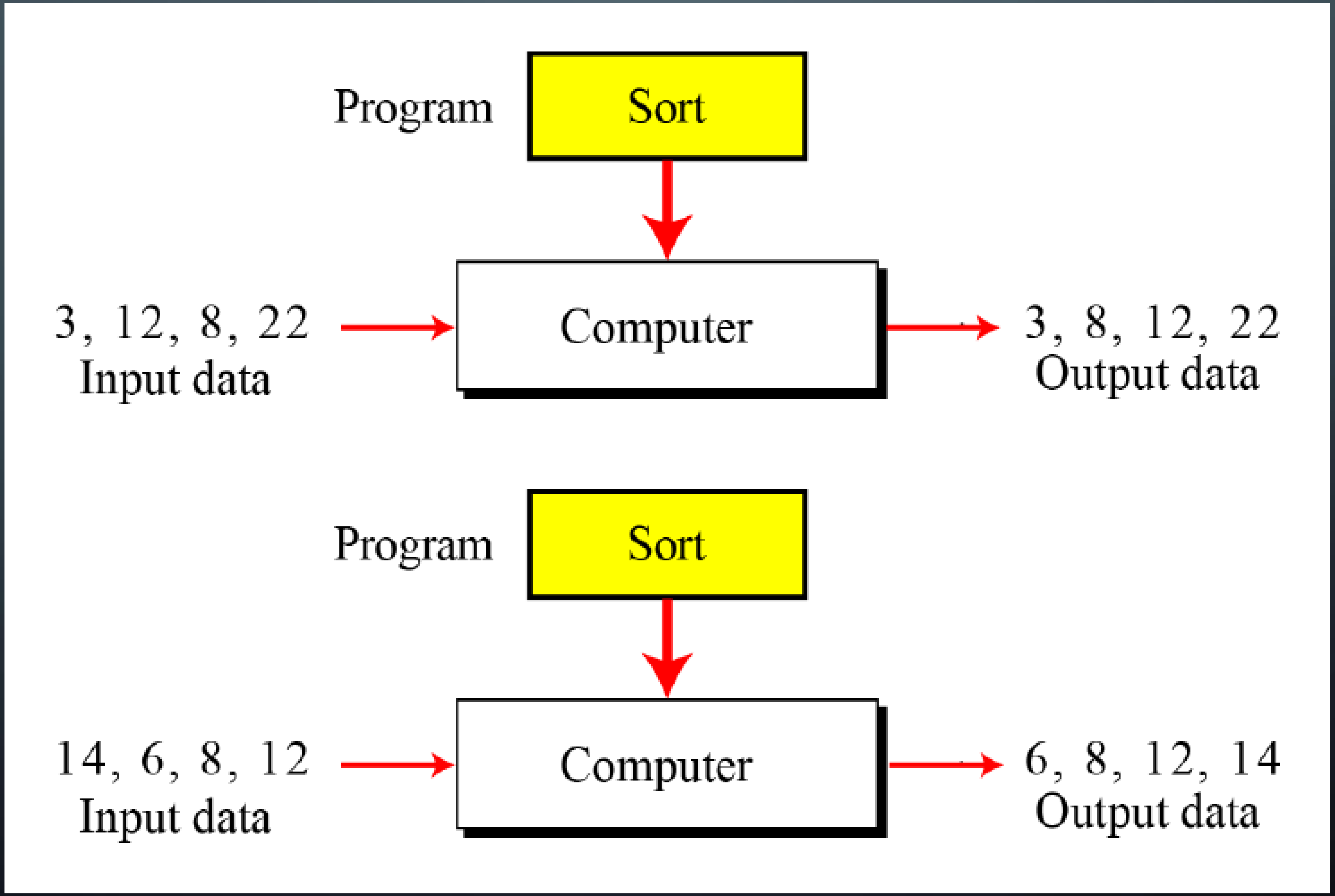
WHERE DID THIS COMPUTER ARCHITECTURE EMERGE FROM?



Program

Input Data → Computer (Data Processor) → Output Data

WHERE DID THIS COMPUTER ARCHITECTURE EMERGE FROM?



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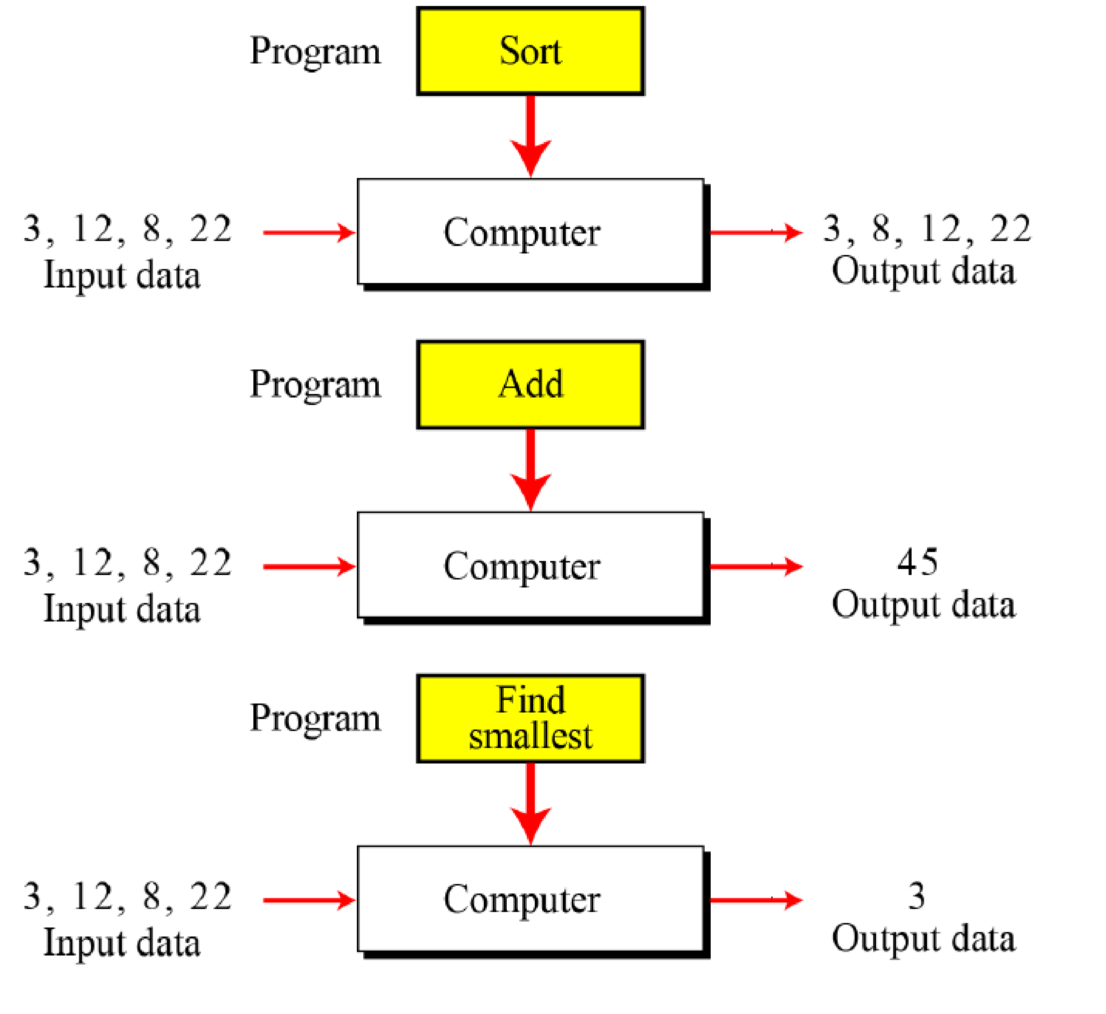
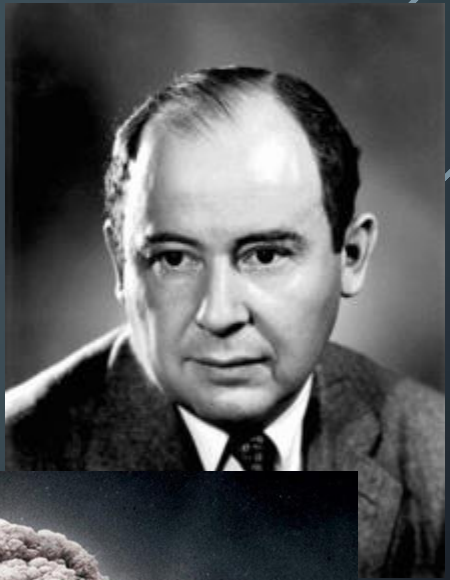


UNIVERSAL TURING MACHINE

- A machine that can do any computation if the appropriate program is provided
- Capable of computing anything that is computable
- All modern computers are Turing complete

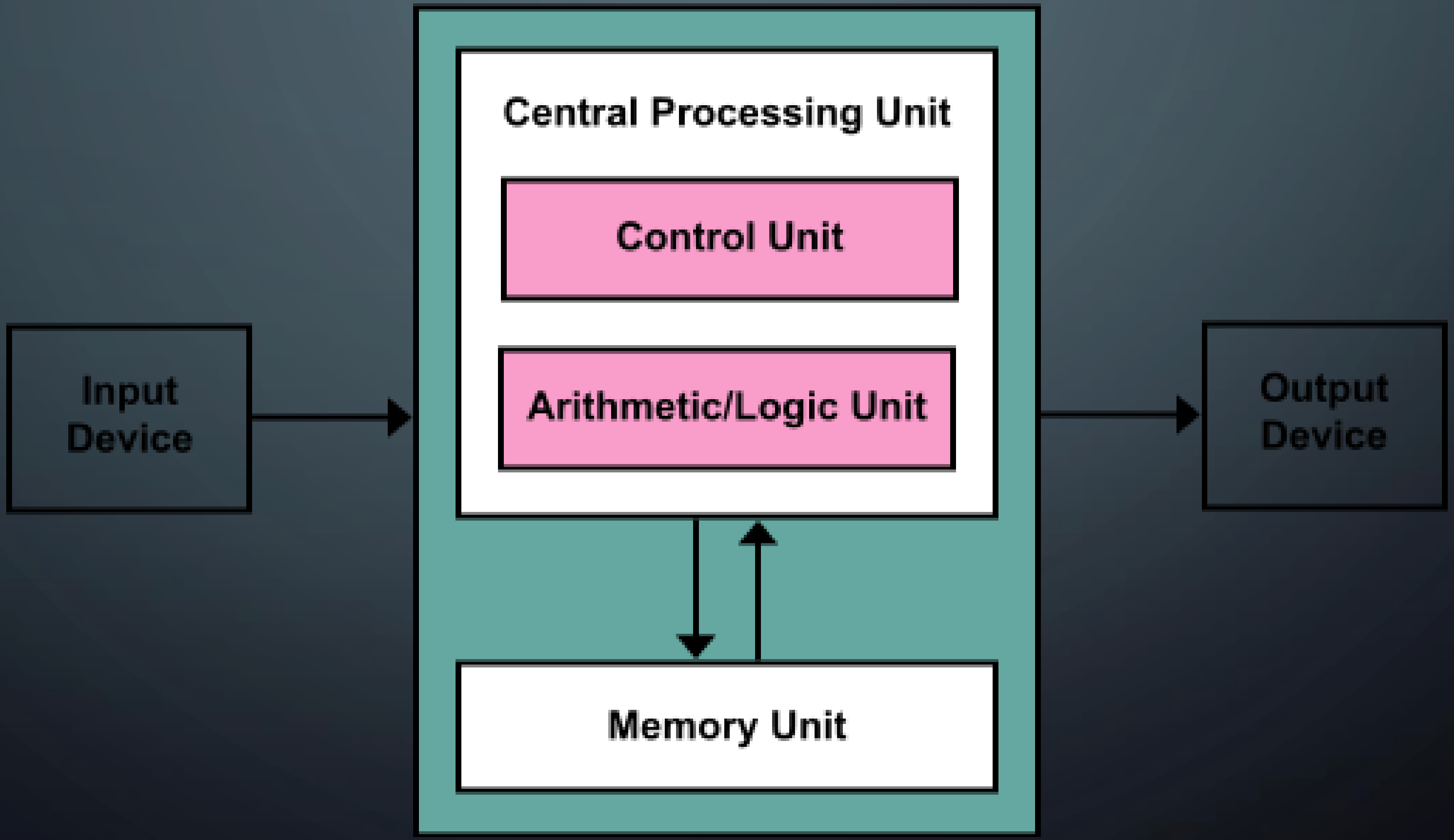
VON NEUMANN



  23543678
x 25379152

???

VON NEUMANN SUBSYSTEMS



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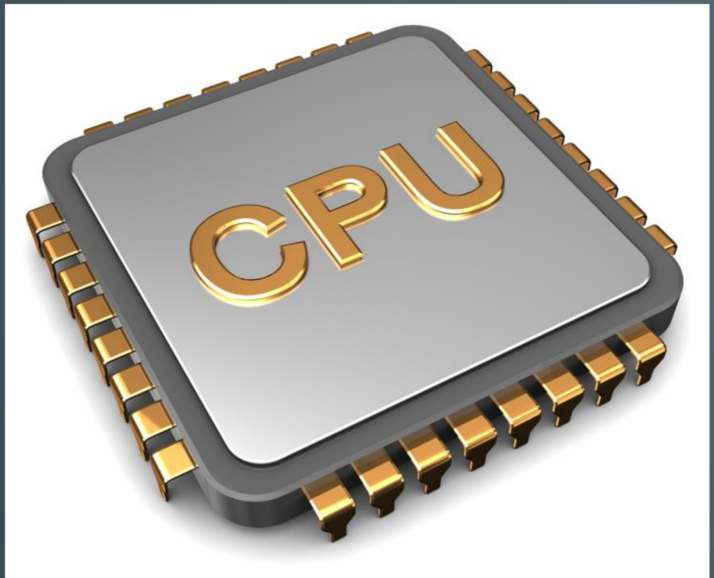
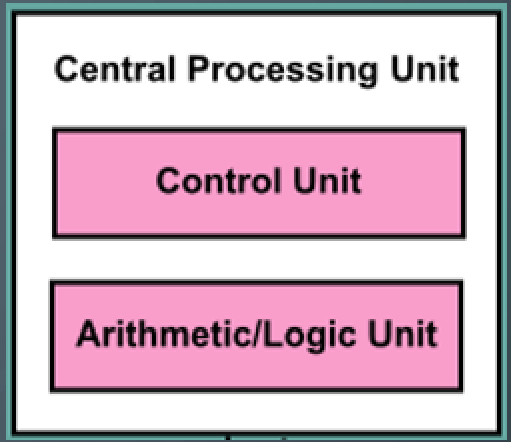
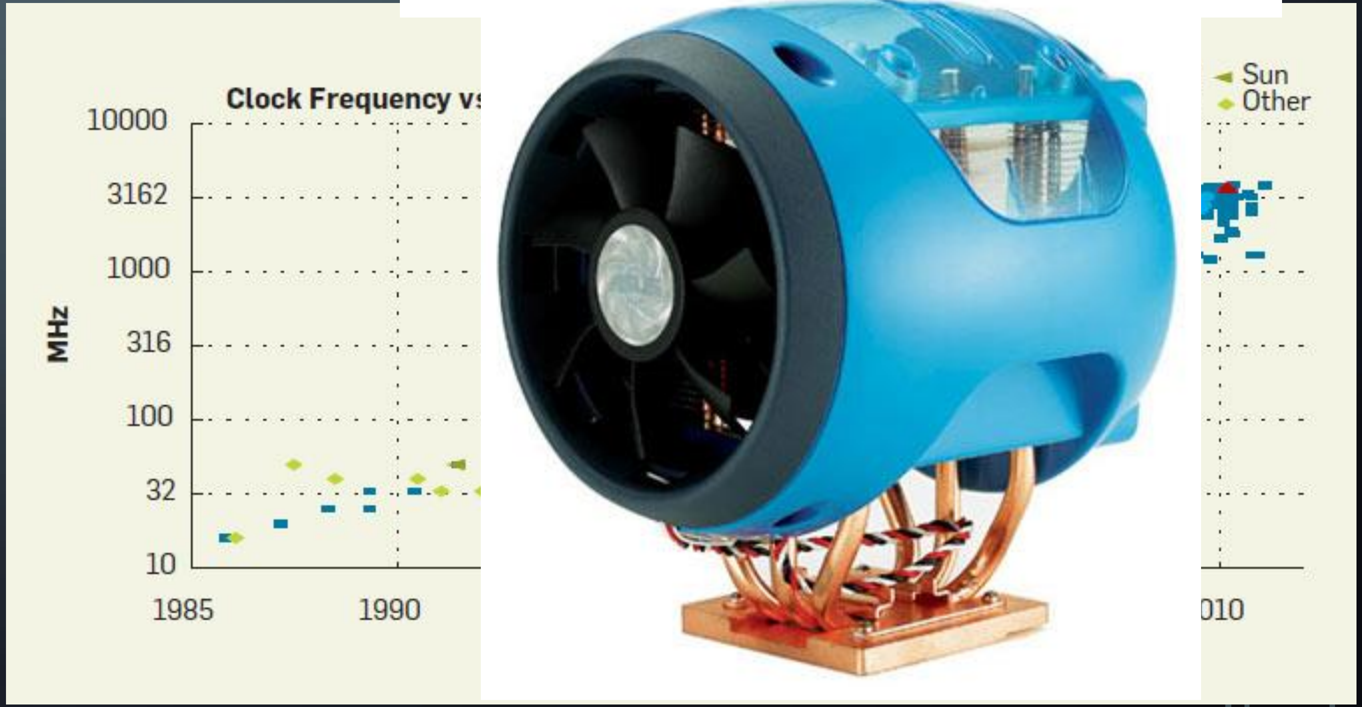




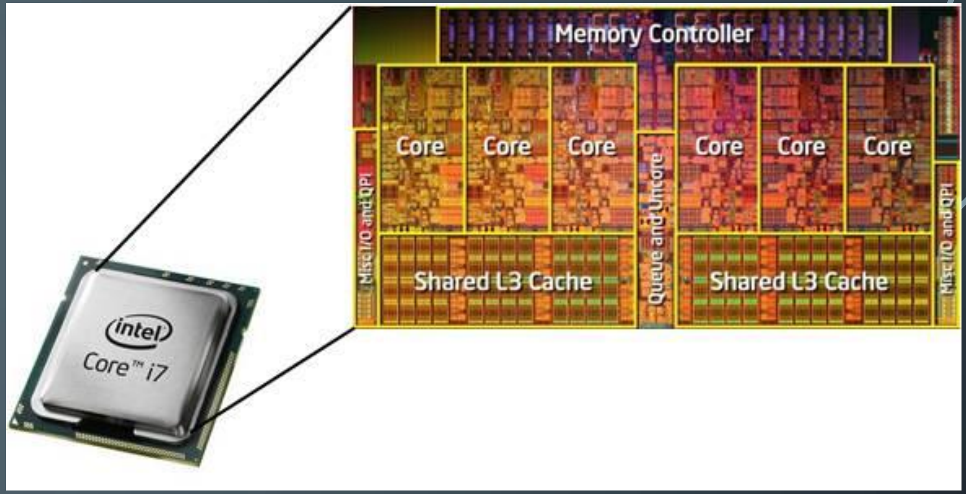
CENTRAL PROCESSING UNIT (CPU)

CENTRAL PROCESSING UNIT

- CPU or Processor for short
- Brain of a computer
  - Does all the computation/work
- Approximately 3x3 cm
- More cores, higher frequency better
  - Higher the frequency -> hotter the chip
  - Multi-core solutions



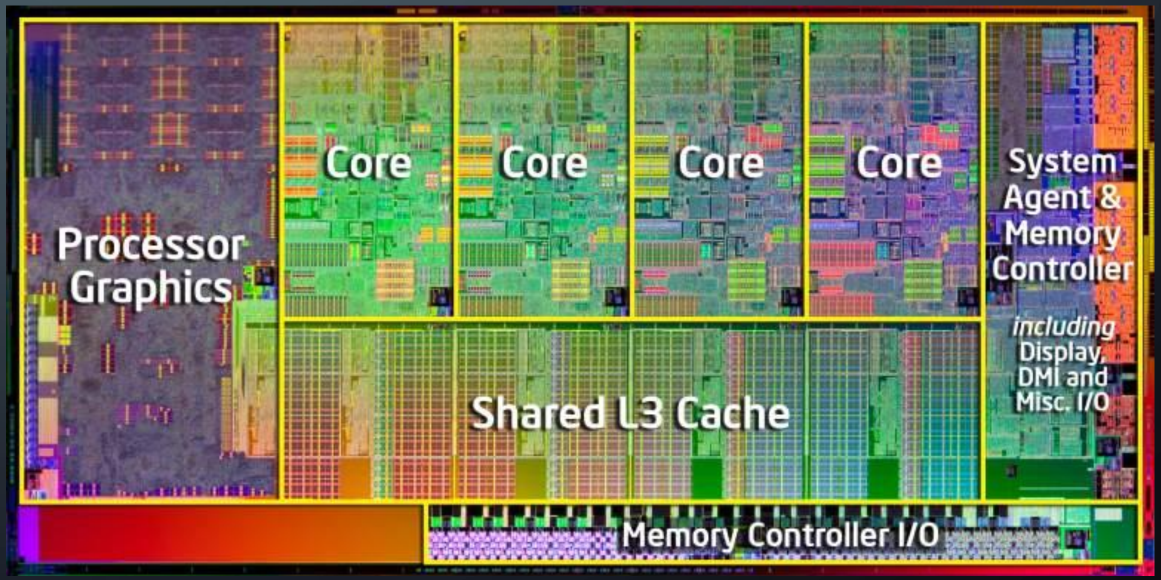
CENTRAL PROCESSING UNIT



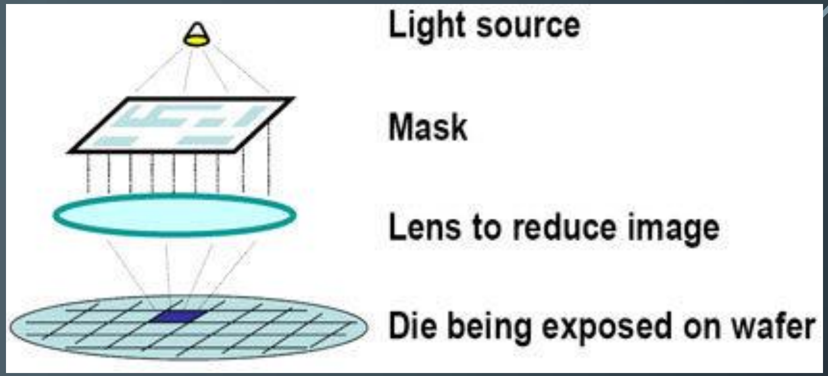
- Current top of the range CPUs have 4-8 cores
  - Intel Knights Landing/Xeon Phi CPU has 72 cores - supercomputers
- Fabricated from silicon – semiconductor technology – transistors
  - Manufacturing process known as Photolithography
    - Most advanced process in the world
- 15 nanometre fabrication (true nanotechnology)
  - Human hair is 80,000- 100,000 nanometres wide
- Massive Intel Fab in Leixlip

CENTRAL PROCESSING UNIT

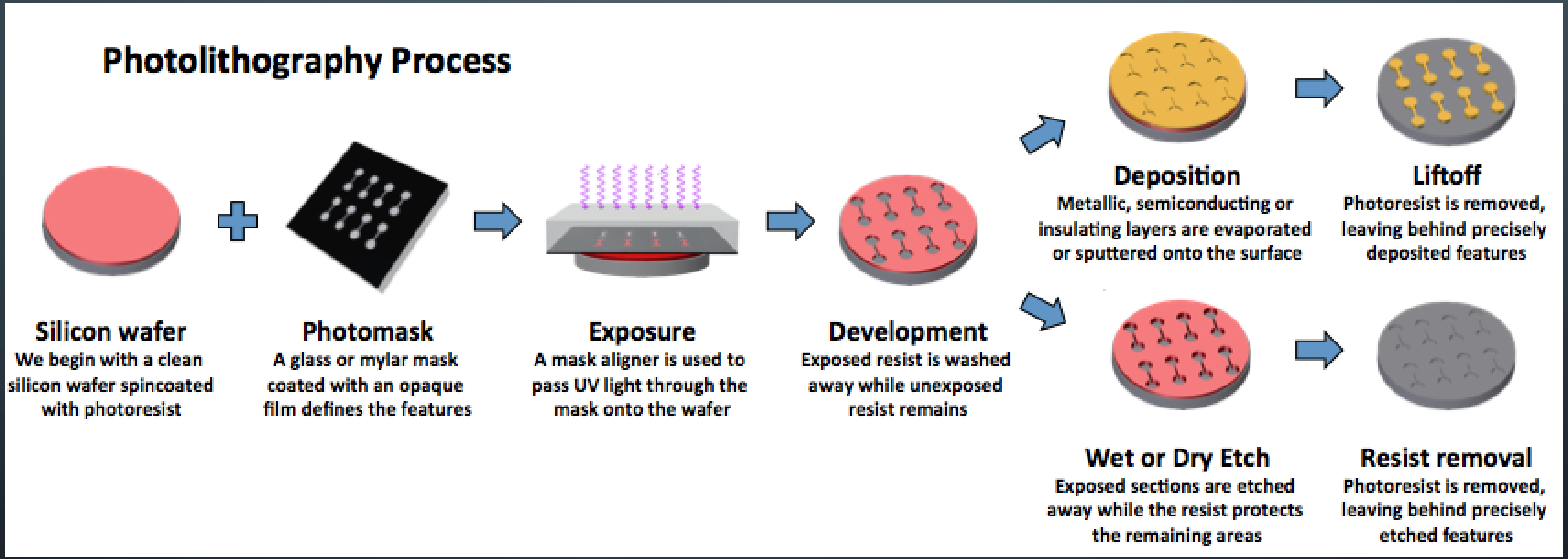
- Integrated Memory (on chip) - called cache
- Can have integrated graphics (on chip) – lower performance
- Current examples – Intel i3, i5, i7; AMD Athlon, Sempron – each has own motherboard socket type
- CPU benchmarks
  - Also available for phones
- Mobile Phones also have CPUs
  - Top of the range are now octa core



CENTRAL PROCESSING UNIT



- Photolithography



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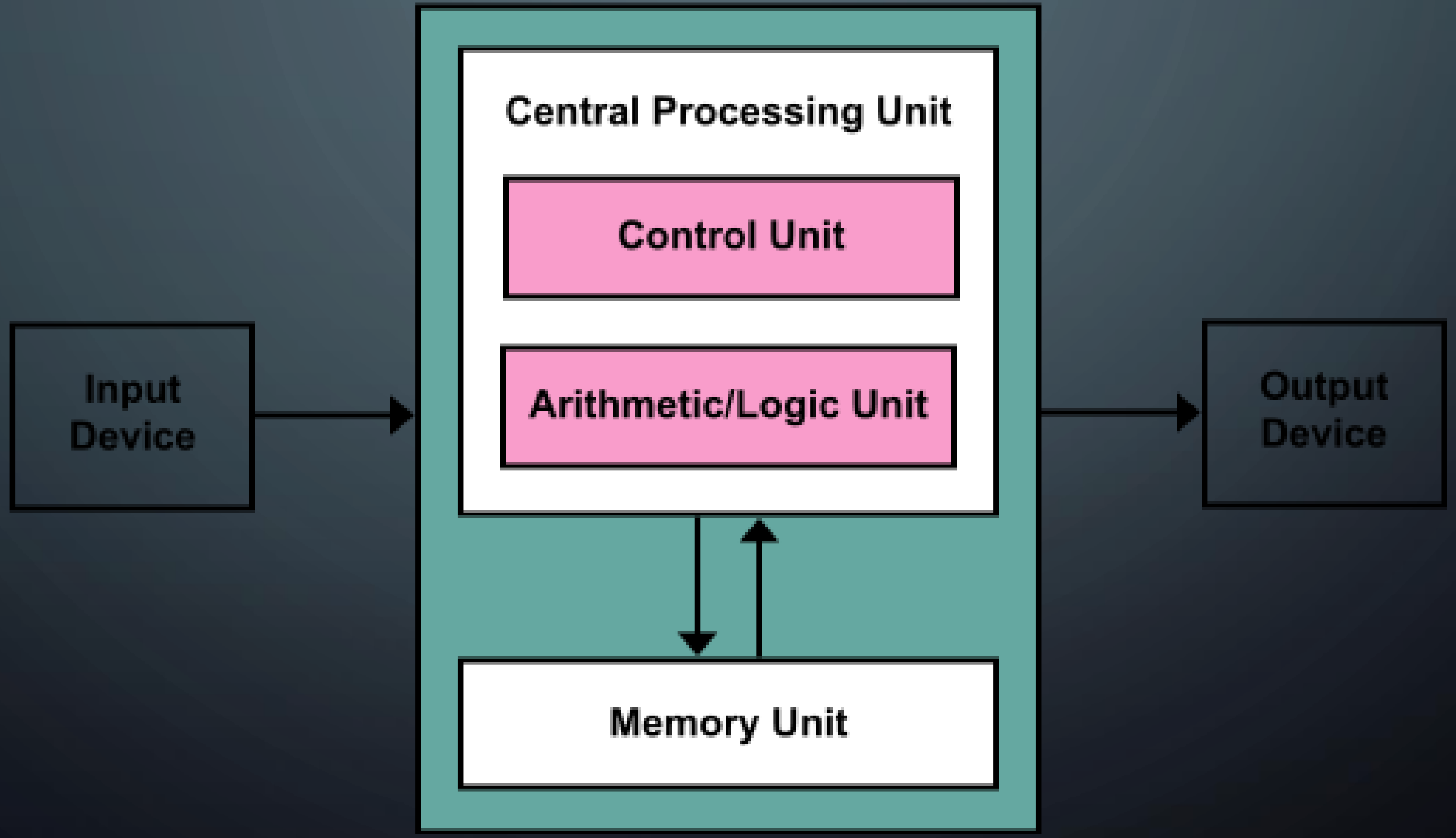
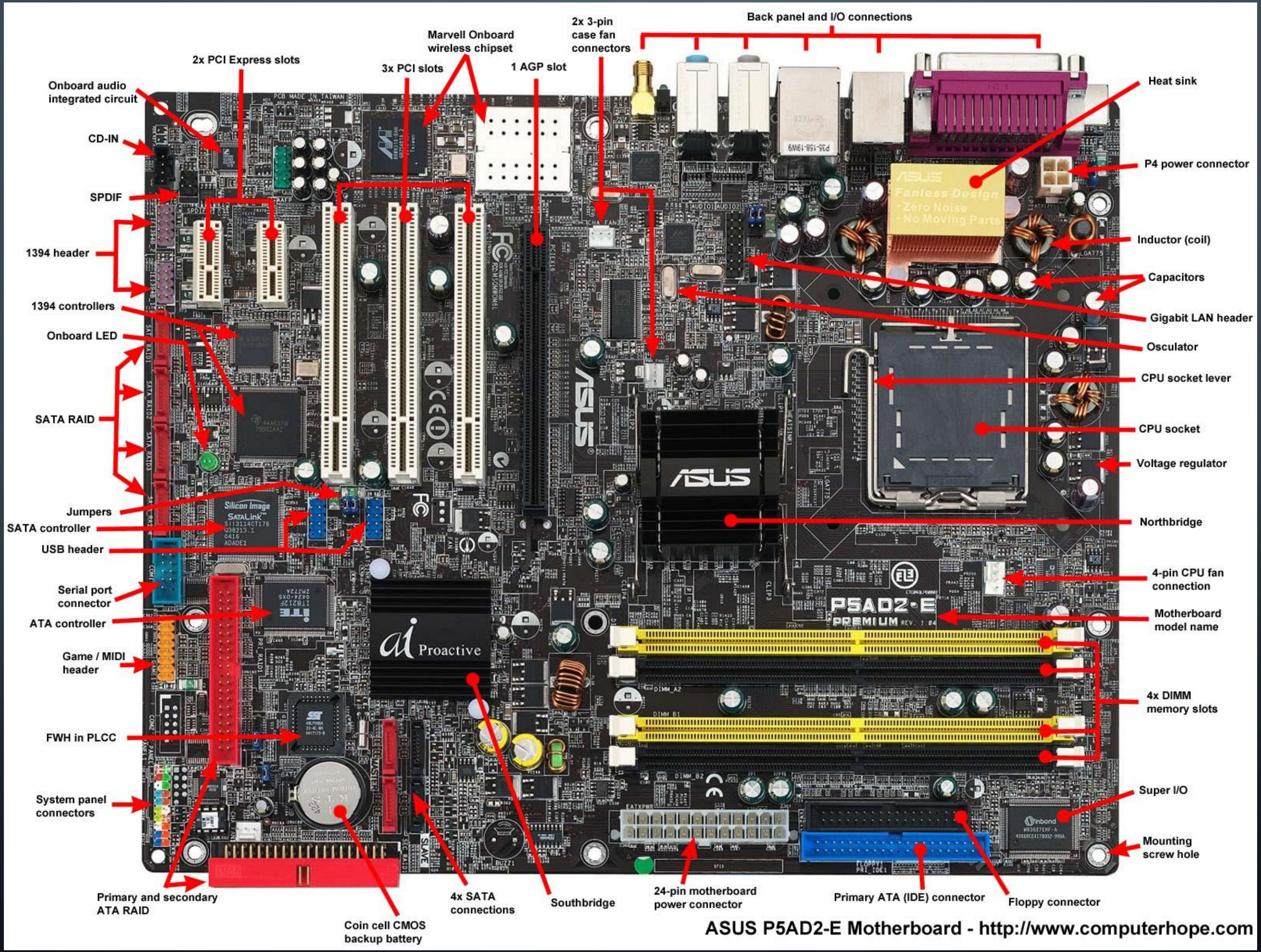
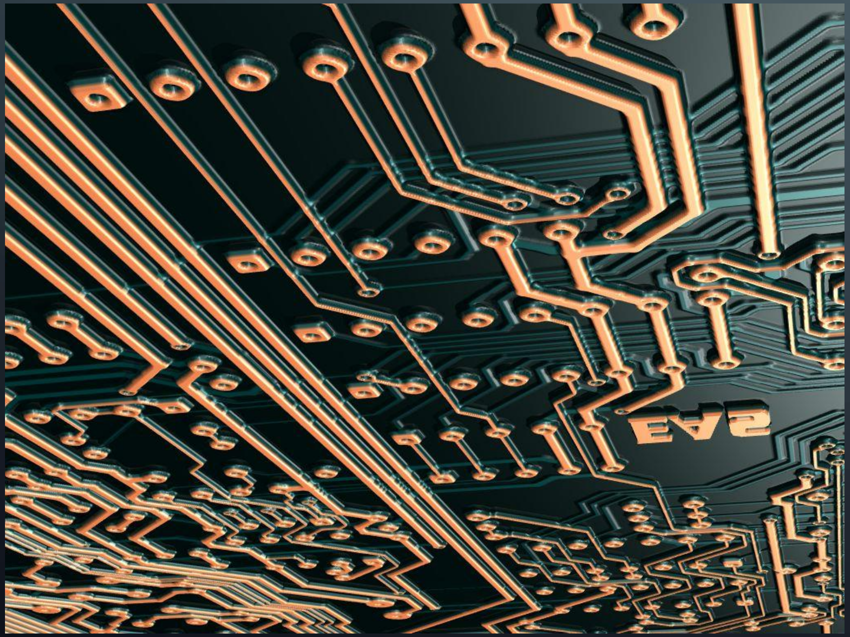
MOTHERBOARD

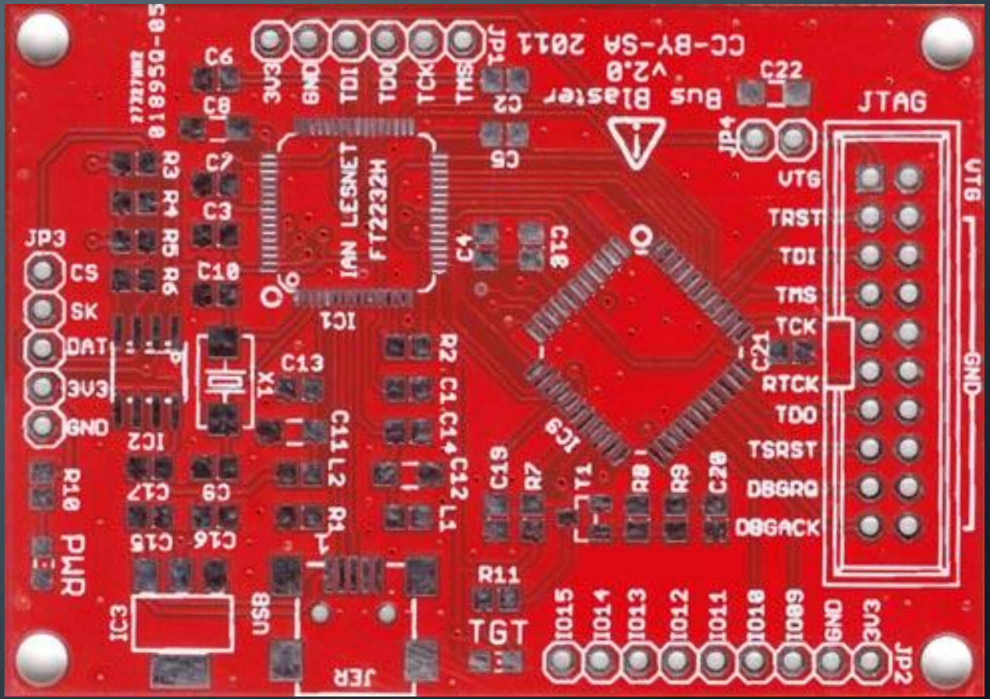
VON NEUMANN RELEVANCE

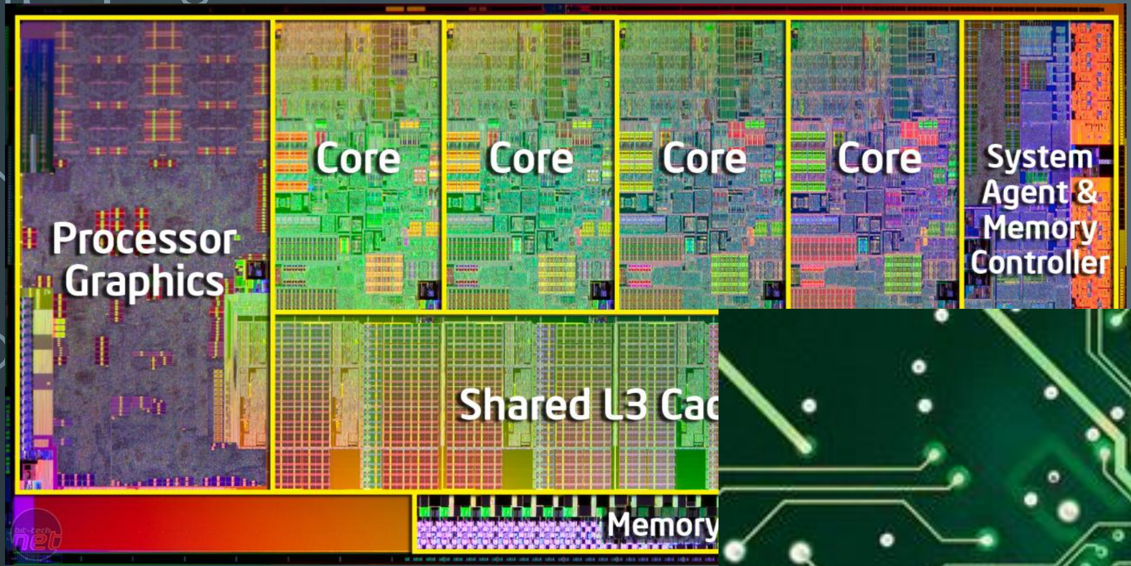




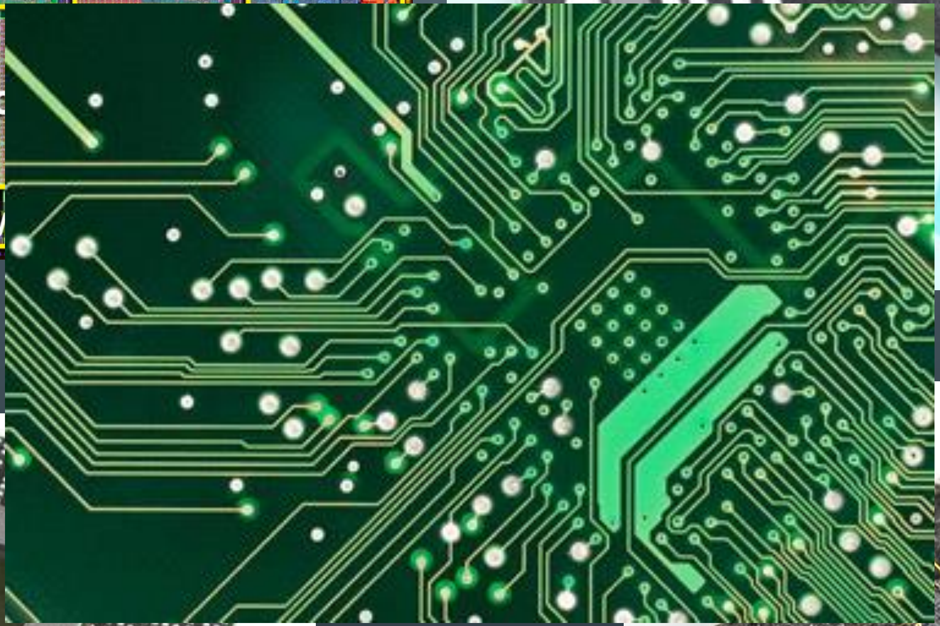
2x PCI Express slots
Onboard audio integrated circuit
CD-IN
SPDIF
1394 header
1394 controllers
Onboard LED
SATA RAID
Jumpers
SATA controller
USB header
Serial port connector
ATA controller
Game / MIDI header
FWH in PLCC
System panel connectors
Primary and secondary ATA RAID
Coin cell CMOS backup battery
4x SATA connections
Southbridge
24-pin motherboard power connector
Primary ATA (IDE) connector
Floppy connector
3x PCI slots
Marvell Onboard wireless chipset
1 AGP slot
2x 3-pin case fan connectors
Back panel and I/O connections
Heat sink
P4 power connector
Inductor (coil)
Capacitors
Gigabit LAN header
Osculator
CPU socket lever
CPU socket
Voltage regulator
Northbridge
4-pin CPU fan connection
Motherboard model name
4x DIMM memory slots
Super I/O
Mounting screw hole
ASUS P5AD2-E Motherboard - http://www.computerhope.com

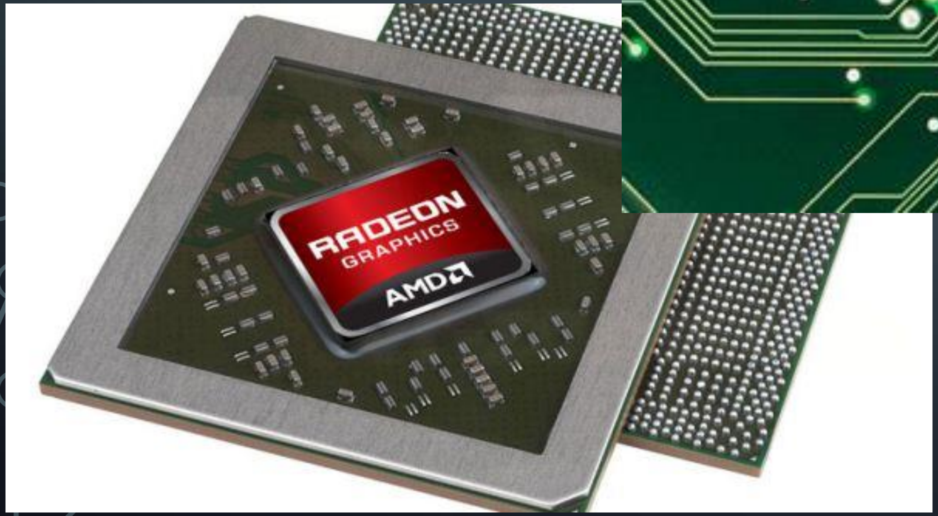


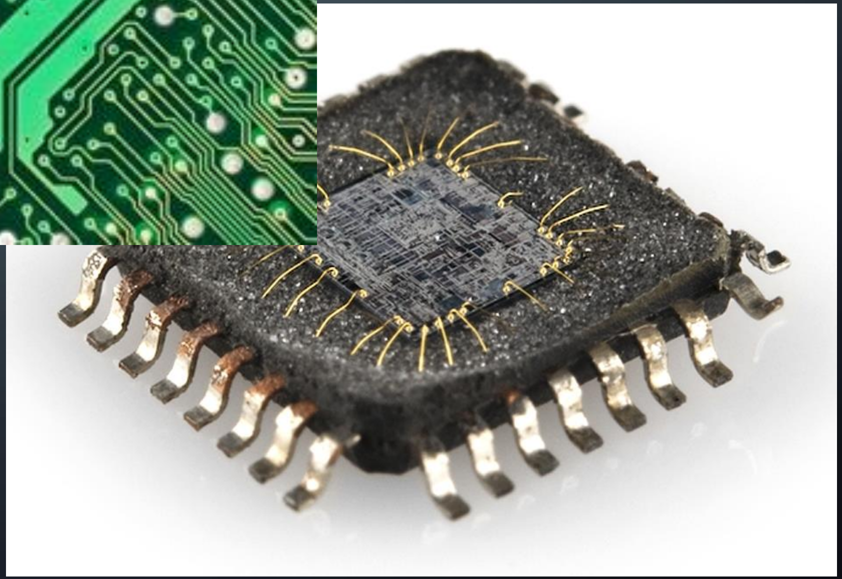

JTAG
VTG
TRST
TDI
TMS
TCK
RTCK
TDO
TSRST
DBGRQ
DBGACK
JP3
CS
SK
DAT
3V3
GND
PWR
TGT
IAN LESNET
FT2232H

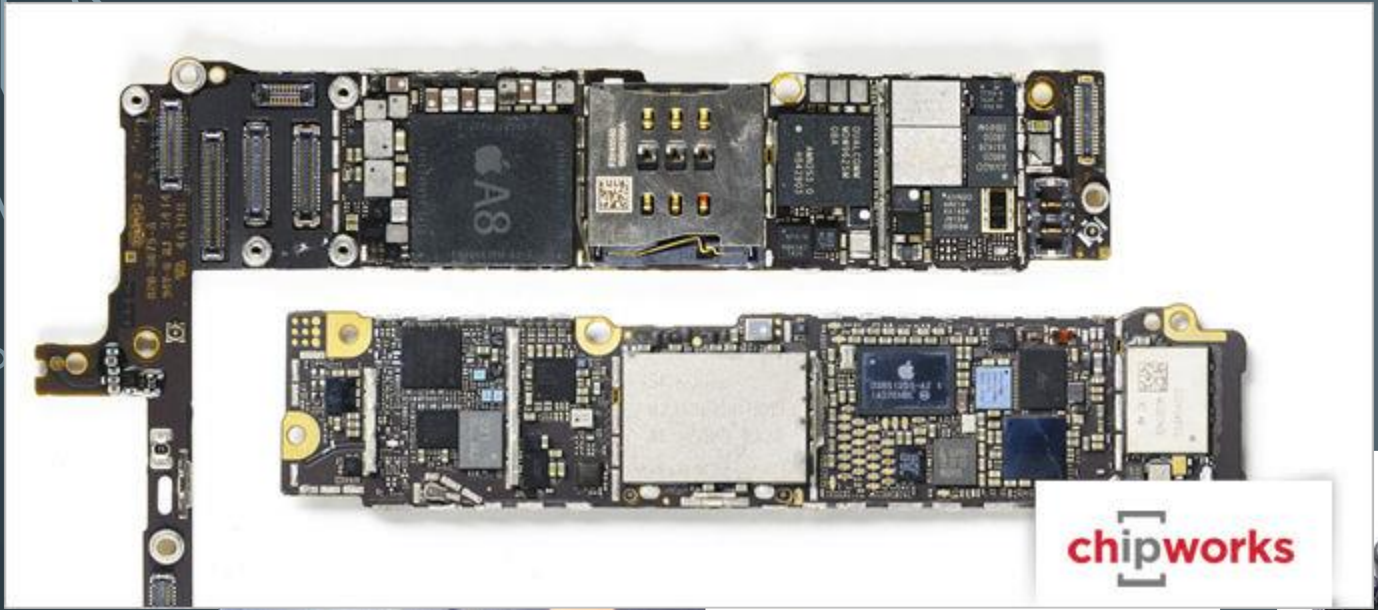

Processor Graphics
Core
Core
Core
Core
System Agent & Memory Controller
Shared L3 Cac
Memory

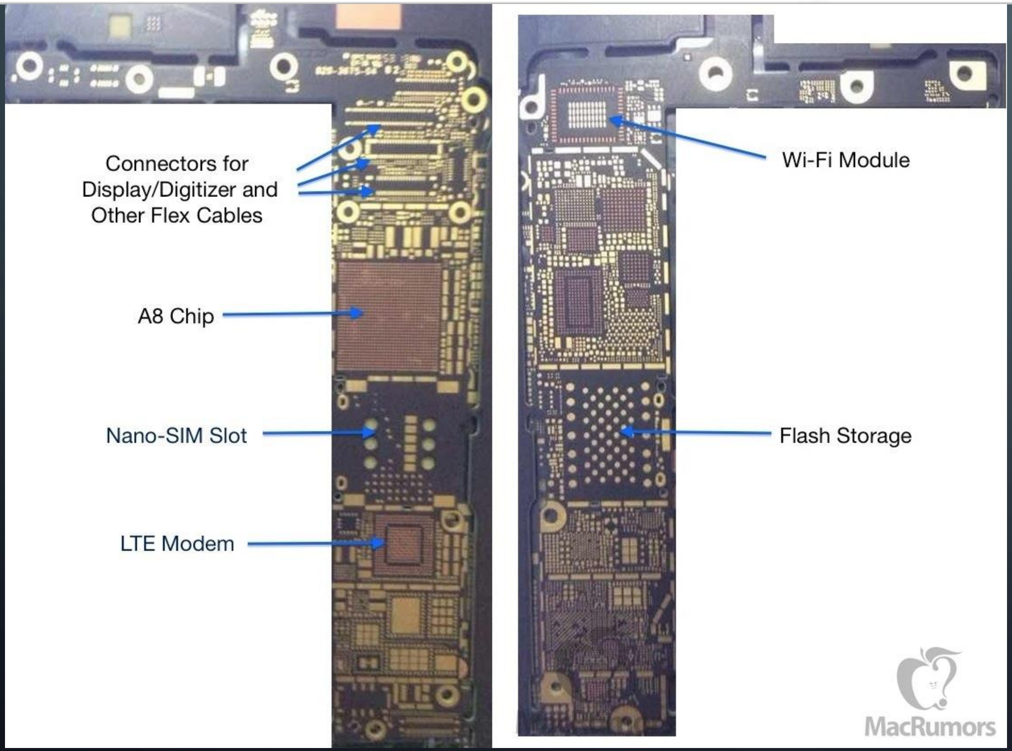

IDT
Wireless Power Receiver IC
Proven architecture
Compact sizes
Broad portfolio
AirFuel Alliance

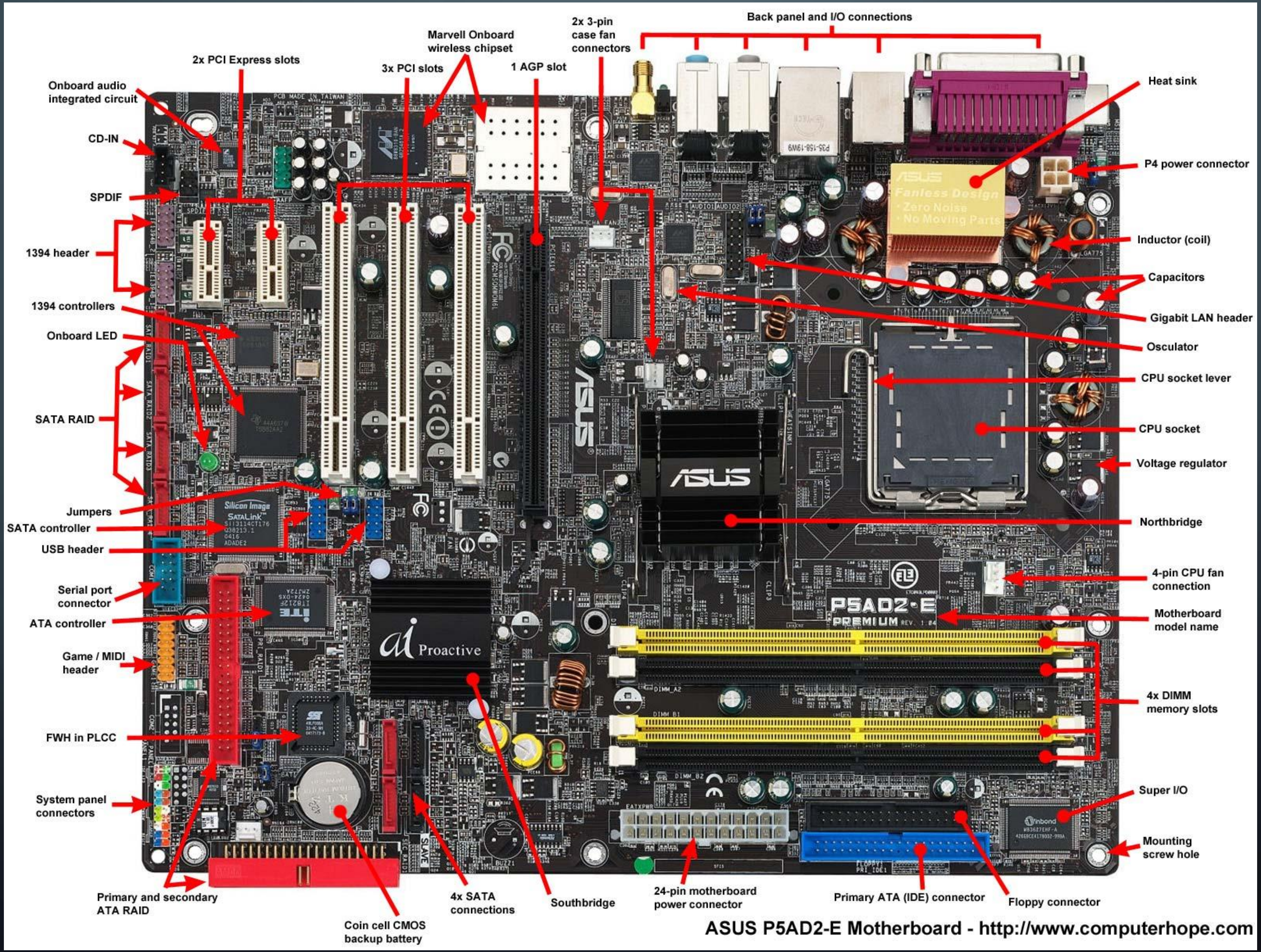



RADEON
GRAPHICS
AMD




A8
chipworks


Connectors for Display/Digitizer and Other Flex Cables
A8 Chip
Nano-SIM Slot
LTE Modem
Wi-Fi Module
Flash Storage
MacRumors



Back panel and I/O connections
2x 3-pin case fan connectors
Marvell Onboard wireless chipset
2x PCI Express slots
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1 AGP slot
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CPU socket
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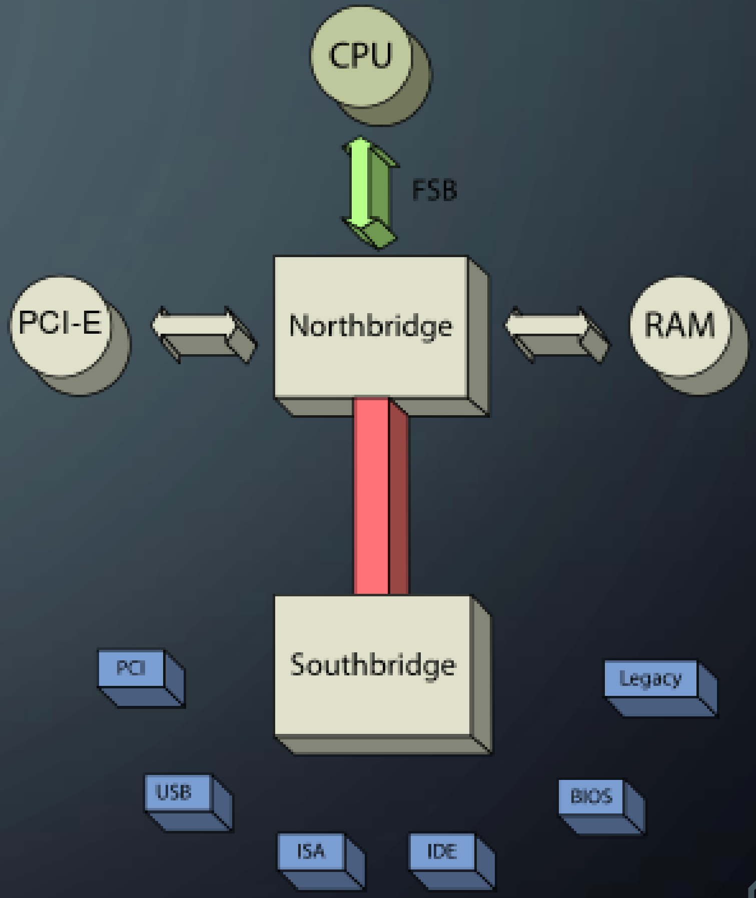
Northbridge
4-pin CPU fan connection
Motherboard model name
4x DIMM memory slots
Super I/O
Mounting screw hole
ASUS P5AD2-E Motherboard - http://www.computerhope.com

LIST OF MOTHERBOARD COMPONENTS

- Chipset: handles communication between processor and the other parts of your computer.
- Central Processing Unit (CPU) slot (socket)
- Buses: connection on the motherboard that carries data between the various parts of the motherboard (chipset, memory, processor, ...)
- Expansion slots: For connecting expansion cards
- Memory slots: For connecting RAM
- Power connector: to supply power to motherboard and to help motherboard supply power to other devices
- Others: like graphics and sound (integrated)
- Clock generator - https://electrosome.com/crystal-oscillator/

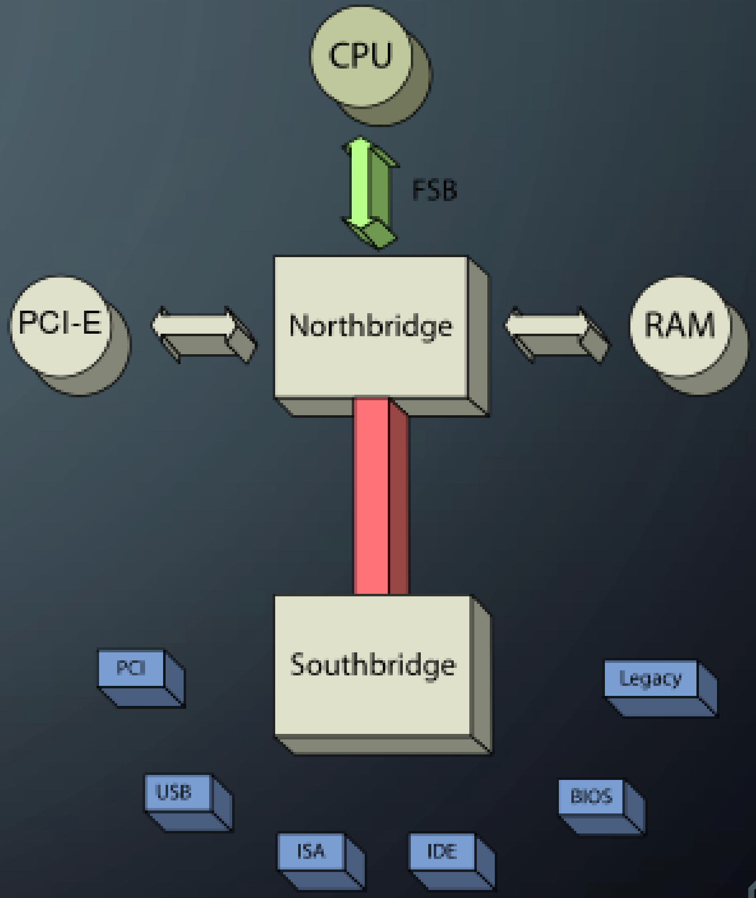
CHIPSET

- Not everything communicates directly with CPU
  - Like having a conversation with 10 people at once
- Chip(s) (IC) that sits on the Motherboard that takes care of communication between devices
- Designed for use with a specific family of processors



CHIPSET

- Northbridge: connects the CPU to high-speed components like RAM and PCI-e (Peripheral Component Interconnect - Express)
- Example: Intel Xeon E5-2695 connects to RAM at 59.7 GB/s.
- Southbridge: connects to slower peripheral devices like PCI slots, USB, IDE, BIOS
- Both bridges are essentially routers. They route data traffic from one bus to another.



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MEMORY

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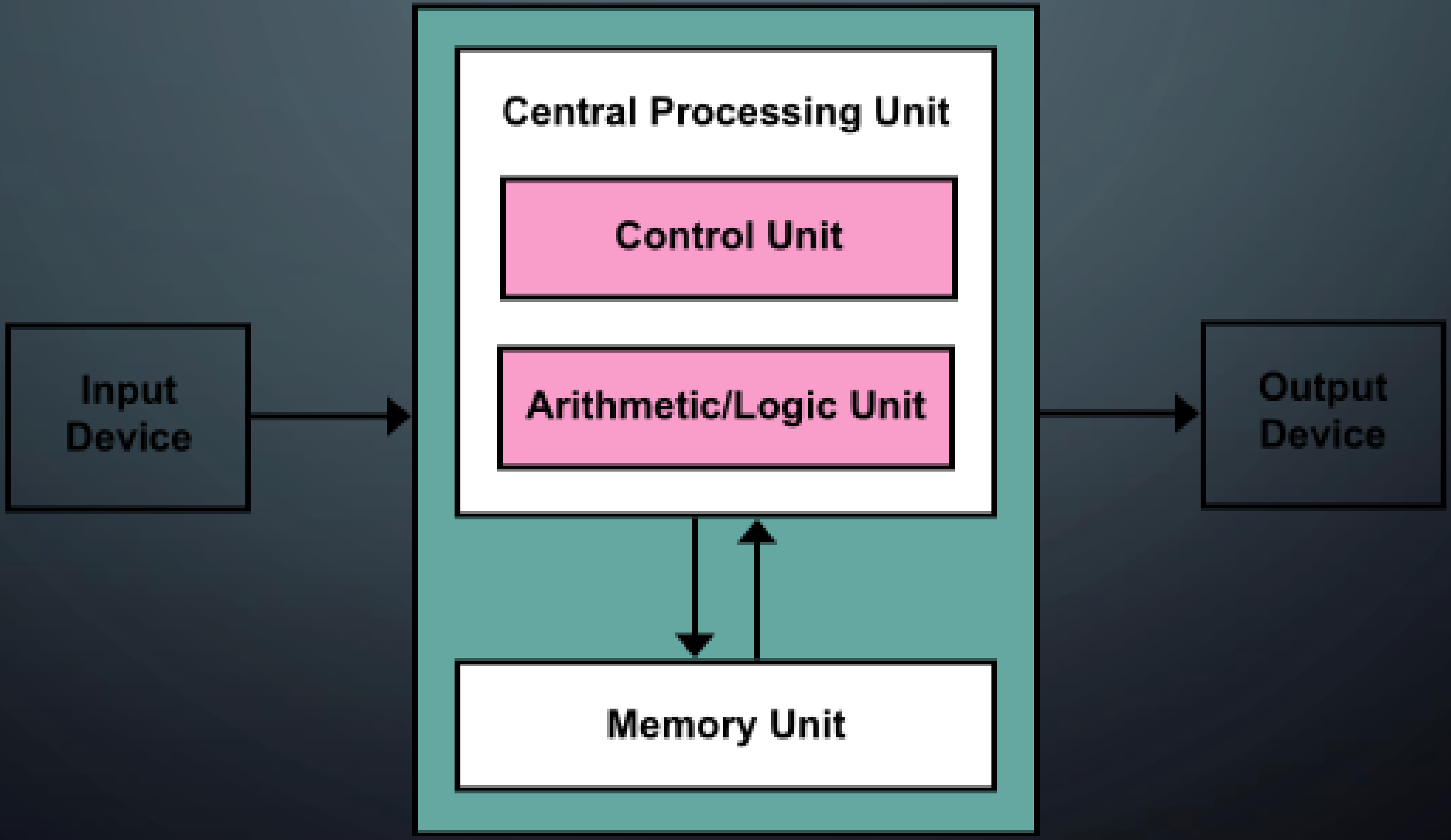
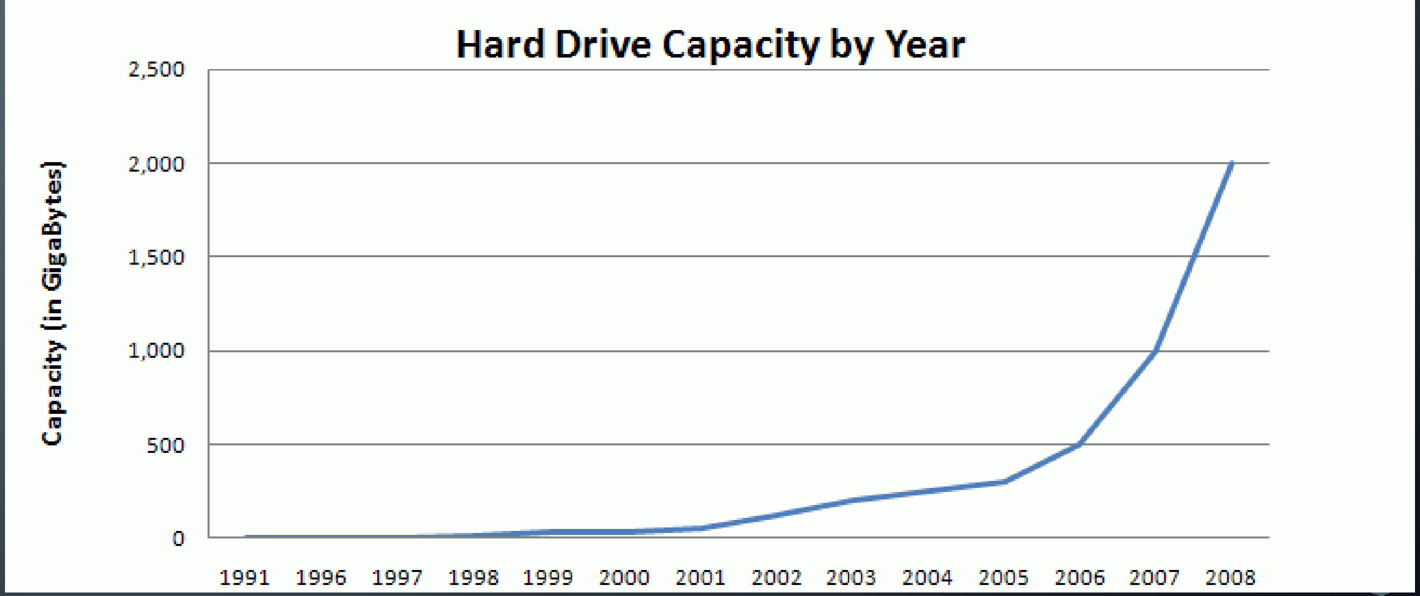


MEMORY SIZES

- 1 bit = 1/0
- 1 byte = 8 bits
- 1 kilo byte (kB) = 1000 bytes
- 1 Mega byte (MB) = 1000kB
- 1 Giga byte (GB) = 1000MB
- 1 Tera byte (TB) = 1000GB
- 1 Peta byte (PB) = 1000TB
- 1 Exa byte (EB) = 1000PB



HOW MANY BYTES?

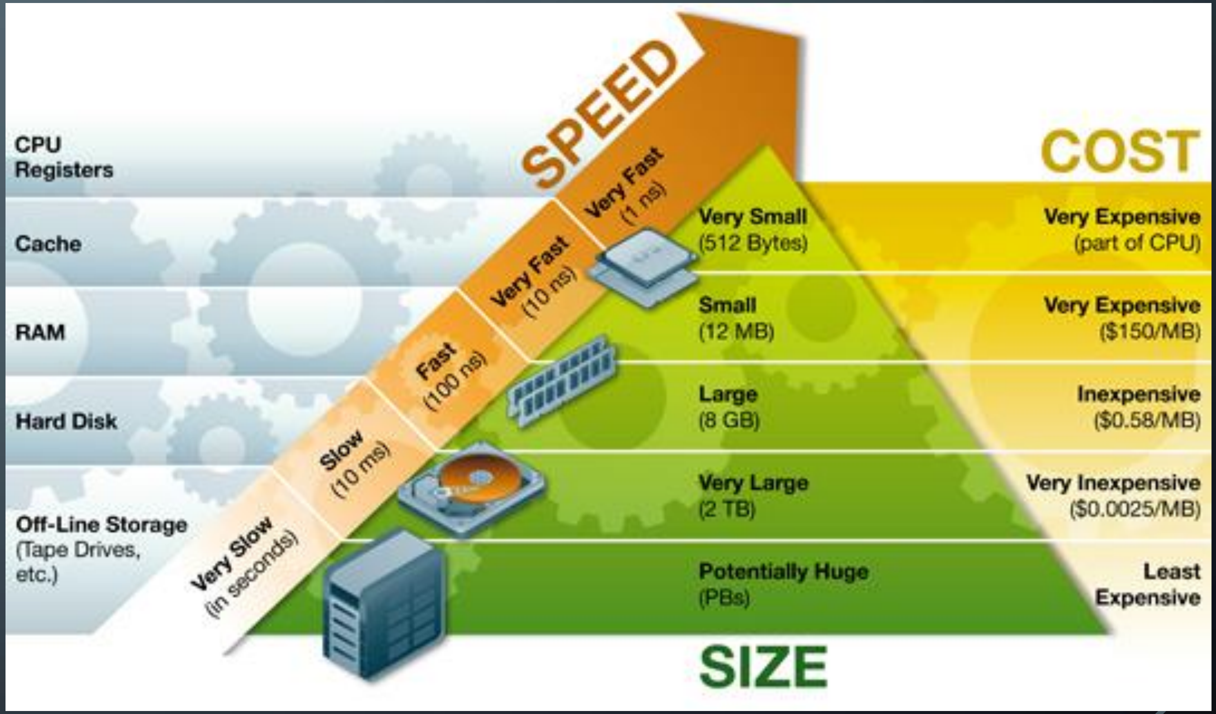
• The complete works of Shakespeare	**~ 500MB**
• A pickup truck filled with books	**1GB**
• The contents of a DVD	**17GB**
• A library floor of academic journals	**100GB**
• 50,000 trees made into paper and printed	**1TB**
• All the printed material in the world	**200PB**
• All the words ever spoken by human beings	**5EB**

The world now produces 2- 3 Exabytes (EB) of data a day (1000EB every year)

An Exabyte is a billion Gigabytes….

MEMORY – DIFFERENT TYPES

- Different types and different speeds
  - Faster = more expensive
  - Computer memory has hierarchical structure
- Term "Memory" typically refers to RAM
  - Technically refers to any storage
  - RAM and Cache data can be accessed v. quickly

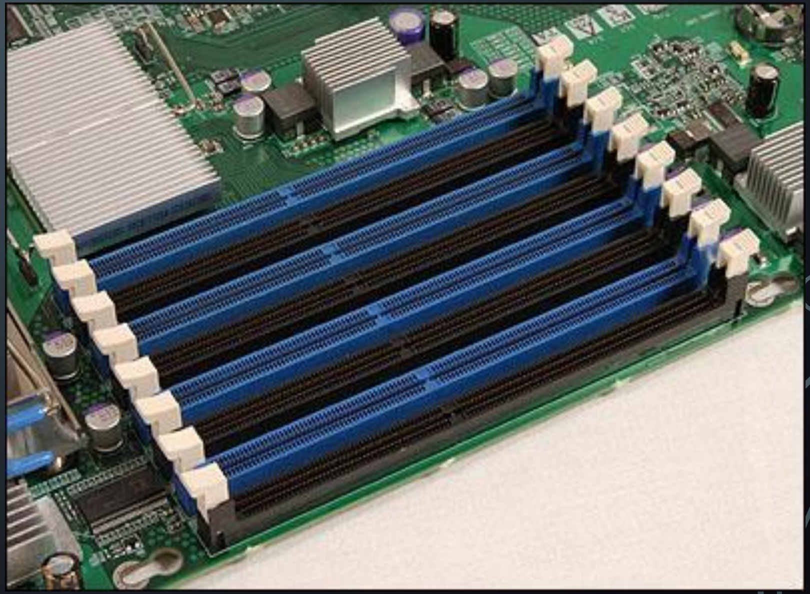


MEMORY HIERARCHY

Level	1	2	3	4	5
Name	registers	cache	main memory	solid state disk	magnetic disk
Typical size	< 1 KB	< 16MB	< 64GB	< 1 TB	< 10 TB
Implementation technology	custom memory with multiple ports CMOS	on-chip or off-chip CMOS SRAM	CMOS SRAM	flash memory	magnetic disk
Access time (ns)	0.25 - 0.5	0.5 - 25	80 - 250	25,000 - 50,000	5,000,000
Bandwidth (MB/sec)	20,000 - 100,000	5,000 - 10,000	1,000 - 5,000	500	20 - 150
Managed by	compiler	hardware	operating system	operating system	operating system
Backed by	cache	main memory	disk	disk	disk or tape

RANDOM ACCESS MEMORY (RAM) ROLE & OPERATION

- Temporary storage of information for fast CPU access.
  - Contains current program data and computer state
- Information is automatically managed by the memory,
  - No user control
- RAM is cleared automatically when the computer is shutdown or rebooted.
  - RAM is volatile (non-permanent).
- Current desktop computers typically have 2 – 16 Gigabytes of RAM



HARD-DRIVE STORAGE (HDD/SSD COMPARISON)

- ~Permanent~ storage of information – also known as “Non-Volatile” storage
- Slower than RAM to access
- 2 Main types of technology
  - Hard **Disk** Drive (HDD) – info stored on spinning magnetic coated disks (platters); Read/write head scans across the platters; cheap storage; (1 Terabyte = €60); Speed measured in RPM (Revolutions per minute); Performance measured in Seek/Write time; Latency
  - Solid State Drive (SSD) – no moving parts, info stored in high-speed, high-performance silicon NAND flash drives; faster but most costly than HDD (1 Terabyte = €370)
  - SSD can be up to 40x times faster than HDD, best way to upgrade performance
    - http://www.storagereview.com/ssd_vs_hdd
- Combination of both works well (in hierarchy)
  - SSD for programs/OS, HDD for (lesser used) files
- Manufacturers?

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INPUT/OUTPUT (I/O)

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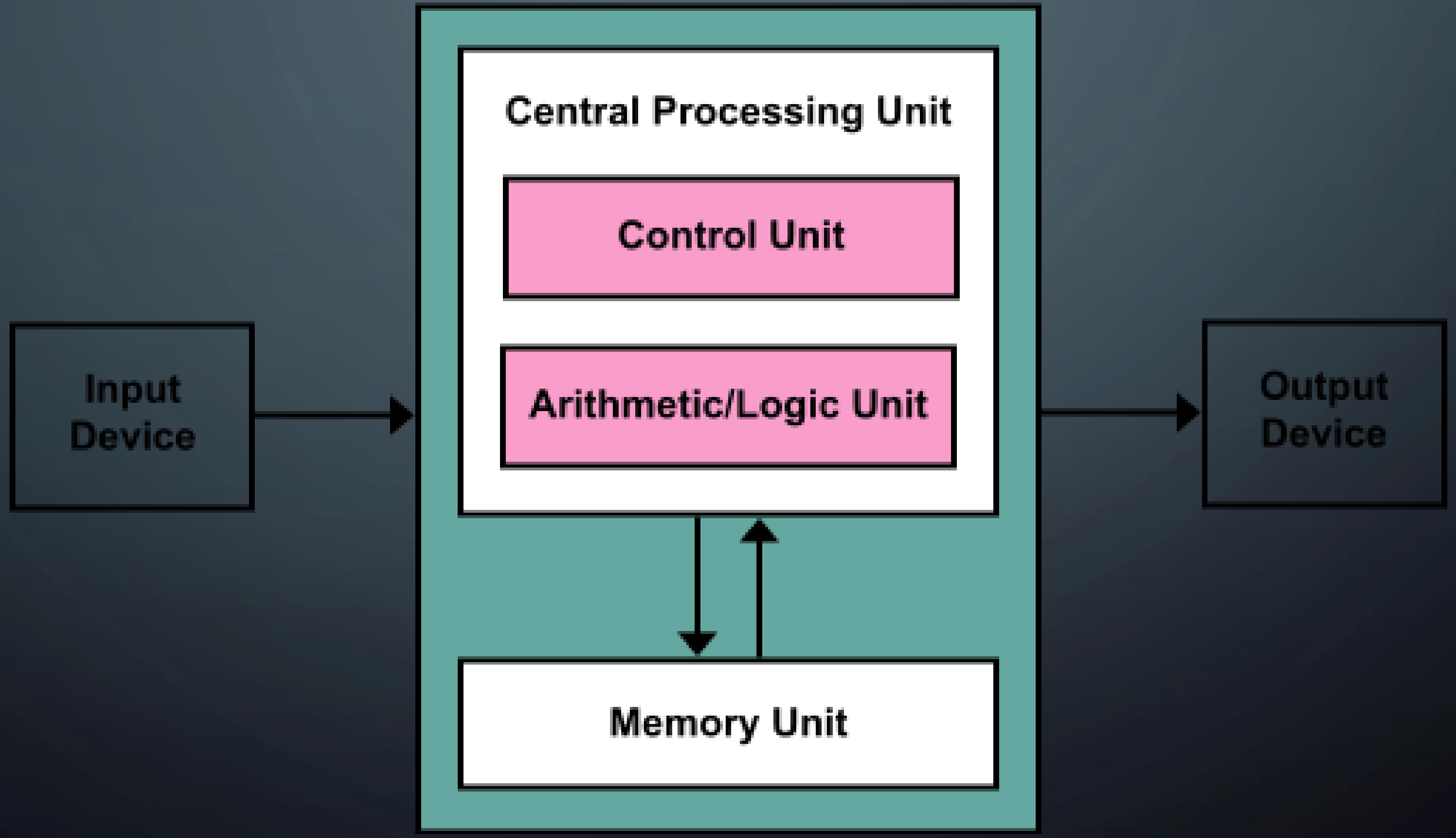
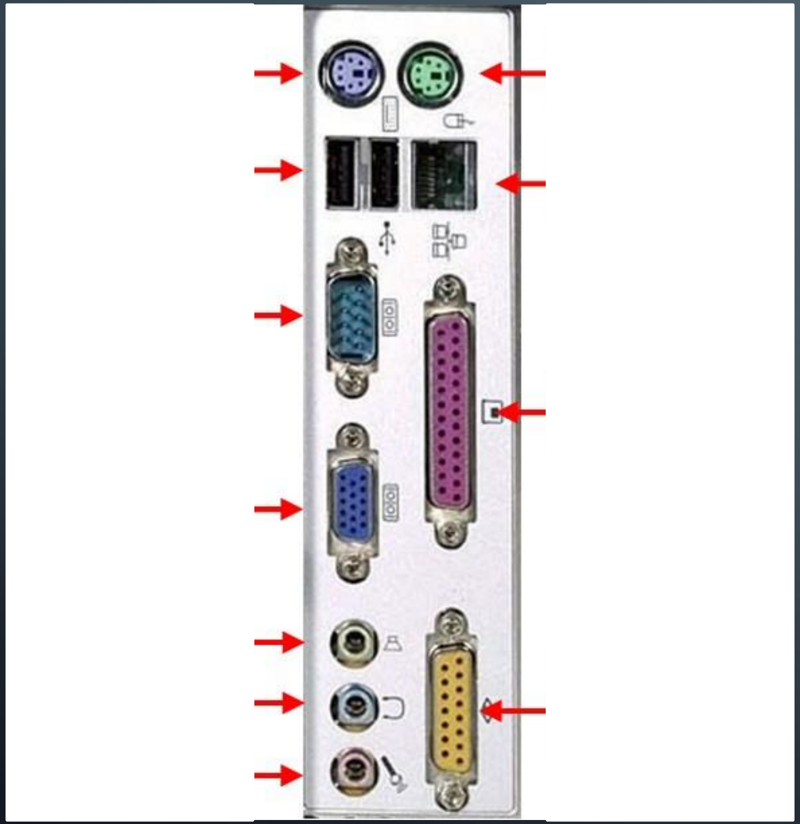


INPUT/OUTPUT (I/O)

- Input/Output (I/O): Refers to the process of getting information into and out of the computer.
  - Input: Those parts of the computer receiving information
  - Output: Those parts of the computer that provide results of computation

INPUT/OUTPUT (I/O) PORTS - EVOLUTION



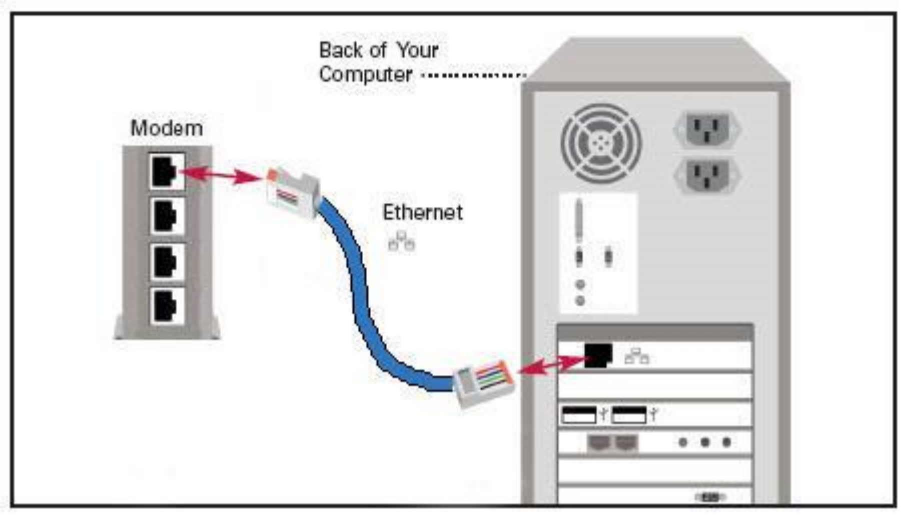
INPUT/OUTPUT (I/O) PORTS

- Monitor port: Used to connect monitor to PC
- Currently 3 main connectors
  - VGA (Video Graphics Array) analog connector (also known as a D-Sub connector) -15 pins in three rows. Typically blue in colour; does not support digital monitors
  - DVI (Digital Video Interface): 24 pins and support for analog as well as digital video; can stream 1920×1200 HD video; does not support High-bandwidth Digital Content Protection (HDCP) encryption (Bluray); no audio support
  - HDMI (High-Definition Multimedia Interface): Default connector on newer HDTVs/monitors; convenient connector; audio support; supports HDCP.

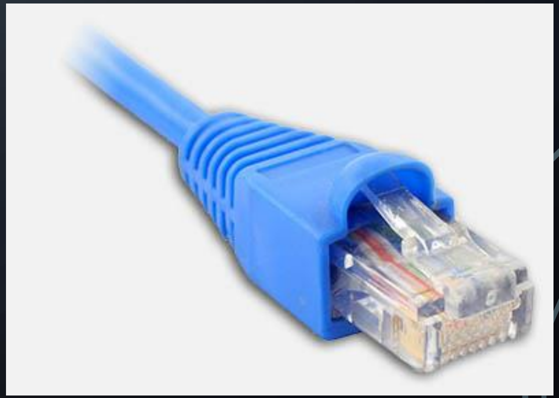
INPUT/OUTPUT (I/O) PORTS - USB

- USB (Universal Serial Bus) Port :
- Industry standard developed in the mid 1990s that replaced many other connections and communication protocols (printer port, mouse port, keyboard port)
- Plug and Play
- Used to connect almost all PC peripheral devices (printers, flash drives etc.).
    - USB 1.1 transmits data at 12 Mb/s at full speed
    - USB 2.0 transmits data at 480 Mb/s.
    - USB 3.0 transmits data at 5 Gb/s.
    - USB 3.1 transmits data at 10 Gb/s.
    - USB C / Thunderbolt (40 GB/s)
        - https://www.extremetech.com/computing/197145-reversible-usb-type-c-finally-on-its-way-alongside-usb-3-1s-10gbit-performance
        - http://www.digitaltrends.com/computing/what-is-usb-3-1-when-will-it-be-released-and-what-will-it-do-for-pcs/
- Can be used to battery charge devices

INPUT/OUTPUT (I/O) - ETHERNET



- Ethernet Port:
- Used for networking and fast internet connections.
- Transmission rates are - 10 Mbps, 100 Mbps, 1 Gbps, 10 Gbps (newest)
- Monitor lights flicker when in use.
- Uses (1) Transmission Control Protocol (**TCP**) and (2) User Datagram Protocol (UDP) as the 2 primary protocols for communicating.
  - What's the key difference?
  - Protocols are foundation of the internet
- Connector also known as RJ45 connector



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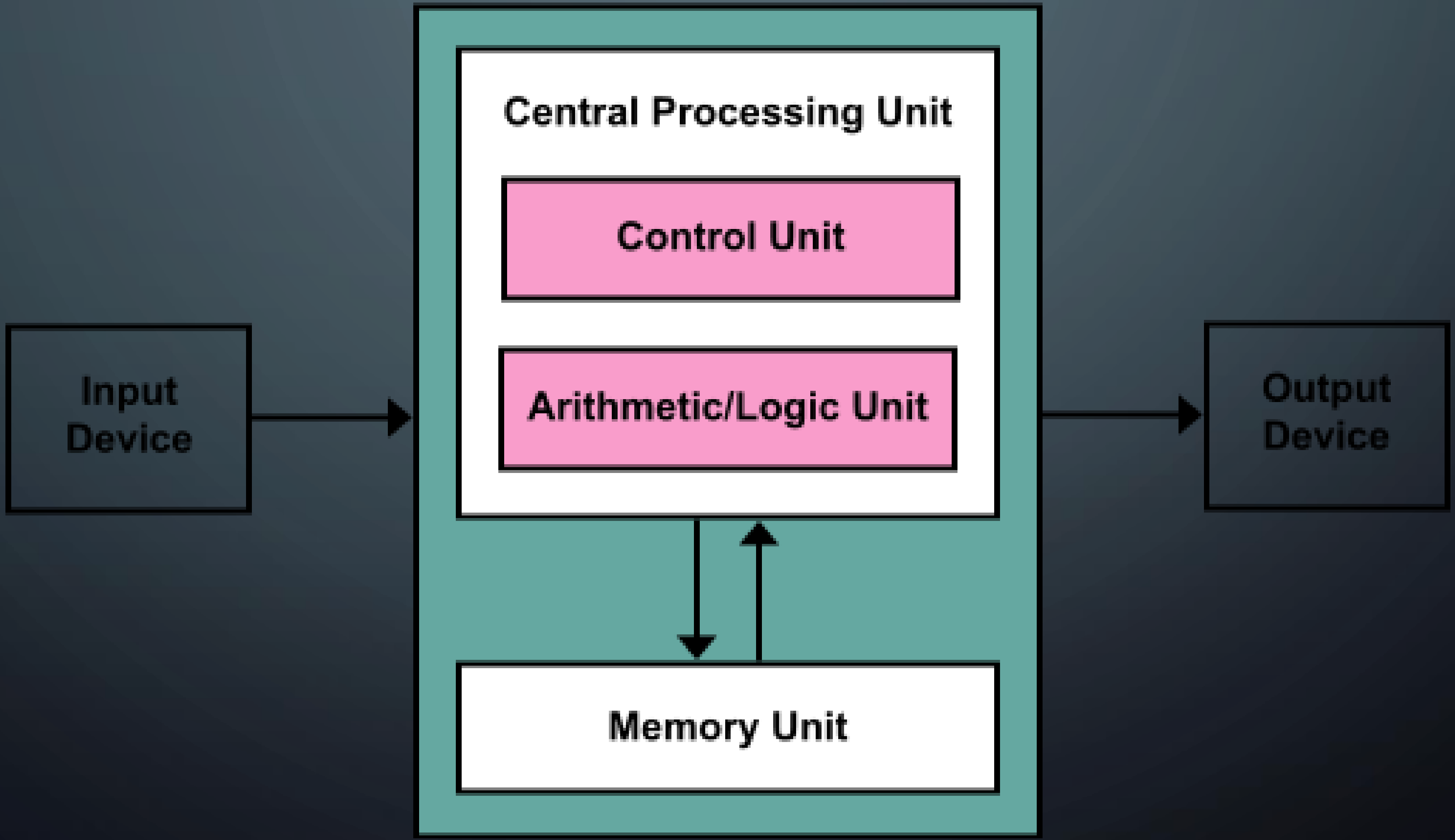
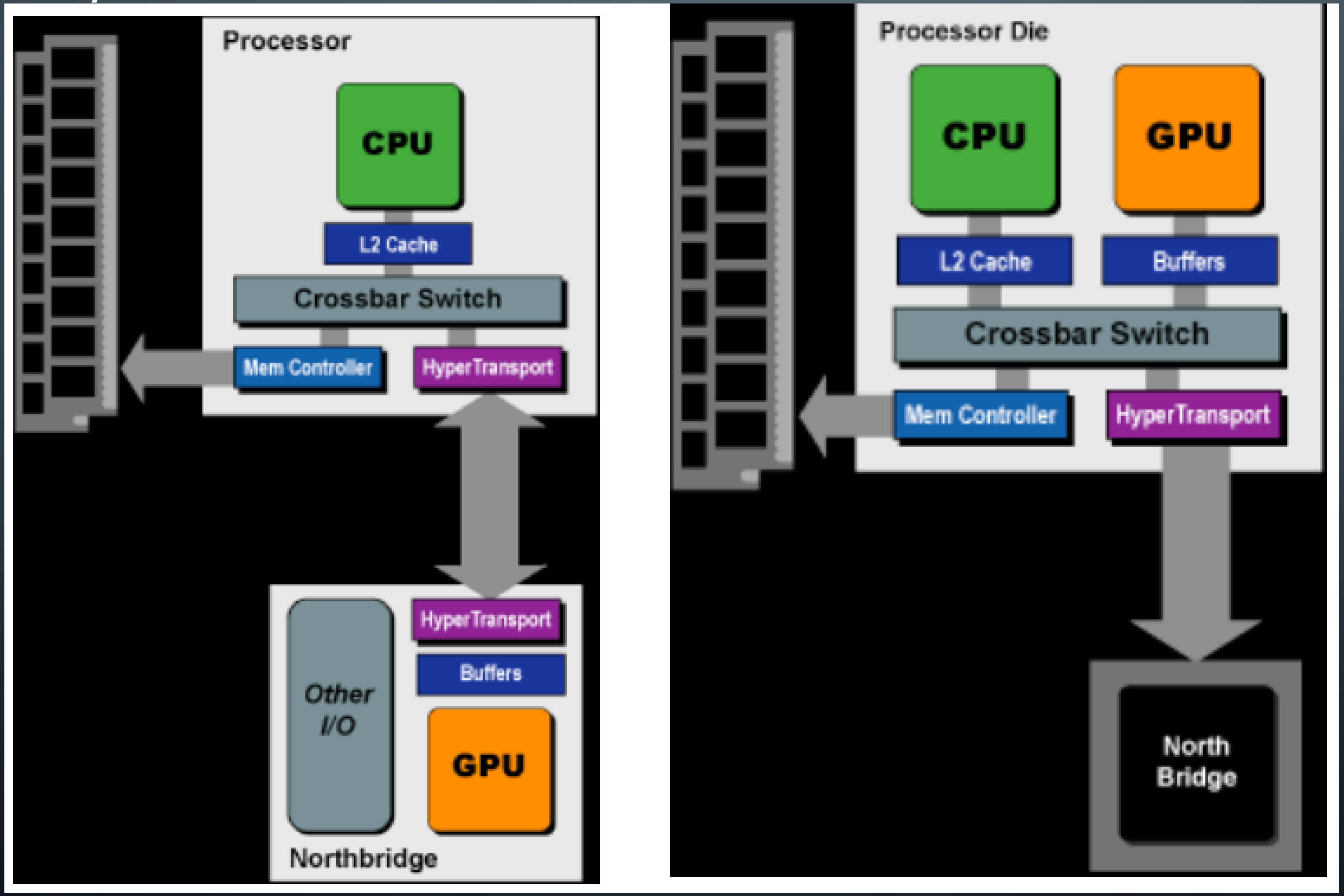
GRAPHICS CARD

VON NEUMANN RELEVANCE



CPU/GPU FUSION (INTEGRATED GRAPHICS)

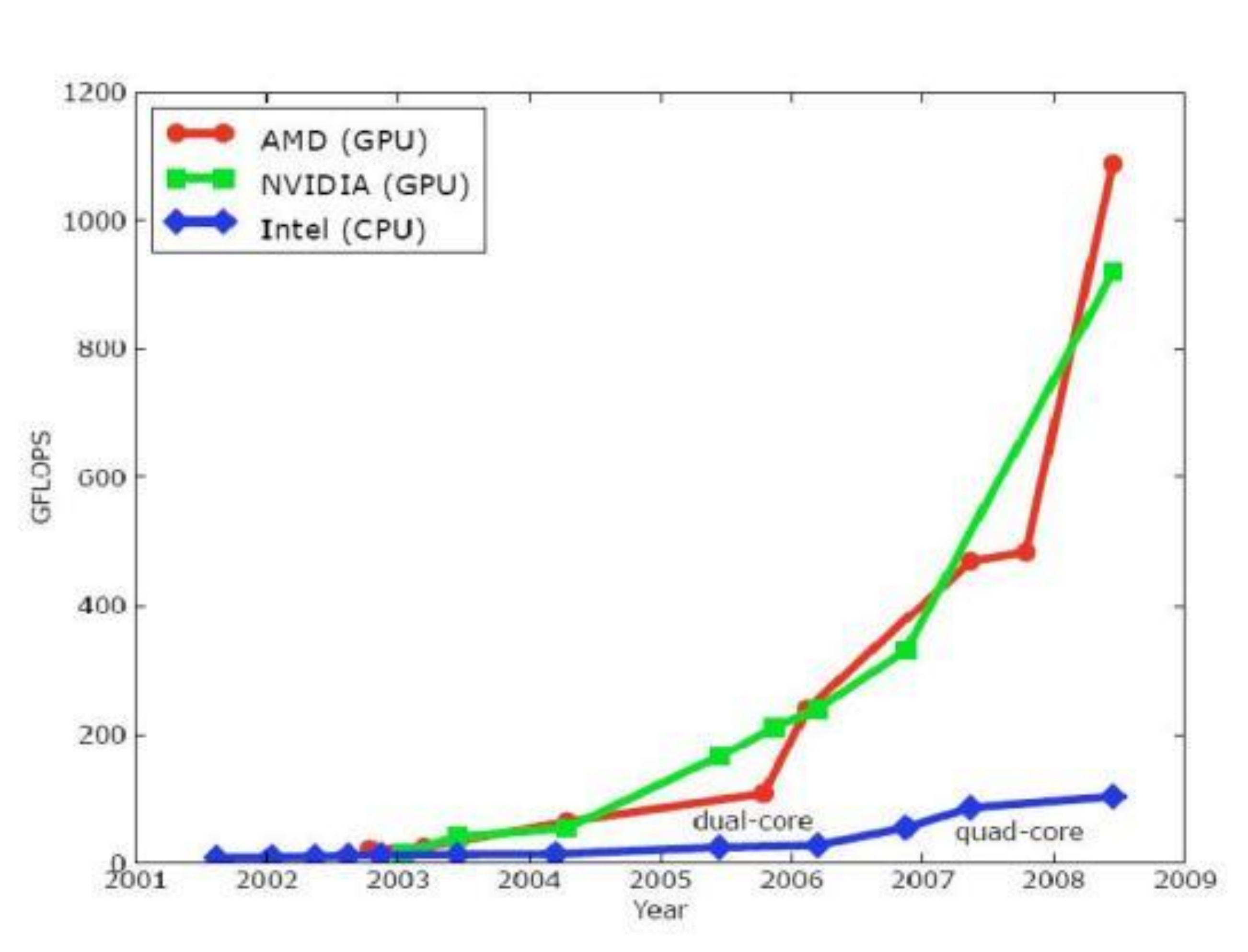


GRAPHICS CARD

- Graphical Processing Unit (GPU) – Can be integrated or a separate board
  - Separate – NVidia and AMD Radeon
  - Integrated – Intel Sandy and Ivy Bridge
- Convert computer image representation to a signal suitable for a monitor.
- Today are general purpose – not only for graphics
  - Self-driving cars
  - Biomedical Imaging
  - Evolutionary Computation

GRAPHICS CARD

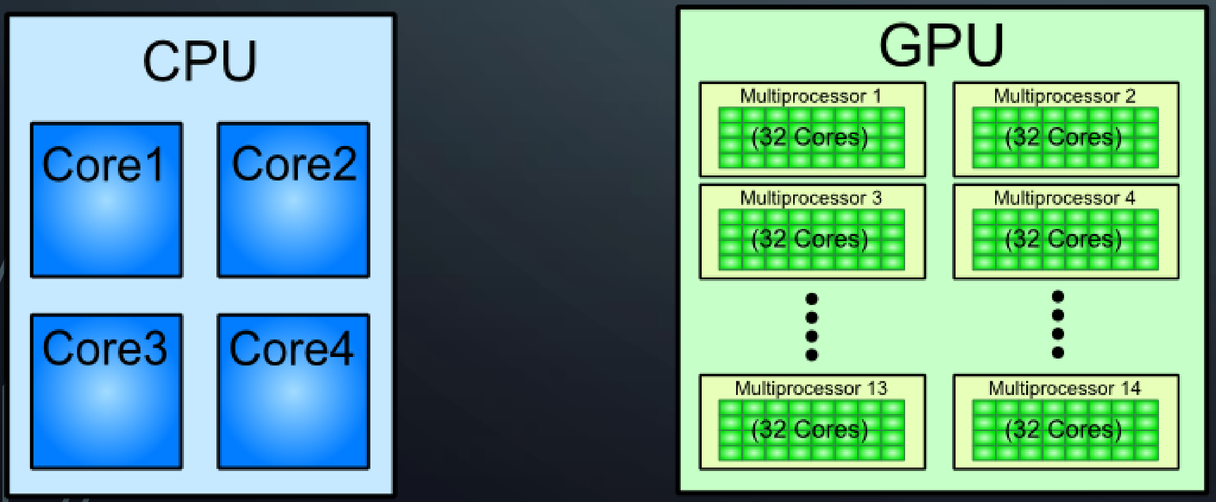
- Giga Floating Point Operations Per Second (GFLOPS)

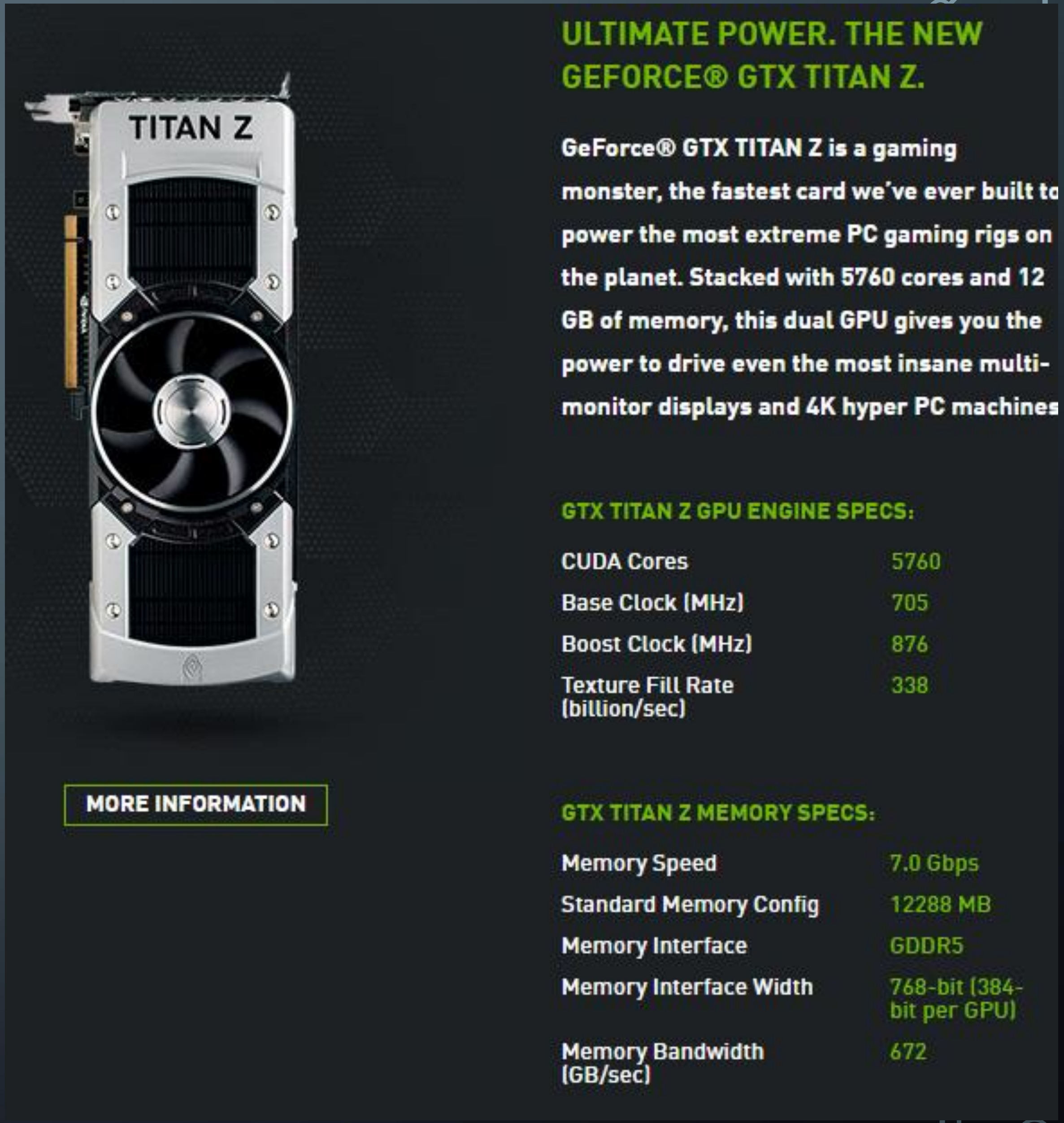


GPU VS CPU

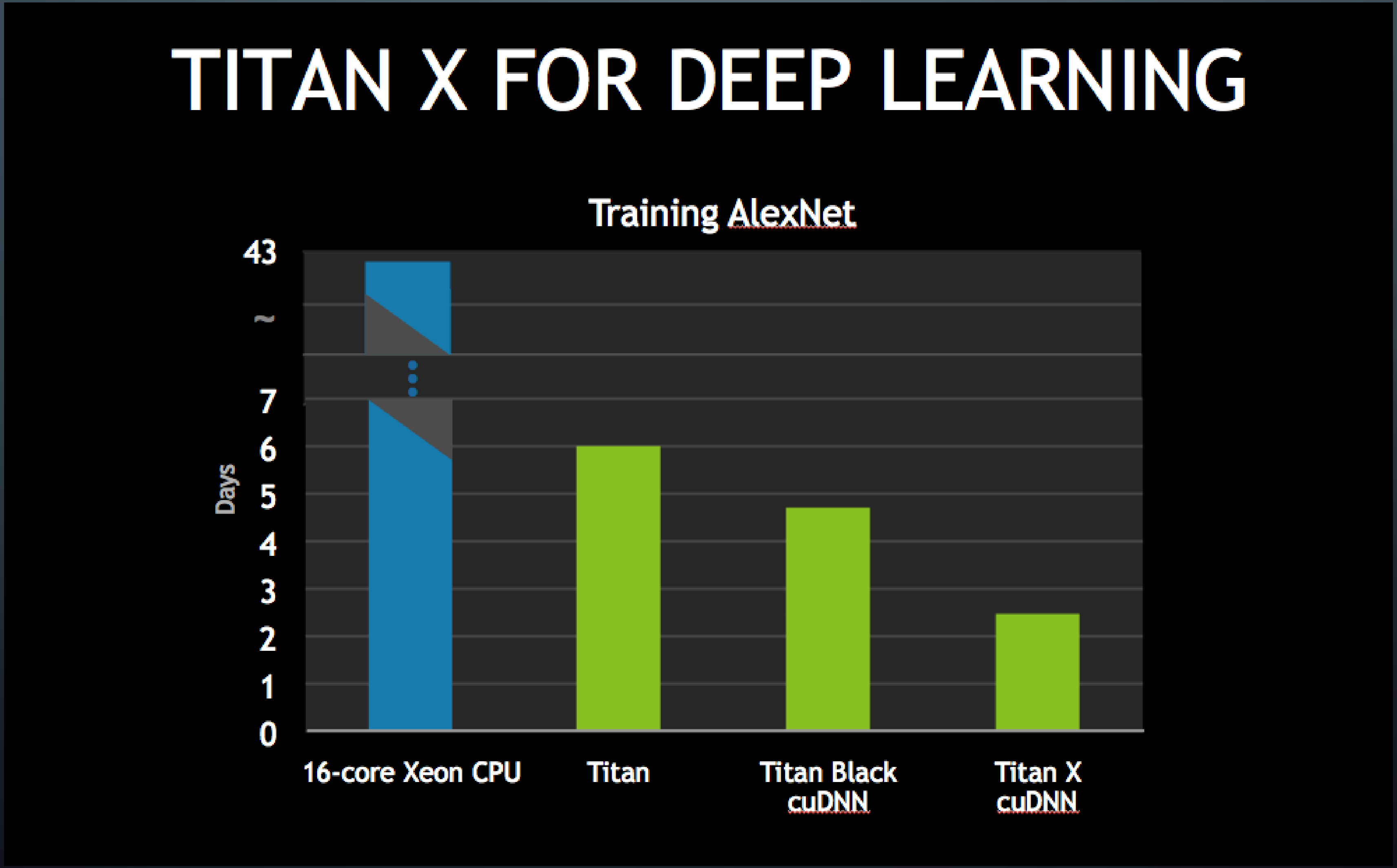
- Highest spec:
  - http://www.nvidia.com/gtx-700-graphics-cards/gtx-titan-z/
  - https://blogs.nvidia.com/blog/2014/03/25/titan-z/

CPU/GPU Architecture Comparison





GPU VS CPU


TITAN X FOR DEEP LEARNING
Training AlexNet
Days
43
~
7
6
5
4
3
2
1
0
16-core Xeon CPU
Titan
Titan Black cuDNN
Titan X cuDNN

GRAPHICS CARD – WHAT TO CONSIDER WHEN PURCHASING?

- The amount of GPU memory
- Number of cores
- Bus width and memory speed
- Power requirements

GRAPHICS CARD – WHAT TO CONSIDER WHEN PURCHASING?

- The amount of GPU memory:
    - The larger the memory, the higher the GPU resolution
    - Ranges from 256MB/1GB in low-end to 6-12GB in high-end
    - Example: you will need 3GB-4GB memory for 2560x1600 with decent frame rates
    - Anti-Aliasing (AA): smoothing out edges -> may require more memory for lower rendered resolution.
- Number of cores:
    - Cores simpler than in a multicore PC chip
    - Called stream processors by AMD; CUDA cores by Nvidia
- The two big players: Nvidia and AMD
    - Different architectures so not easy to compare by core count

GRAPHICS CARD – WHAT TO CONSIDER WHEN PURCHASING?

- Bus width and memory speed - E.g.
  - GTX 680: 6GHz memory and 256-bit interface = 192.2 GB/s
  - GTX Titan: 6GHz memory and 384-bit interface = 288.4 GB/s
- Power requirements:
  - Most GPUs use PCIe power connectors (6-pin or 8-pin)
  - Most high-end cards will draw 100-200W of power under load
  - May need 500-650W PSU (power supply unit) for entire system.
- Example:
  - EVGA GeForce Titan X SuperClock
    - **Stream Processors**: 3072 | **Core Clock:** 1127MHz | **Memory:** 12GB | **Memory Clock**: 7010MHz | **Power Connectors:** 1 x 6-pin, 1 x 8-pin | **Length:** 267mm |**Outputs:** 3 x DisplayPort, 1 x HDMI, 1 x DVI – €**1144.65**

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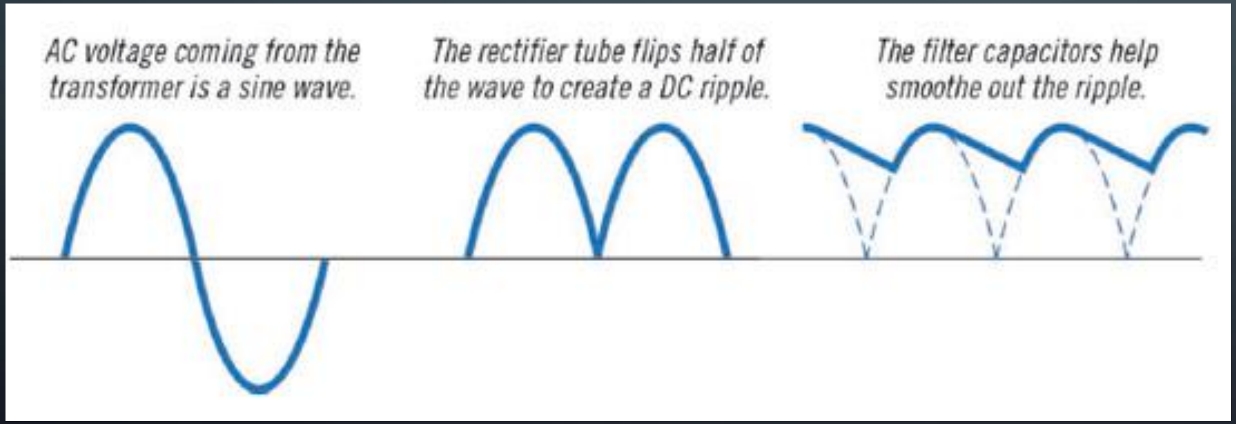
OTHER COMPONENTS

POWER SUPPLY

- Provides power to all components by converting alternating current (AC) supplied by the wall connection to direct current (DC).
- In Ireland 220-240V AC transformed to 12V, 5V and 3.3V DC



COOLING

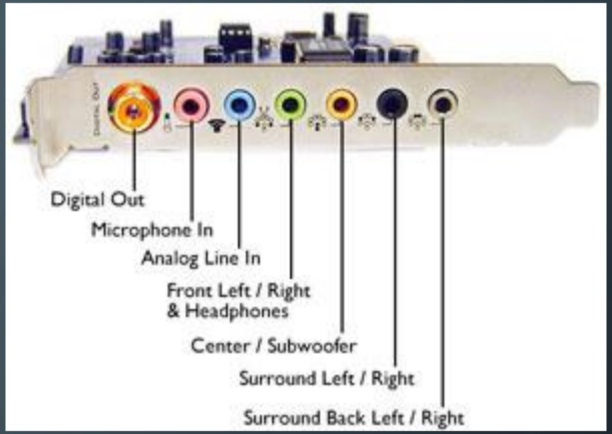
- Computer (CPU especially) can get very hot and requires assistive cooling
- Two standard methods:
- Air:
  - Case fans range in size from 80 - 120mm
  - CPU's, video cards, power supply, and other components often have their own fans
  - Heatsinks (normally constructed from copper/aluminium) directly mounted on microchips.
  - A fan blows air across the heatsink which transfers heat absorbed from the CPU into the air.
  - Passive cooling – Apple's large data centre in Athenry
  - Advantages: Less failure points, easier to install, lower cost
  - Disadvantages: Loud; air not as good a conductor as liquid, have to clean fans

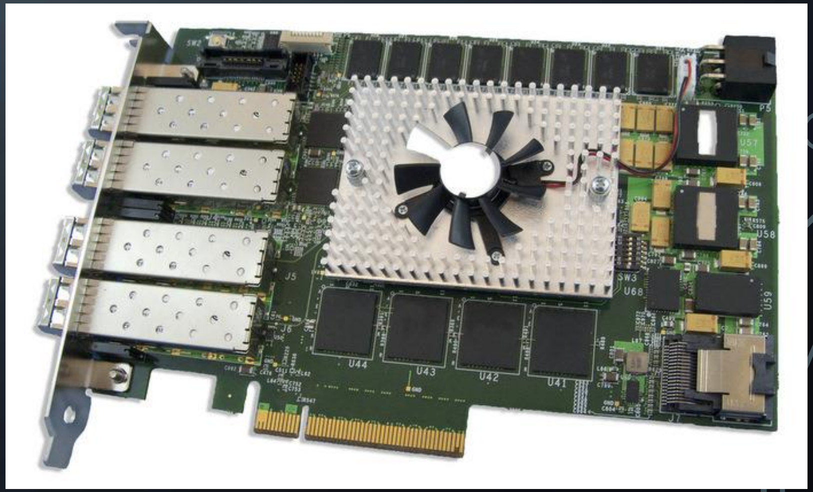
LIQUID COOLING

- Uses liquid (usually water) pushed trough a radiator to cool computer components via a pump, reservoir, and tubing.
- Used to cool high end servers, desktops, and super computers like the Cray systems.
- 34% more efficient than air cooling.
- Advantages: Disperses more heat, Quieter
- Disadvantages: More failure points, more complicated installation, higher cost, more power hungry, leaks are not good.
- E.g. – Google uses sea-water from the Bay of Finland to cool data centre there

PCI EXPANSION CARDS

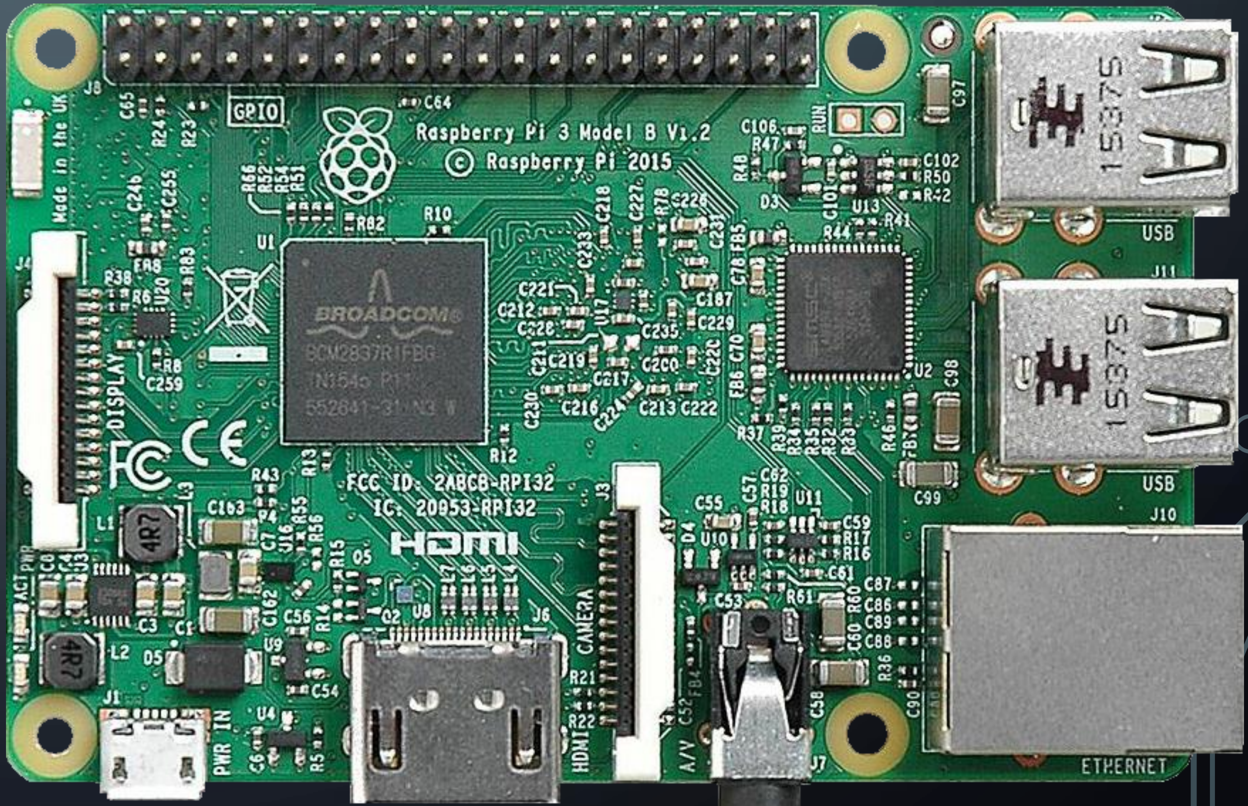
- Peripheral Component Interconnect (PCI)
- Interconnection system between CPU and attached devices connected by expansion slots
- Used to add/improve functionality of the computer.
- E.g. Sound Card – Used to input and output sound under program control.
  - Better sound quality than built in audio
- E.g. Network Card – Used to provide connection to a network.





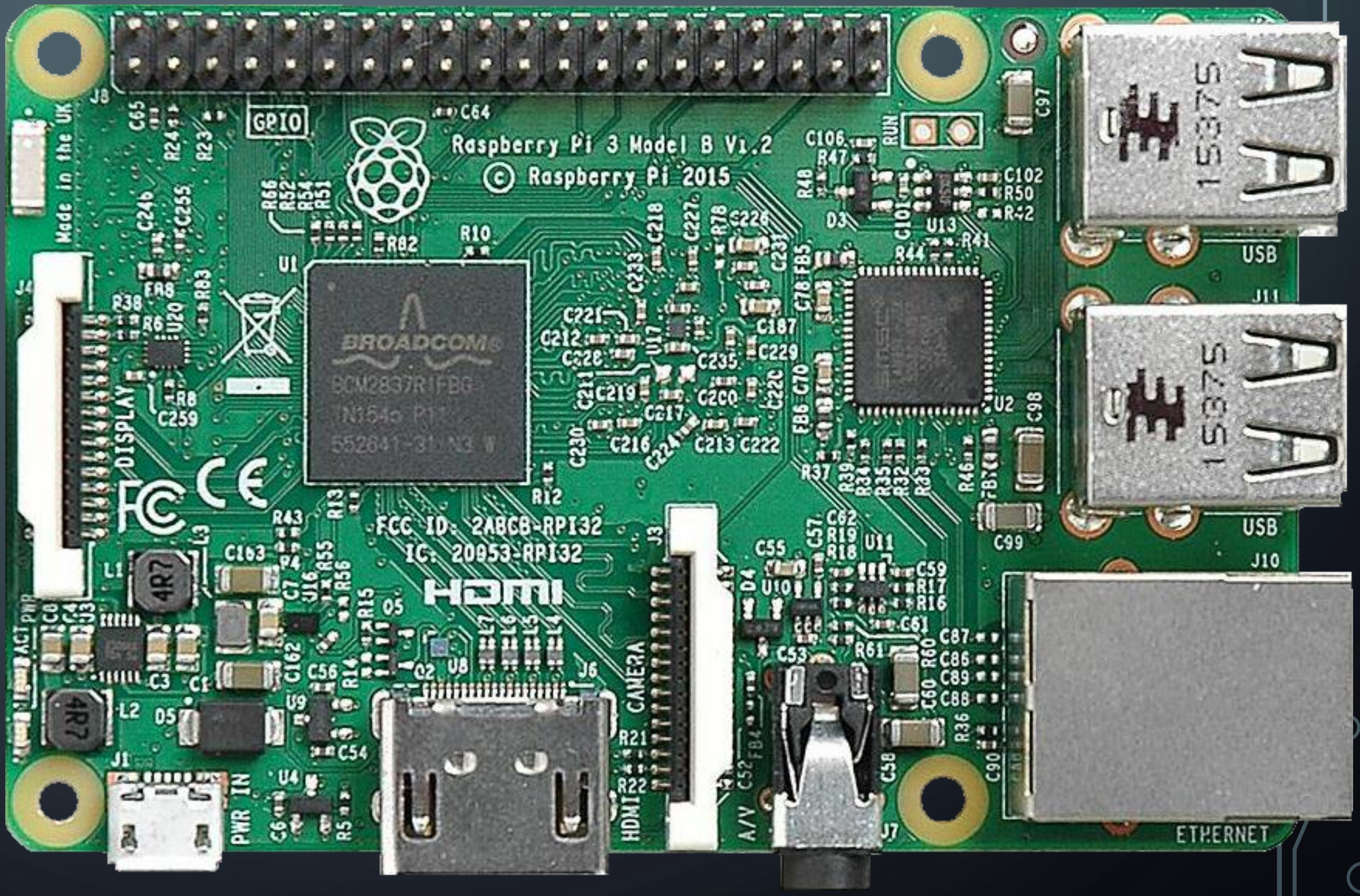
RASPBERRY PI

- Credit card-sized single-board computers
- Over 5 million sold
- Broadcom CPU 1.2GHz
  - Quad-core Cortex-A53
- Wi-Fi and Bluetooth
- HD video output
- Rasbian Linux distro
- 1GB RAM



HOW MUCH?

- £18.49 - £32.99



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.st0{fill:#6FD5F2;} .st1{fill:#FFFFFF;}

Lifewire

PCI Express (PCIe)

Search the site Search GO

PCI Express (PCIe)

PCI Express Definition

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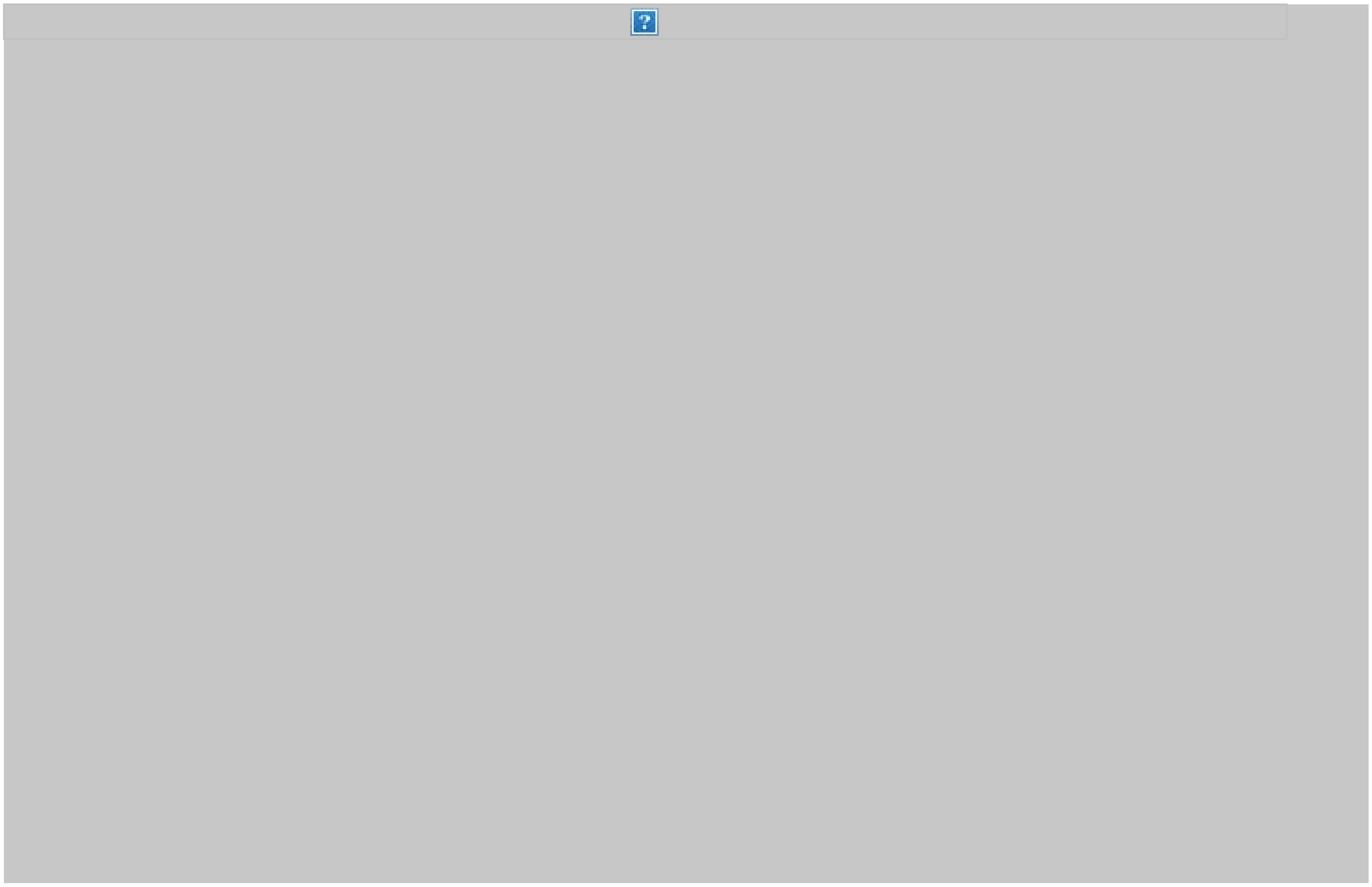

Closeup of a PCIe x4 Interface (SHPM2280P2H/240G SSD Card). © Kingston Digital

by Tim Fisher
Updated December 08, 2017

PCI Express, technically *Peripheral Component Interconnect Express* but often seen abbreviated as *PCIe* or *PCI-E*, is a standard type of connection for internal devices in a computer.

Generally, PCI Express refers to the actual expansion slots on the motherboard that accept PCIe-based expansion cards and to the types of expansion cards themselves.

PCI Express has all but replaced AGP and PCI, both of which replaced the oldest widely-used connection type called ISA.

While computers may contain a mix of various types of expansion slots, PCI Express is considered the standard internal interface. Many computer motherboards today are manufactured *only* with PCI Express slots.

How Does PCI Express Work?

Similar to the older standards like PCI and AGP, a PCI Express based device (like the one shown in the photo on this page) physically slides into a PCI Express slot on the motherboard.

The PCI Express interface allows high bandwidth communication between the device and the motherboard, as well as other hardware.

While not very common, an external version of PCI Express exists as well, unsurprisingly called *External PCI Express* but often shortened to *ePCIe*.

ePCIe devices, being external, require a special cable to connect whatever external, ePCIe device is being used to the computer via an ePCIe port, usually located on the back of the computer, supplied by either the motherboard or a special internal PCIe card.

What Types of PCI Express Cards Exist?

Thanks to the demand for faster and more realistic video games and video editing tools, video cards were the first types of computer peripherals to take advantage of the improvements offered by PCIe.

While video cards are easily still the most common type of PCIe card you'll find, other devices that benefit from considerably faster connects to the motherboard, CPU, and RAM is also increasingly being manufactured with PCIe connections instead of PCI ones.

For example, many high-end sound cards now use PCI Express, as do an increasing number of both wired and wireless network interface cards.

Hard drive controller cards may be the most to benefit with PCIe after video cards. Connecting a high-speed SSD drive to this high bandwidth interface allows for much faster reading from, and writing to, the drive. Some PCIe hard drive controllers even include the SSD built in, drastically altering how storage devices have traditionally been connected inside a computer.

Of course with PCIe replacing PCI and AGP completely in newer motherboards, just about every type of internal expansion card that relied on those older interfaces are being redesigned to support PCI Express. This includes things like USB expansion cards, Bluetooth cards, etc.

What Are the Different PCI Express Formats?

PCI Express x1... PCI Express 3.0... PCI Express x16. What does the 'x' mean? How do you tell if your computer supports which? If you have a *PCI Express x1* card but you only have a *PCI Express x16* port, does that work? If not, what are your options?

Confused? Don't worry, you're not alone!

It's often not at all clear when you're shopping for an expansion card for your computer, like a new video card, which of the various PCIe technologies work with your computer or which is better than the other.

However, as complex as it all looks, it's actually pretty simple once you understand the two important pieces of information about PCIe: the part that describes the physical size, and the part that describes the technology version, both explained below.

PCIe Sizes: x16 vs x8 vs x4 vs x1

As the heading suggests, the number after the x indicates the physical size of the PCIe card or slot, with x16 being the largest and x1 being the smallest.

Here's how the various sizes shape up:

	Number of Pins	Length
PCI Express x1	18	25 mm
PCI Express x4	32	39 mm
PCI Express x8	49	56 mm
PCI Express x16	82	89 mm

No matter what size the PCIe slot or card is, the *key notch*, that little space in the card or slot, is always at *Pin 11*.

In other words, it's the length of Pin 11 that keeps getting longer as you move from PCIe x1 to PCIe x16. This allows some flexibility to use cards of one size with slots of another.

PCIe cards fit in any PCIe slot on a motherboard that is at least as big as it is. For example, a PCIe x1 card will fit in any PCIe x4, PCIe x8, or PCIe x16 slot. A PCIe x8 card will fit in any PCIe x8 or PCIe x16 slot.

PCIe cards that are larger than the PCIe slot *may* fit in the smaller slot but only if that PCIe slot is open-ended (i.e. does not have a stopper at the end of the slot).

In general, a larger PCI Express card or slot supports greater performance, assuming the two cards or slots you're comparing support the same PCIe version.

You can see a full pinout diagram at the pinouts.ru website.

PCIe Versions: 4.0 vs 3.0 vs 2.0 vs 1.0

Any number after PCIe that you find on a product or motherboard is indicating the latest version number of the PCI Express specification that's supported.

Here's how the various versions of PCI Express compare:

	Bandwidth (per lane)	Bandwidth (per lane in an x16 slot)
PCI Express 1.0	2 Gbit/s (250 MB/s)	32 Gbit/s (4000 MB/s)
PCI Express 2.0	4 Gbit/s (500 MB/s)	64 Gbit/s (8000 MB/s)
PCI Express 3.0	7.877 Gbit/s (984.625 MB/s)	126.032 Gbit/s (15754 MB/s)
PCI Express 4.0	15.752 Gbit/s (1969 MB/s)	252.032 Gbit/s (31504 MB/s)

All PCI Express versions are backward and forward compatible, meaning no matter what version the PCIe card or your motherboard supports, they should work together, at least at a minimum level.

As you can see, the major updates to the PCIe standard drastically increased the bandwidth available each time, greatly increasing the potential of what the connected hardware can do.

Version improvements also fixed bugs, added features, and improved power management, but the increase in bandwidth is the most important change to note from version to version.

Maximizing PCIe Compatibility

PCI Express, as you read in the *sizes* and *versions* sections above, supports pretty much any configuration you can imagine. If it physically fits, it probably works... which is great.

One important thing to know, however, is that to get the increased bandwidth (which usually equates to the greatest performance), you'll want to choose the highest PCIe version that your motherboard supports and choose the largest PCIe size that will fit.

For example, a PCIe 3.0 x16 video card will give you the greatest performance, but only if your motherboard also supports PCIe 3.0 and has a free PCIe x16 slot. If your motherboard only supports PCIe 2.0, the card will only work up to that supported speed (e.g. 64 Gbit/s in the x16 slot).

Most motherboards and computers manufactured in 2013 or later probably support PCI Express v3.0. Check your motherboard or computer manual if you're not sure.

If you can't find any definitive information on the PCI version that your motherboard supports, I recommending buying the largest and latest version PCIe card, so long as it'll fit, of course.

What Will Replace PCIe?

Video game developers are always looking to design games that are ever more realistic but can only do that if they can pass more data from their game programs into your VR headset or computer screen and faster interfaces are required for that to happen.

Because of this, PCI Express won't continue to reign supreme resting on its laurels. PCI Express 3.0 is amazingly fast, but the world wants faster.

PCI Express 5.0, due to be complete by 2019, will support a bandwidth of 31.504 GB/s per lane (3938 MB/s), *twice* what's offered by PCIe 4.0. There are a number of other non-PCIe interface standards being looked at by the technology industry but since they would require major hardware changes, PCIe looks to remain the leader for some time to come.

Submit

- **[What Is an Expansion Slot?]**
- **[OWC Mercury Accelsior E2 Review]**
- **[What is Accelerated Graphics Port (AGP)?]**
- **[What Does the Inside of Your PC Look Like?]**
- **[The Old Way to Change Your Peripherals - PCI]**
- **[What are AMIBIOS Beep Codes and What Do They Mean?]**
- **[Will PCs Ever See a SATA-Express Drive?]**
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-

How the M.2 Interface is Going to Make Your PC Even Faster

- **What is a Peripheral Device?**

- **Things to Consider When Picking a Motherboard for Your PC**

- **Here's What to Do When Your Computer Freezes During Windows Startup**

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NUMBER SYSTEMS AND BINARY NUMBERS

ALL COMPUTER DATA IS STORED/PROCESSED AS BINARY NUMBERS

!MATH WARNING!

- Today's lecture contains trace amounts of arithmetic and algebra
- Please be advised that calculators will be allowed (and that you probably won't need them)

OVERVIEW/QUESTIONS

- What gives a number its value?
- What is a number system?
- What’s a binary number?
- What kind of numbers do computers store and manipulate?

TYPES OF NUMBER

- Natural Numbers
  - Zero and any number obtained by repeatedly adding one to it.
  - Examples: 100, 0, 45645, 32
- Negative Numbers
  - A value less than 0
  - Denoted with a ‘–’ sign
  - Examples: -24, -1, -45645, -32

TYPES OF NUMBER

- Integers
  - Set of natural and negative numbers
  - Examples: 249, 0, -45645, -32
- Real numbers
  - Numbers that have decimal representations and have a finite or infinite sequence of digits to the right of the decimal point.
  - They can be positive, negative, or zero.

NUMBERING SYSTEMS

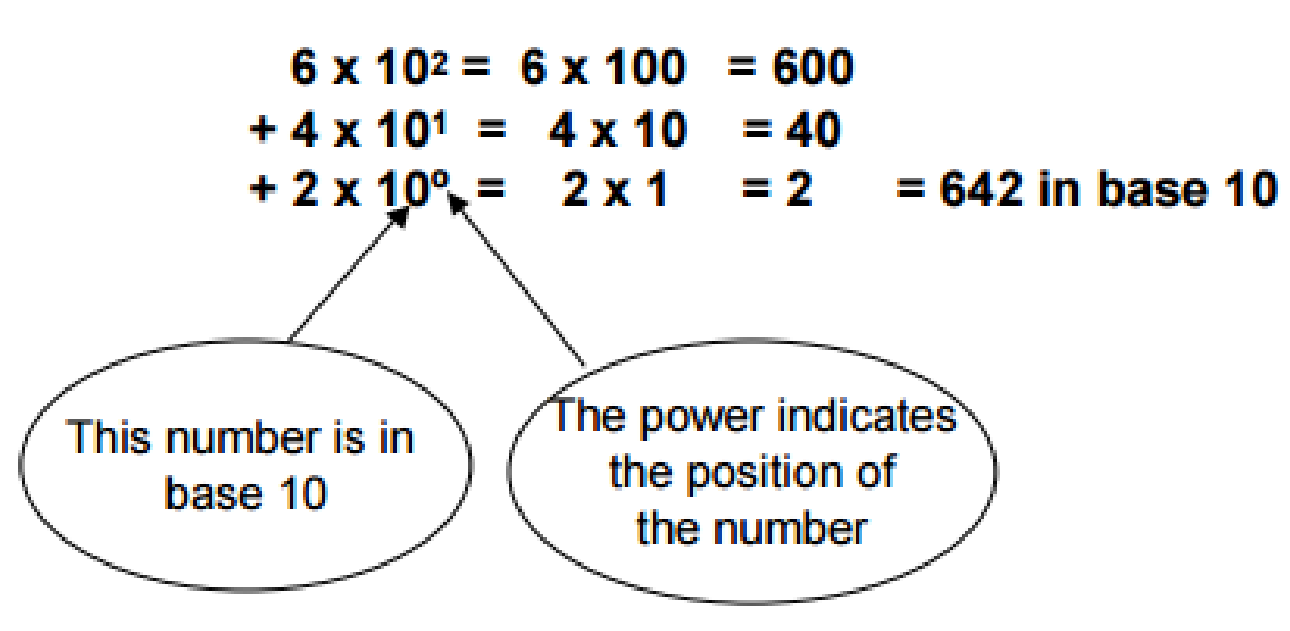
- A numbering system assigns meaning to the position of the numeric symbols.
- For example, consider this set of symbols:
  - 642
  - What number is it?
  - Why?

NUMBERING SYSTEMS

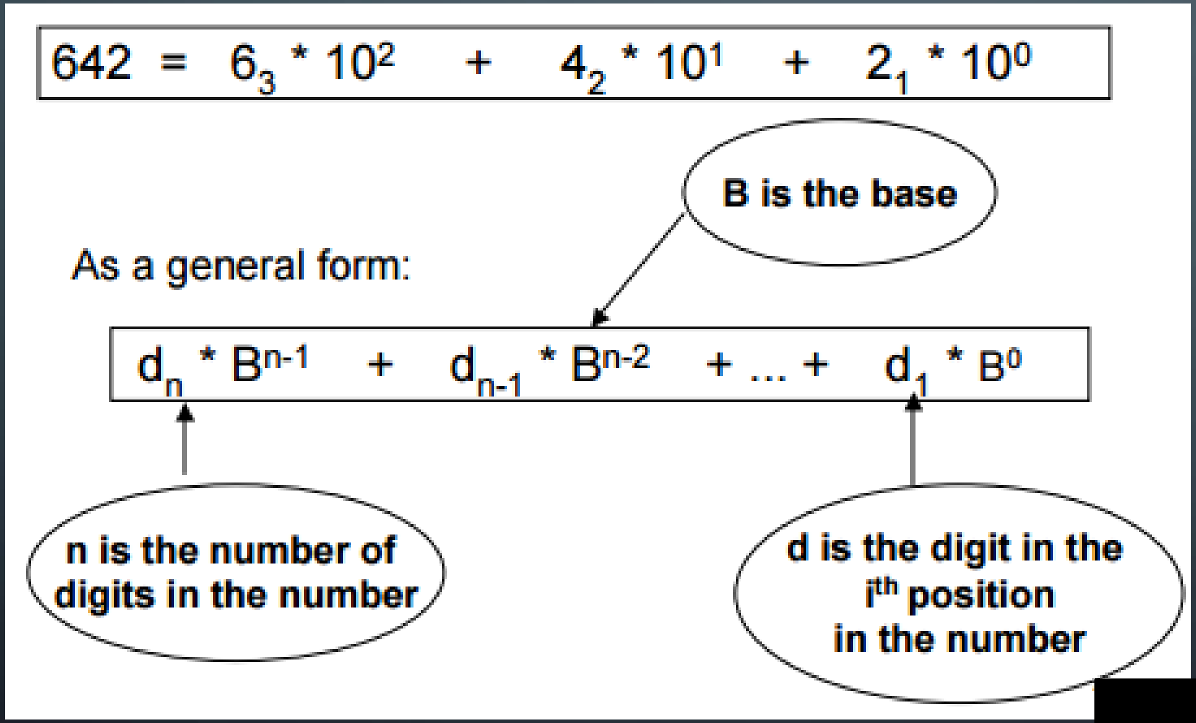
- It depends on the numbering system.
  - 642 is 600 + 40 + 2 in BASE 10
- The base of a number determines the number of digits (e.g. symbols) and the value of digit positions

POSITIONAL NOTATION

- Continuing with our example…
- 642 in base 10 positional notation is:



POSITIONAL NOTATION



[redacted]

BINARY NUMBERS

- Digital computers are made up of electronic circuits, which have exactly 2 states: on and off.
- Computers use a numbering system which has exactly 2 symbols, representing on and off.
- 0V and 5V (3.3V)

BINARY NUMBERS

- Decimal is base 10 and has 10 digits:
  - 0,1,2,3,4,5,6,7,8,9
- Binary is base 2 and has 2, so we use only 2 symbols:
  - 0,1
- For a given base, valid numbers will include digits in that base, ranging from 0 up to (but not including) the base.

BINARY NUMBERS AND COMPUTERS

- A binary digit or bit can take on only these two values.
  - Low Voltage = 0
  - High Voltage = 1
- Binary numbers are built by concatenating a string of bits together.
  - Example: 10101010

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NUMBER CONVERSION

POSITIONAL NOTATION: BINARY NUMBERS

- Recall this general form: $d_n * B^{n-1} + d_{n-1} * B^{n-2} + ... + d_1 * B^0$

- The same can be applied to base-2 numbers:

$$1011_{bin} = 1 * 2^3 + 0 * 2^2 + 1 * 2^1 + 1 * 2^0$$

$$1011_{bin} = (1 * 8) + (0 * 4) + (1 * 2) + (1 * 1)$$

$$1011_{bin} = 8 + 0 + 2 + 1 = 11_{dec}$$

16

CONVERTING BINARY TO DECIMAL

- What is the decimal equivalent of the binary number 01101110?
  - (you try it! Work left-to-right)

CONVERTING BINARY TO DECIMAL

- What is the decimal equivalent of the binary number 01101110?
  - (you try it! Work left-to-right)

$$
\begin{aligned}
& 0 \times 2^7 = 0 \times 128 = 0 \\
+ & 1 \times 2^6 = 1 \times 64 = 64 \\
+ & 1 \times 2^5 = 1 \times 32 = 32 \\
+ & 0 \times 2^4 = 0 \times 16 = 0 \\
+ & 1 \times 2^3 = 1 \times 8 = 8 \\
+ & 1 \times 2^2 = 1 \times 4 = 4 \\
+ & 1 \times 2^1 = 1 \times 2 = 2 \\
+ & 0 \times 2^0 = 0 \times 1 = 0 \\
& = 110 \text{ (decimal)}
\end{aligned}
$$

CONVERTING BINARY TO DECIMAL

- Try another one.
- What is the decimal equivalent of the binary number 10101011?
  - (you try it! Work left-to-right)

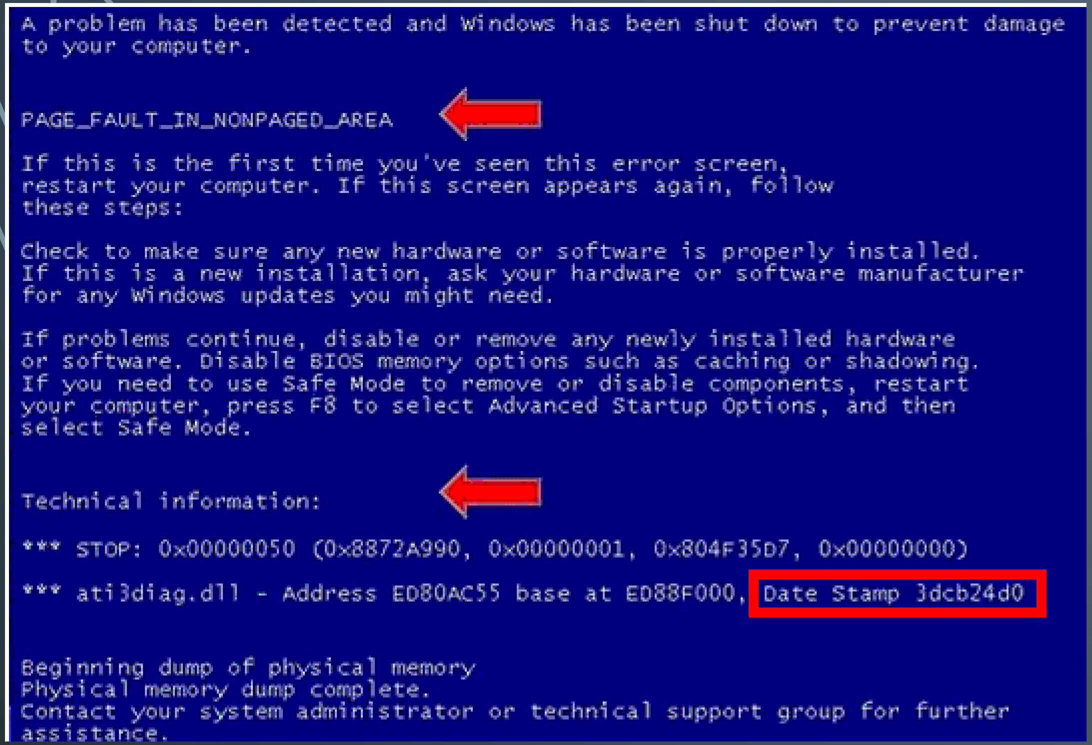
CONVERTING BINARY TO DECIMAL

- Try another one.
- What is the decimal equivalent of the binary number 10101011?
  - (you try it! Work left-to-right)

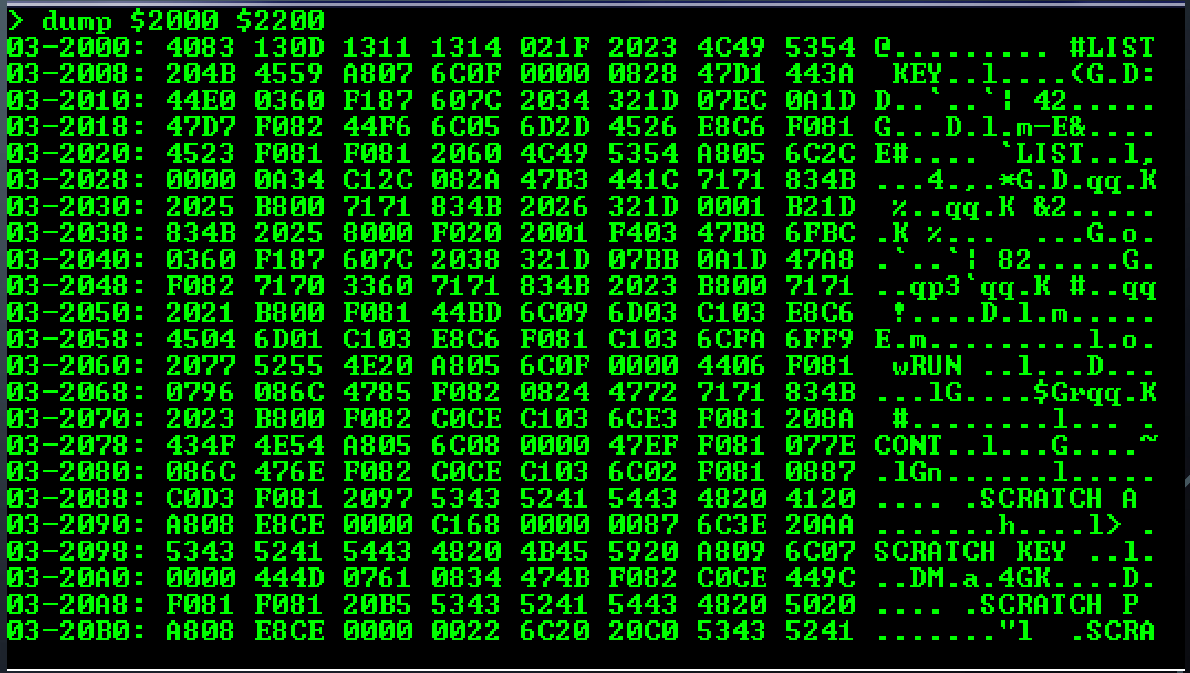
$$
\begin{aligned}
& 1 \times 2^7 = 1 \times 128 = 128 \\
+ & 0 \times 2^6 = 0 \times 64 = 0 \\
+ & 1 \times 2^5 = 1 \times 32 = 32 \\
+ & 0 \times 2^4 = 0 \times 16 = 0 \\
+ & 1 \times 2^3 = 1 \times 8 = 8 \\
+ & 0 \times 2^2 = 0 \times 4 = 0 \\
+ & 1 \times 2^1 = 1 \times 2 = 2 \\
+ & 1 \times 2^0 = 1 \times 1 = 1 \\
& = 171 \text{ (decimal)}
\end{aligned}
$$

HEX: ANOTHER COMPUTING NUMBER SYSTEM

- Hex – short for hexadecimal
  - Binary – base 2
  - Decimal – base 10
  - Hexadecimal – base 16 – numbers 0-9 and letters A-F
- 1 hex character corresponds to 4 bits also known as a nibble
  - 2 hex chars correspond to a byte
- Computer memory organised as bytes
  - Hex characters used to represent computer memory



A problem has been detected and Windows has been shut down to prevent damage to your computer.
PAGE_FAULT_IN_NONPAGED_AREA
If this is the first time you've seen this error screen, restart your computer. If this screen appears again, follow these steps:
Check to make sure any new hardware or software is properly installed. If this is a new installation, ask your hardware or software manufacturer for any Windows updates you might need.
If problems continue, disable or remove any newly installed hardware or software. Disable BIOS memory options such as caching or shadowing. If you need to use Safe Mode to remove or disable components, restart your computer, press F8 to select Advanced Startup Options, and then select Safe Mode.
Technical information:
*** STOP: 0x00000050 (0x8872A990, 0x00000001, 0x804F35D7, 0x00000000)
*** ati3diag.dll - Address ED80AC55 base at ED88F000, Date Stamp 3dcb24d0
Beginning dump of physical memory
Physical memory dump complete.
Contact your system administrator or technical support group for further assistance.



> dump $2000 $2200
03-2000: 4083 130D 1311 1314 021F 2023 4C49 5354 @......... #LIST
03-2008: 204B 4559 A807 6C0F 0000 0828 47D1 443A KEY..l....<G.D:
03-2010: 44E0 0360 F187 607C 2034 321D 07EC 0A1D D..`..`| 42.....
03-2018: 47D7 F082 44F6 6C05 6D2D 4526 E8C6 F081 G...D.l.m-E&....
03-2020: 4523 F081 F081 2060 4C49 5354 A805 6C2C E#.... `LIST..l,
03-2028: 0000 0A34 C12C 082A 47B3 441C 7171 834B ...4.,.*G.D.qq.K
03-2030: 2025 B800 7171 834B 2026 321D 0001 B21D %..qq.K &2.....
03-2038: 834B 2025 8000 F020 2001 F403 47B8 6FBC .K %... ...G.o.
03-2040: 0360 F187 607C 2038 321D 07BB 0A1D 47A8 .`..`| 82.....G.
03-2048: F082 7170 3360 7171 834B 2023 B800 7171 ..qp3`qq.K #..qq
03-2050: 2021 B800 F081 44BD 6C09 6D03 C103 E8C6 !....D.l.m.....
03-2058: 4504 6D01 C103 E8C6 F081 C103 6CFA 6FF9 E.m.........l.o.
03-2060: 2077 5255 4E20 A805 6C0F 0000 4406 F081 wRUN ..l...D...
03-2068: 0796 086C 4785 F082 0824 4772 7171 834B ...lG....$Grqq.K
03-2070: 2023 B800 F082 C0CE C103 6CE3 F081 208A #........l... .
03-2078: 434F 4E54 A805 6C08 0000 47EF F081 077E CONT..l...G....~
03-2080: 086C 476E F082 C0CE C103 6C02 F081 0887 .lGn......l.....
03-2088: C0D3 F081 2097 5343 5241 5443 4820 4120 .... .SCRATCH A
03-2090: A808 E8CE 0000 C168 0000 0087 6C3E 20AA ....h....l> .
03-2098: 5343 5241 5443 4820 4B45 5920 A809 6C07 SCRATCH KEY ..l.
03-20A0: 0000 444D 0761 0834 474B F082 C0CE 449C ..DM.a.4GK....D.
03-20A8: F081 F081 20B5 5343 5241 5443 4820 5020 .... .SCRATCH P
03-20B0: A808 E8CE 0000 0022 6C20 20C0 5343 5241 ...."l .SCRA

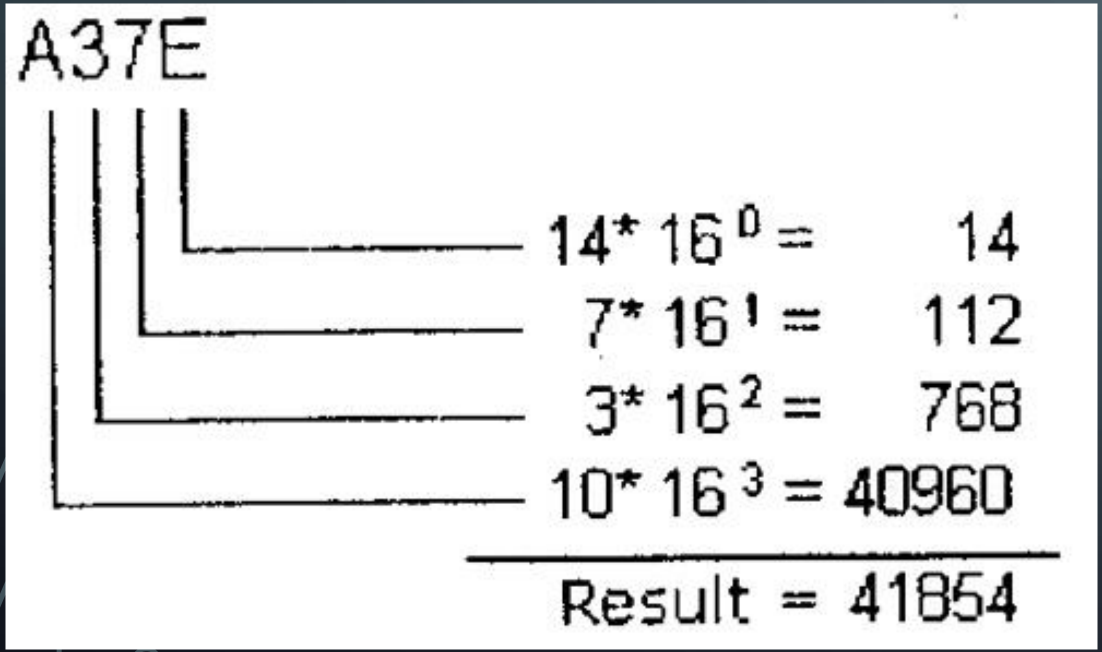
BINARY TO HEX CONVERSION

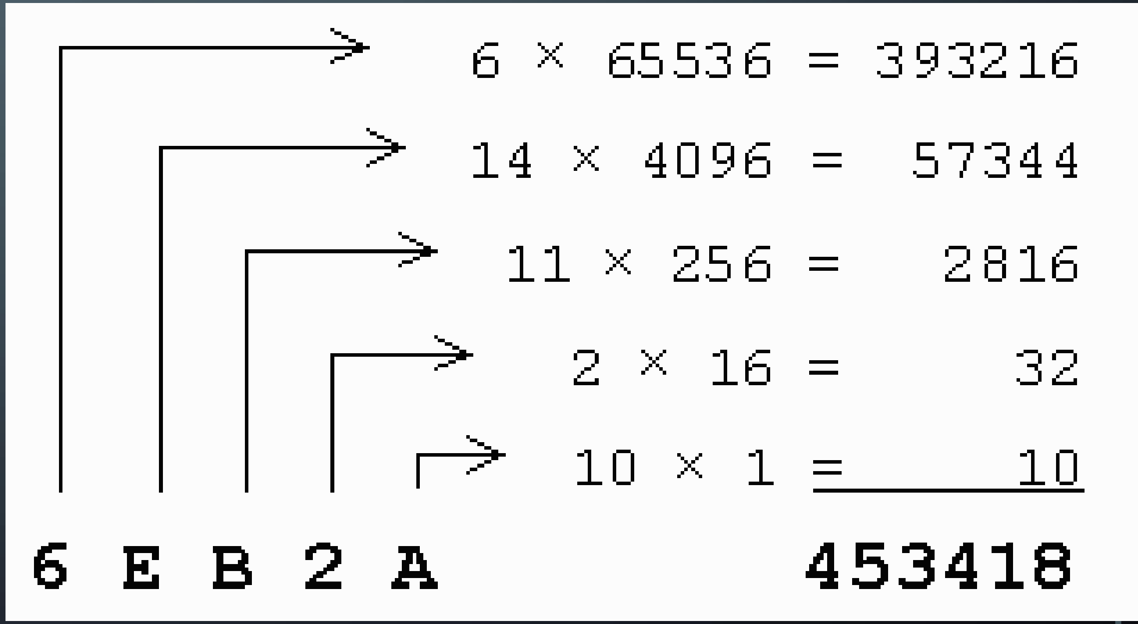
- Example: Convert the binary number 11111011110_2 to its hex equivalent

1. Separate the digits into groups from right to left where each group contains 4 bits. If there are binary digits missing, **<u>replace with zeros</u>** = **<u>0</u>**111 1101 1110
2. Find the equivalent hexadecimal number for each group
   - $0111_2 = 7_{10} = 7_{16}$
   - $1101_2 = 13_{10} = D_{16}$
   - $1110_2 = 14_{10} = E_{16}$
3. Result = $7DE_{16}$

HEX TO DECIMAL CONVERSION

- 2 examples





ASCII TEXT ENCODING

- **ASCII** stands for American Standard Code for Information Interchange.
- Computers can only understand numbers, so an **ASCII** code is the numerical representation of a character such as 'a' or '%'
- Each alphanumeric character is represented using 8 bits/2 nibbles/1 bytes
- The characters encoded are numbers 0 to 9, lowercase letters a to z, uppercase letters A to Z, basic punctuation symbols and a space.

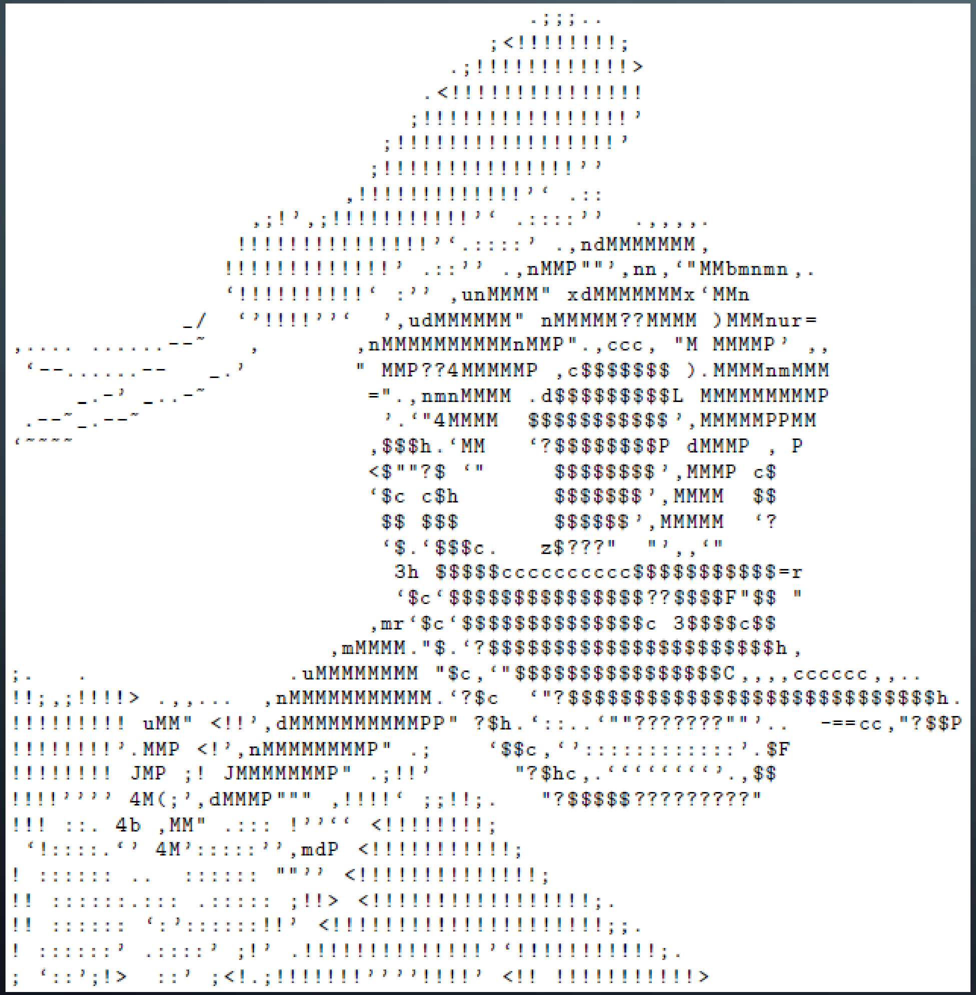
ASCII TEXT ENCODING

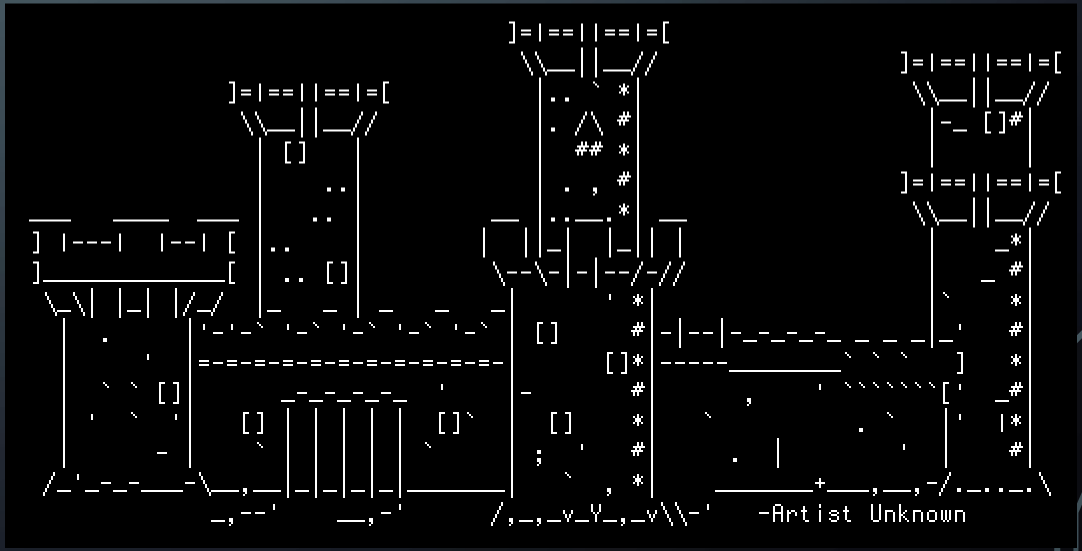
- For example:
  - ‘Z’ = $5A_{16}$ = 90_{10}
- ‘5’ and ‘A’ are the 2 nibbles that make up the ASCII byte

ASCII	Hex	Symbol	ASCII	Hex	Symbol	ASCII	Hex	Symbol	ASCII	Hex	Symbol
0	0	NUL	16	10	DLE	32	20	(space)	48	30	0
1	1	SOH	17	11	DC1	33	21	!	49	31	1
2	2	STX	18	12	DC2	34	22	"	50	32	2
3	3	ETX	19	13	DC3	35	23	#	51	33	3
4	4	EOT	20	14	DC4	36	24	$	52	34	4
5	5	ENQ	21	15	NAK	37	25	%	53	35	5
6	6	ACK	22	16	SYN	38	26	&	54	36	6
7	7	BEL	23	17	ETB	39	27	'	55	37	7
8	8	BS	24	18	CAN	40	28	(	56	38	8
9	9	TAB	25	19	EM	41	29	)	57	39	9
10	A	LF	26	1A	SUB	42	2A	*	58	3A	:
11	B	VT	27	1B	ESC	43	2B	+	59	3B	;
12	C	FF	28	1C	FS	44	2C	,	60	3C	<
13	D	CR	29	1D	GS	45	2D	-	61	3D	=
14	E	SO	30	1E	RS	46	2E	.	62	3E	>
15	F	SI	31	1F	US	47	2F	/	63	3F	?

ASCII	Hex	Symbol	ASCII	Hex	Symbol	ASCII	Hex	Symbol	ASCII	Hex	Symbol
64	40	@	80	50	P	96	60	`	112	70	p
65	41	A	81	51	Q	97	61	a	113	71	q
66	42	B	82	52	R	98	62	b	114	72	r
67	43	C	83	53	S	99	63	c	115	73	s
68	44	D	84	54	T	100	64	d	116	74	t
69	45	E	85	55	U	101	65	e	117	75	u
70	46	F	86	56	V	102	66	f	118	76	v
71	47	G	87	57	W	103	67	g	119	77	w
72	48	H	88	58	X	104	68	h	120	78	x
73	49	I	89	59	Y	105	69	i	121	79	y
74	4A	J	90	5A	Z	106	6A	j	122	7A	z
75	4B	K	91	5B	[	107	6B	k	123	7B	{
76	4C	L	92	5C	\	108	6C	l	124	7C	|
77	4D	M	93	5D	]	109	6D	m	125	7D	}
78	4E	N	94	5E	^	110	6E	n	126	7E	~
79	4F	O	95	5F	_	111	6F	o	127	7F	

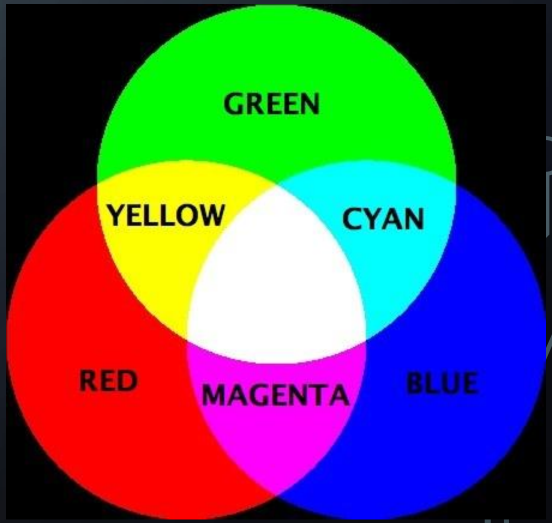
ASCII ART



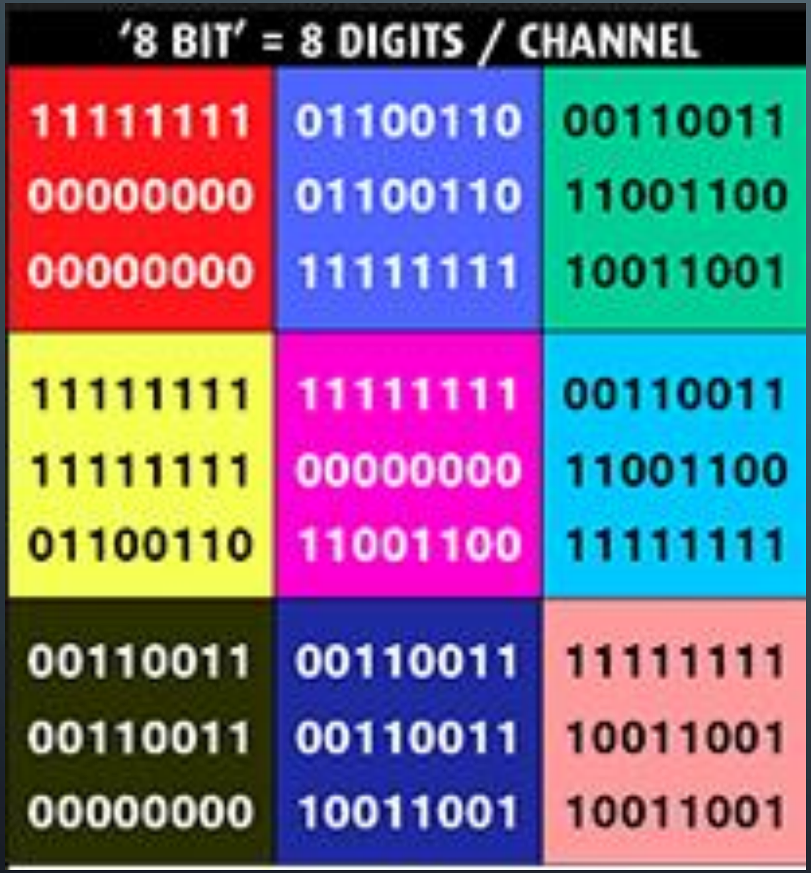


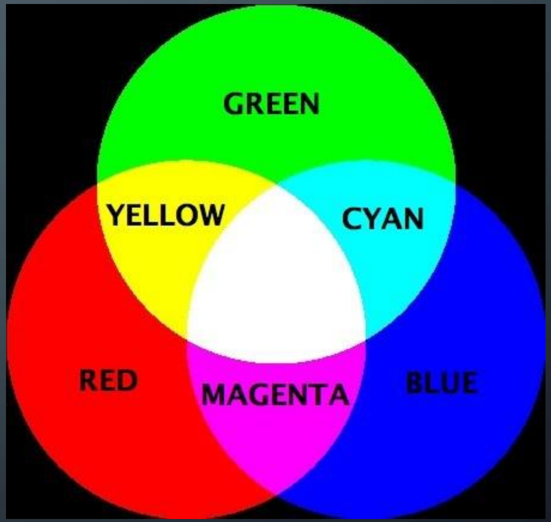
COMPUTER IMAGES

- Represented by mix of 3 primary colours (Red, Blue and Green – R,G,B)
- For each pixel, each colour component represented by 1-byte (8 bits)
  - Therefore each pixel = 3 bytes (or 24 bits (or 6 hex chars))
  - Image your viewing is 1280x720 = 921,600 x 3 = 2.8MBytes (lots of data)
  - 24-bits known as TrueColour = 16,777,216 colour variations.
    - Human eye can discriminate up to ten million colors



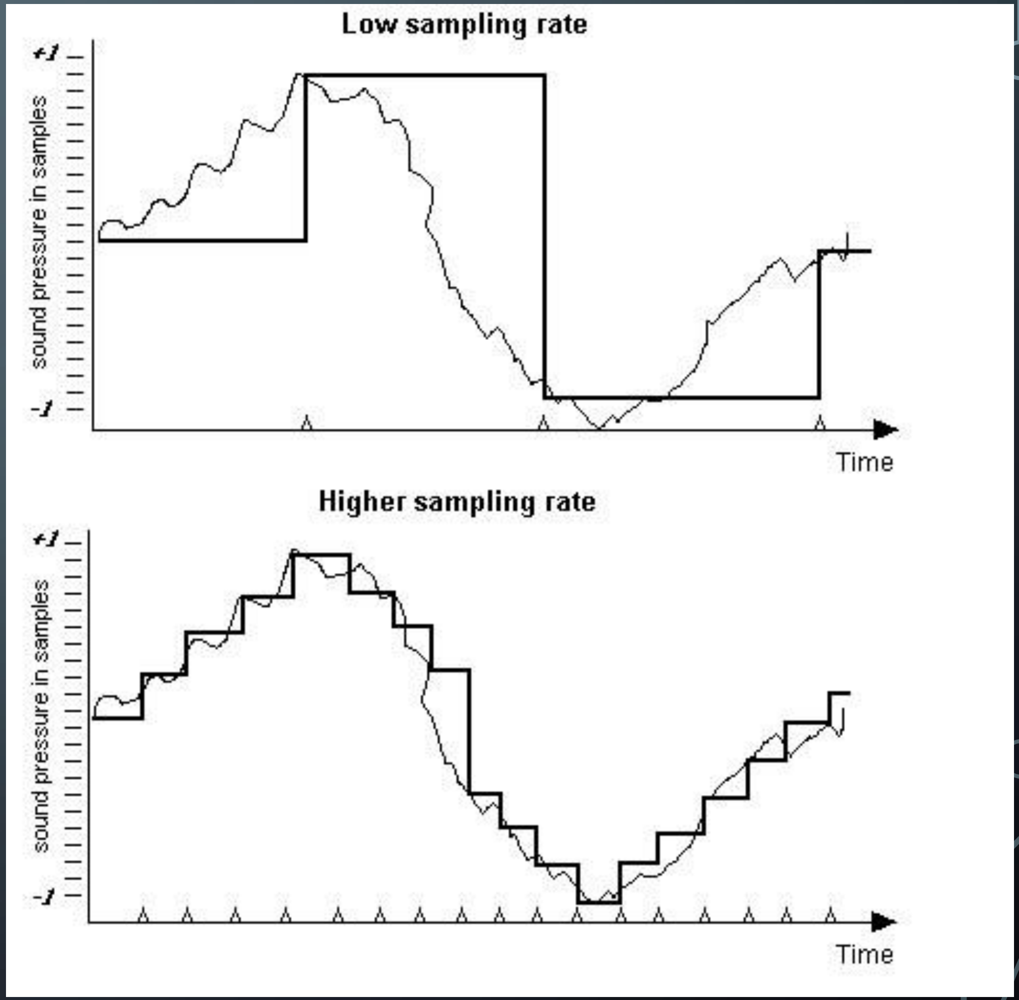
COMPUTER IMAGES





COMPUTER AUDIO

- Blu-ray quality audio is 192,000 samples per second
- Each sample is 24 bits (6 hex chars) per sample
- Therefore 1 second of data = 0.57MB per second



RECAP

- Outlined relationship between base 10 numbers and binary/hexadecimal
- Demonstrated conversions between varying formats
- Illustrated how following data is encoded on a computer system using binary/hex numbers:
  - Numbers
  - Text
  - Images
  - Audio

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Counting Using Different Number Systems

(Base 2) Binary	(Base 8) Octal	(Base 10) Decimal	(Base 16) Hexadecimal
0	0	**0**	0
1	1	**1**	1
10	2	**2**	2
11	3	**3**	3
100	4	**4**	4
101	5	**5**	5
110	6	**6**	6
111	7	**7**	7
1000	**10**	**8**	8
1001	11	**9**	9
1010	12	**10**	A
1011	13	**11**	B
1100	14	**12**	C
1101	15	**13**	D
1110	16	**14**	E
1111	17	**15**	F
10000	20	**16**	**10**
10001	21	**17**	11
10010	22	**18**	12
10011	23	**19**	13
10100	24	**20**	14
10101	25	**21**	15
10110	26	**22**	16
10111	27	**23**	17
11000	30	**24**	18
11001	31	**25**	19
11010	32	**26**	1A
11011	33	**27**	1B
11100	34	**28**	1C
11101	35	**29**	1D
11110	36	**30**	1E
11111	37	**31**	1F
100000	40	**32**	20

Homework

Task 1: Convert your first name and the initials of your surname into their ASCII hexadecimal and binary representations. Investigate online how to achieve this. Make sure to capitalise the first letter of your name and initials. Additionally, add a space character between your first-name and initials.

Task 2: Pick a famous person and identify their **year** of birth (year between 1800-2018). Convert this 4 digit decimal number into binary and hex formats. Use the methods described in the videos to achieve this.

Format your answers as I have posted in the forum

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BINARY ARITHMETIC

THIS VIDEO

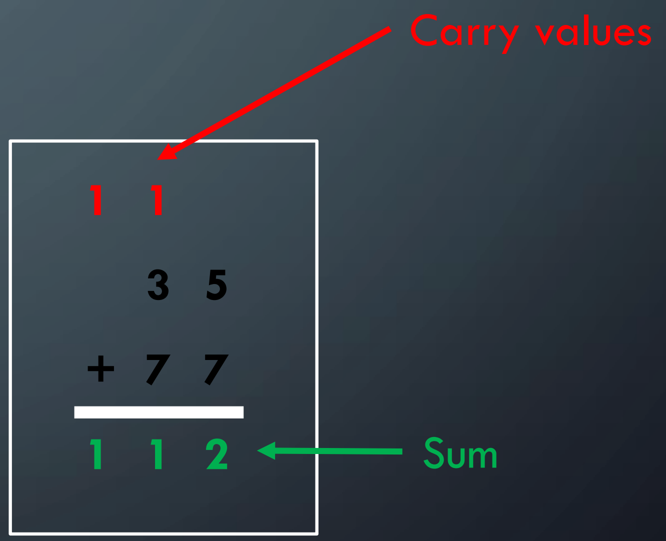
- Counting in binary
- Adding binary numbers
- Encoding negative numbers
- Subtraction is a special case of addition
- Binary floating point numbers

RECAP: COUNTING IN BINARY

0	0
1	1
1 0	2
1 1	3
1 0 0	4
1 0 1	5
1 1 0	6
1 1 1	7
1 0 0 0	8

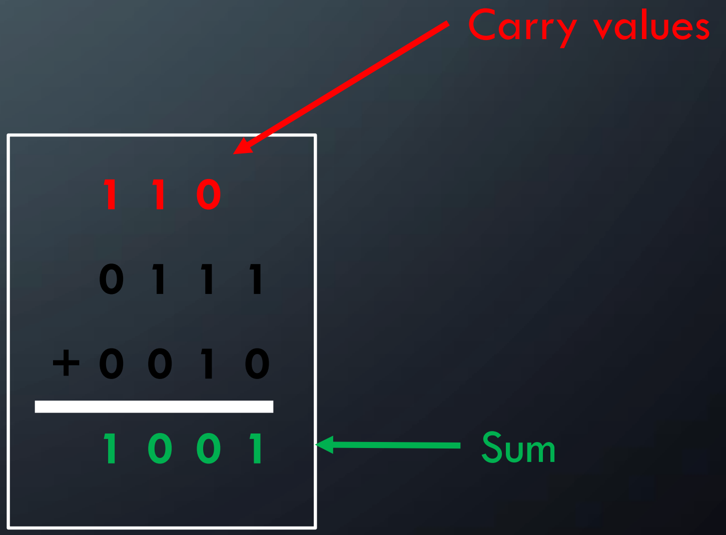
RECALL: ADD WITH CARRY

- Recall how to add 2 multi-digit decimal numbers:
- Example: adding 35 + 77
  - 5 + 7 is 12, or 2 with a carry of 1
- Always work right to left



BINARY: ADD WITH CARRY

- We're already able to add 1 – counting
- Remember that there are only 2 digits in binary, 0 and 1
  - 1 + 1 = 0 with a carry of 1

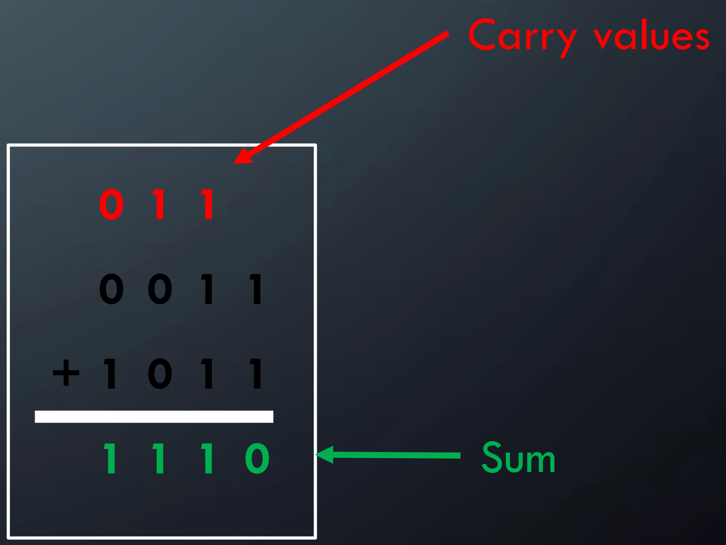


TRY IT:

- 0011 + 1011
- Hint: work columns right to left.
- Remember to carry as needed.

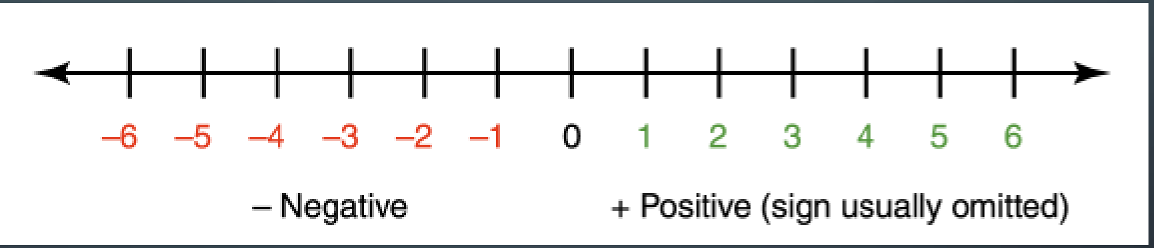
TRY IT:

- 0011 + 1011
- Hint: work columns right to left.
- Remember to carry as needed.



NEGATIVE NUMBERS

- Signed-magnitude numbers
  - The sign represents the ordering, and the digits represent the magnitude of the number.

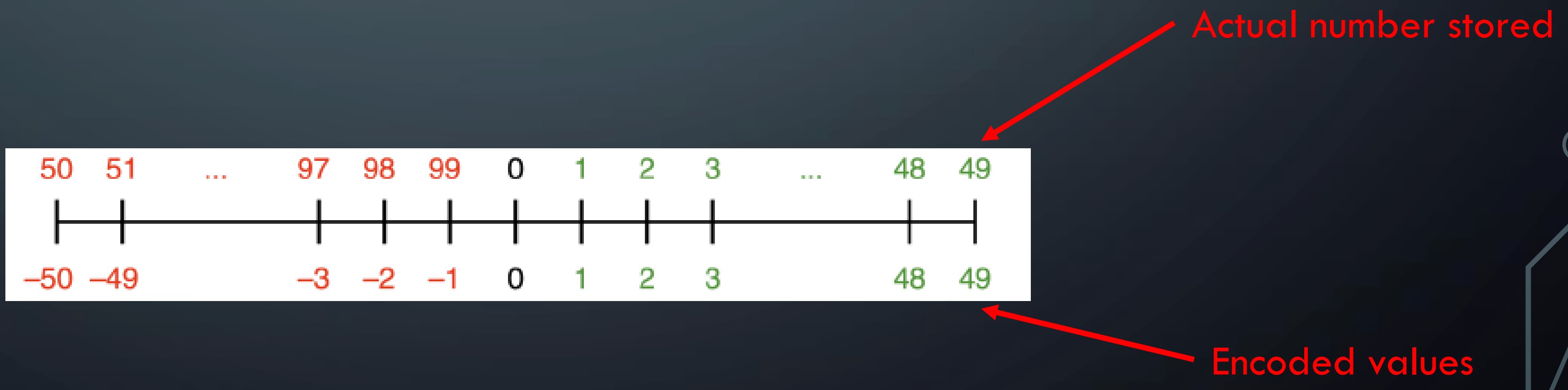


NEGATIVE NUMBERS

- Problem:
  - In signed-magnitude representation, there is a plus zero and minus zero – complexity.
- Solution
  - Store all numbers as natural integer values, with half of them representing negative numbers

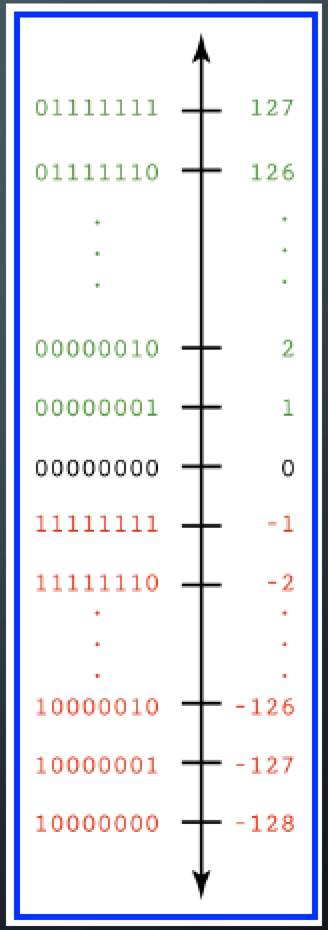
NEGATIVE NUMBERS

- An example using two decimal digits,
  - Let numbers 0-49 represent 0-49
  - Let numbers 50-99 represent -50 to -1
- This representation scheme is called: ten's complement.



2'S COMPLEMENT

- Two's Complement - Using binary numbers, we call this the two's complement
- All numbers are stored as positive binary numbers
  - Half are *encoded* to be interpreted as negative.
- What do you observe about the left-most bit?



2'S COMPLEMENT

- How To Calculate a Two's Complement Number
  - First, find the equivalent binary number.
  - If the decimal number was positive: you're done.
  - If the decimal number was negative: invert all the bits, and add 1 (with carries as needed).
- Example:
  - 25 decimal is 00011001 binary. It's positive, so all done.
  - How about -25 decimal?

2'S COMPLEMENT

- Example:
  - 25 decimal is 00011001 binary. It's positive, so all done.
  - How about -25 decimal?
  - Begin with binary: 00011001
  - Invert all the bits to get: 11100110
  - Add 1 to get: 11100111 (decimal value -25)

2'S COMPLEMENT ARITHMETIC

- With 2s complement, we can use addition instead of subtraction
  - much easier!

```
  123          01111011
-  25         +11100111
  ---         ---------
   98          01100010
```

- (last bit carried is ignored)

NUMBER OVERFLOW

- If each value is stored using eight bits, consider adding 127 to 3:

```
   01111111
+  00000011
-----------
   10000010
```

- Carry falls off a cliff
- How do we interpret the value 10000010?
  - Adding two positive integers yields a negative integer. This is an example of overflow.

NUMBER OVERFLOW

- We interpret the result 10000010 as decimal number -126.
- How did that happen?
  - The left-most bit is 1, so we know it is negative.
  - The most negative signed 8-bit number is binary 10000000, which is -128 (-27) in decimal.
  - Add binary 00000010 (2) to get 10000010, which is -126 decimal.
- What does one do about overflow?
  - Prevent by using a wider bit-depth – so carry is captured

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LOGIC GATES

OBJECTIVES

- Identify the basic gates and describe the behaviour of each
- Describe how gates are implemented using transistors
- Combine basic gates into circuits
- Describe the behaviour of a gate or circuit using Boolean expressions, truth tables, and logic diagrams

GATES AND CIRCUITS

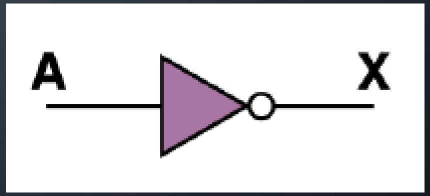
- Gate
  - A device that performs a basic operation on electrical signals
- Circuit
  - Gates combined to perform more complicated tasks
  - Gates are building blocks of a circuit

HOW DO WE DESCRIBE THE BEHAVIOUR OF GATES AND CIRCUITS?

- Boolean expressions
  - Uses Boolean algebra, a mathematical notation for expressing two-valued logic
  - Note: George Boole was 1st professor of mathematics at University College Cork (UCC)

$$X = A'$$

- Logic diagrams
  - A graphical representation of a circuit; each gate has its own symbol



- Truth tables
  - A table showing all possible input value and the associated output values

A	X
0	1
1	0

GATES

- Six types of gates
  - NOT
  - AND
  - OR
  - XOR
  - NAND
  - NOR
- Typically, logic diagrams are black and white with gates distinguished only by their shape

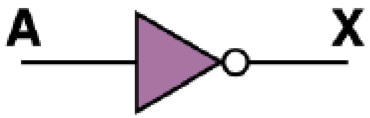
NOT GATE

- A NOT gate accepts one input signal (0 or 1) and returns the opposite signal as output

Boolean Expression

$$X = A'$$

Logic Diagram Symbol



Truth Table

A	X
0	1
1	0

Various representations of a NOT gate

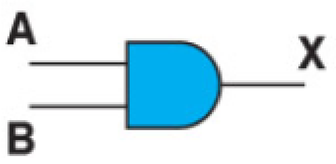
AND GATE

- An AND gate accepts two input signals
- If both are 1, the output is 1; otherwise, the output is 0

Boolean Expression

$$X = A \cdot B$$

Logic Diagram Symbol



Truth Table

A	B	X
0	0	0
0	1	0
1	0	0
1	1	1

Various representations of an AND gate

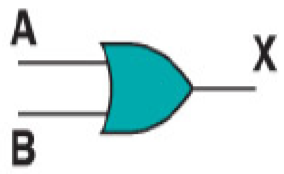
OR GATE

- An OR gate accepts two input signals
- If both are 0, the output is 0; otherwise, the output is 1

Boolean Expression

$$X = A + B$$

Logic Diagram Symbol



Truth Table

A	B	X
0	0	0
0	1	1
1	0	1
1	1	1

Various representations of a OR gate

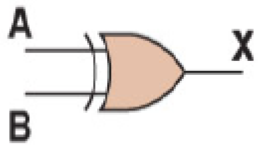
XOR GATE

- An XOR gate accepts two input signals
- If both are the same, the output is 0; otherwise, the output is 1

Boolean Expression

$$X = A \oplus B$$

Logic Diagram Symbol



Truth Table

A	B	X
0	0	0
0	1	1
1	0	1
1	1	0

Various representations of an XOR gate

XOR GATE

- Note the difference between the XOR gate and the OR gate; they differ only in one input situation
- When both input signals are 1, the OR gate produces a 1 and the XOR produces a 0
- XOR is called the exclusive OR

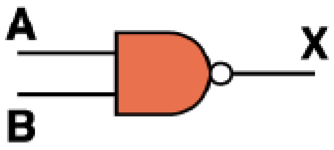
NAND GATE

- The NAND gate accepts two input signals
- If both are 1, the output is 0; otherwise, the output is 1

Boolean Expression

$$X = (A \cdot B)'$$

Logic Diagram Symbol



Truth Table

A	B	X
0	0	1
0	1	1
1	0	1
1	1	0

Various representations of a NAND gate

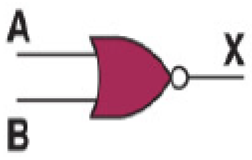
NOR GATE

- The NOR gate accepts two input signals
- If both are 0, the output is 1; otherwise, the output is 0

Boolean Expression

$$X = (A + B)'$$

Logic Diagram Symbol



Truth Table

A	B	X
0	0	1
0	1	0
1	0	0
1	1	0

Various representations of a NOR gate

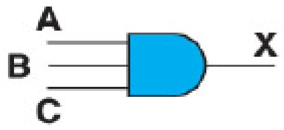
GATES WITH MORE INPUTS

- Gates can be designed to accept three or more input values
- A three-input AND gate, for example, produces an output of 1 only if all input values are 1

Boolean Expression

$X = A \cdot B \cdot C$

Logic Diagram Symbol



Truth Table

A	B	C	X
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	1

Various representations of a three-input AND gate

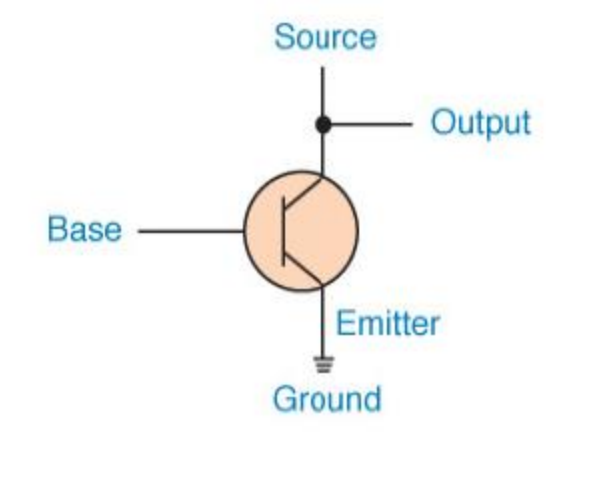
REVIEW OF GATE PROCESSING

- A NOT gate inverts its single input
- An AND gate produces 1 if both input values are 1
- An OR gate produces 0 if both input values are 0
- An XOR gate produces 0 if input values are the same
- A NAND gate produces 0 if both inputs are 1
- A NOR gate produces a 1 if both inputs are 0

CONSTRUCTING GATES - TRANSISTORS

- Transistor
  - One of most important inventions of 20th century - Bardeen, Brattain, and Shockley earned 1956 Nobel Physics Prize
  - A device that acts either as a wire that conducts electricity or as an open circuit that blocks the flow of electricity, depending on the voltage level of an input signal
  - A transistor has no moving parts, yet acts like a switch (electronic switch, that is!).
  - It is made of a semiconductor material (silicon - neither a particularly good conductor of electricity nor a particularly good insulator)

TRANSISTOR

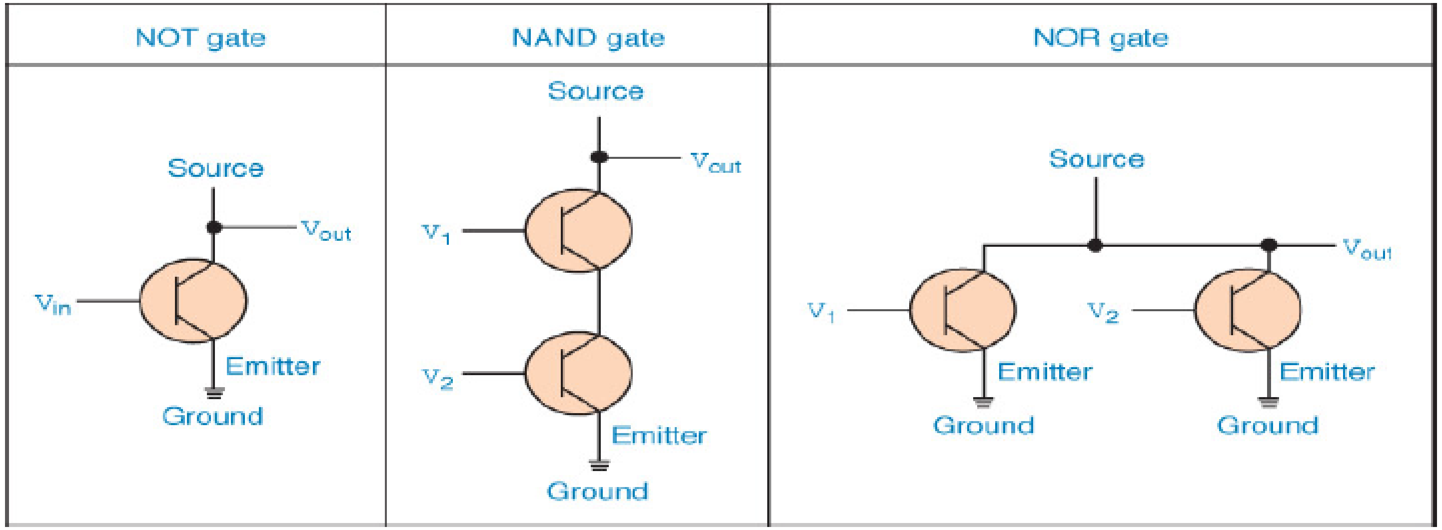


The connections of a transistor

- A transistor has three terminals
  - A source
  - A base
  - An emitter, typically connected to a ground wire
- If the base is low (0V), the current from Source to Emitter is blocked. Therefore the current is backed up causing a high voltage at the output

CONSTRUCTING GATES

- The easiest gates to create are the NOT, NAND, and NOR gates
- Any circuit can be created using NAND or NOR gates
  - Functionally complete



Constructing gates using transistors

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REPRESENTING REAL NUMBERS

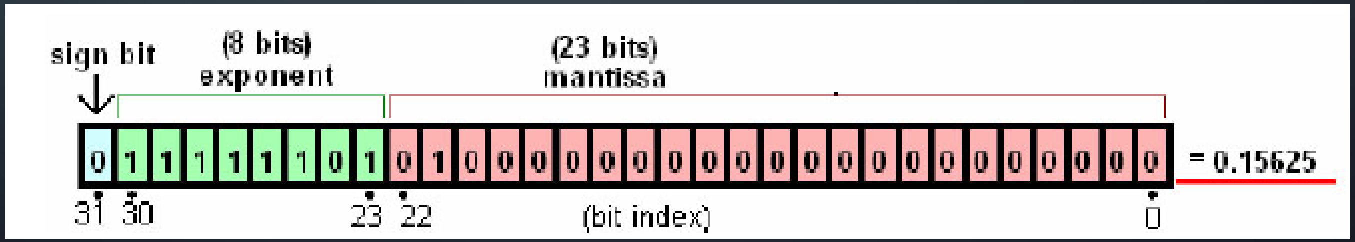
- A number with a whole part and a fractional part
  - 3.14159
- A real value in base 10 can be defined by the following formula:
  - $sign * mantissa * 10^{exp}$
- The mantissa (or precision) is a decimal number.
  - The representation is called floating point because the number of digits of precision is fixed but the decimal point floats.
  - Example: 12345.67 can be expressed as 1.234567 X 10^4

BINARY FLOATING POINT NUMBERS

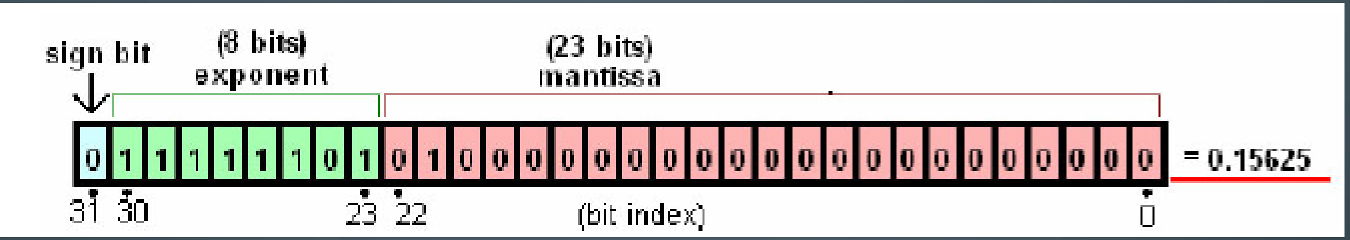
- Same rules apply in binary as in decimal.
- Decimal point is actually called the **radix point**.
- Positions to the right of the radix point in binary are:
    - 2^{-1} (one half),
    - 2^{-2} (one quarter),
    - 2^{-3} (one eighth)
    - …

BINARY FLOATING POINT NUMBERS

- IEEE 754
  - A standard for representation of binary floating point numbers, as expressed by the formula:
    - sign * mantissa * 2^{exp}
- A single-precision binary floating-point number is stored using 32-bits



BINARY FLOATING POINT NUMBERS



- Decoding the example shown above:
  - The sign is 0 = this is a positive number
  - The exponent is 11111101 = −3 (decimal)
  - The mantissa is 1.01 (binary) = 1.25 (decimal)
- The represented number is therefore
  - $+1.25 \times 2^{-3} = +0.15625$ in decimal.

JAVA NUMERIC TYPES

- short – 16 bits
- int – 32 bits
- long – 64 bits
- float – 32 bits
- double – 64 bits

BINARY FLOATING POINT NUMBERS

- 32-bit floating point numbers range is:
  - $3.40282347 \times 10^{38}$, $1.40239846 \times 10^{-45}$
- 64-bit floating point numbers range is:
  - $1.7976931348623157 \times 10^{308}$, $4.9406564584124654 \times 10^{-324}$
- Only approximations (but very good approximations) of real numbers

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