Introduction to Scientific Computing I

Lecture 2

Amir Farbin

From transistor to iPhone…
(Hardware)

Abstraction

- Definitions:
    - the quality of dealing with ideas rather than events
    - the process of considering something independently of its associations, attributes, or concrete accompaniments.
- Usage: (wikipedia)
    - *Computer scientists* use abstraction to make models that can be used and re-used without having to re-write all the program code for each new application on every different type of computer.
    - Abstraction in *mathematics* is the process of extracting the underlying essence of a mathematical concept, removing any dependence on real world objects with which it might originally have been connected, and generalizing it so that it has wider applications or matching among other abstract descriptions of equivalent phenomena.
- Why am I bring this up? Important skill
    - Comfortably think/work above the abstraction barrier… → play!
    - Sufficiently (usually qualitatively) understand the underlying dynamics… → use!
    - Peek below when necessary…

Abstraction Example

- Imagine you wish teach a child to cook mac-and-cheese
  - the recipe on the left would not be sufficient
- Requires how to:
  - Turn on a stove … boil water … melt butter, …
  - → These are tasks that each have several steps that a child would not *a priori* know…
  - and most adults have learned.
- These are levels of abstraction that the recipe assumes.
- In order to teach someone to cook, you start with basic skills and build on them → chef.
- Now imagine trying to teach a robot…

Simple Macaroni and Cheese

allrecipes

Prep 10 m | Cook 20 m | Ready In 30 m

Tom Thumb Food & Pharmacy
1701 W Randol Mill Rd
ARLINGTON, TX 76012

Recipe By: g0dluvsugly

"A very quick and easy fix to a tasty side-dish. Fancy, designer mac and cheese often costs forty or fifty dollars to prepare when you have so many exotic and expensive cheeses, but they aren't always the best tasting. This recipe is cheap and tasty."

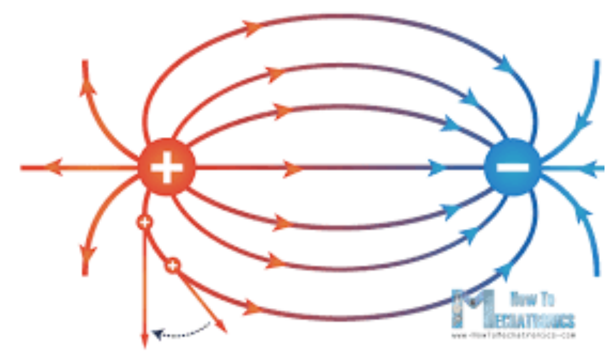
Ingredients

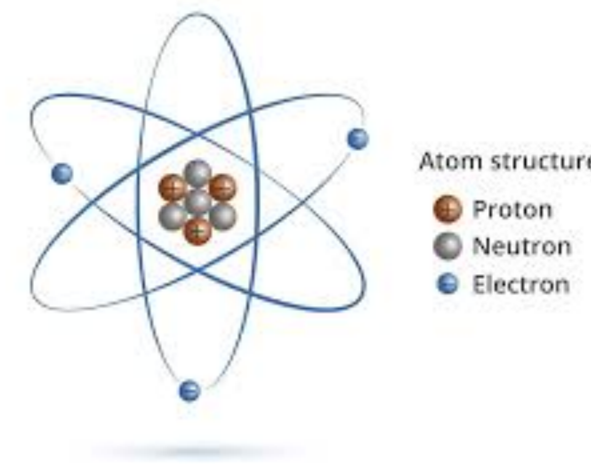
1 (8 ounce) box elbow macaroni
1/4 cup butter
1/4 cup all-purpose flour
1/2 teaspoon salt
ground black pepper to taste
2 cups milk
2 cups shredded Cheddar cheese

Directions

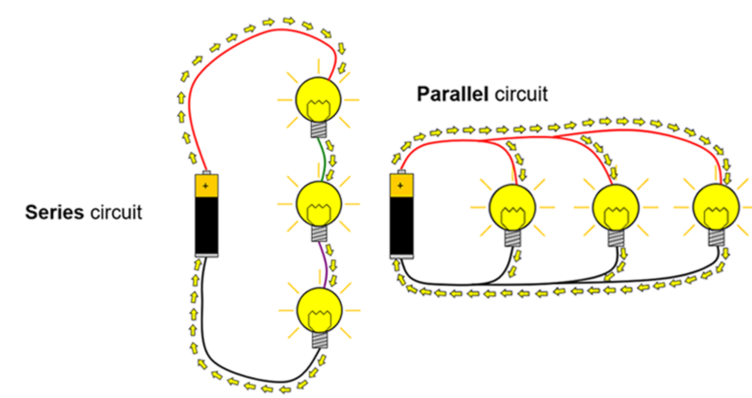
1 Bring a large pot of lightly salted water to a boil. Cook elbow macaroni in the boiling water, stirring occasionally until cooked through but firm to the bite, 8 minutes. Drain.
2 Melt butter in a saucepan over medium heat; stir in flour, salt, and pepper until smooth, about 5 minutes. Slowly pour milk into butter-flour mixture while continuously stirring until mixture is smooth and bubbling, about 5 minutes. Add Cheddar cheese to milk mixture and stir until cheese is melted, 2 to 4 minutes.
3 Fold macaroni into cheese sauce until coated.

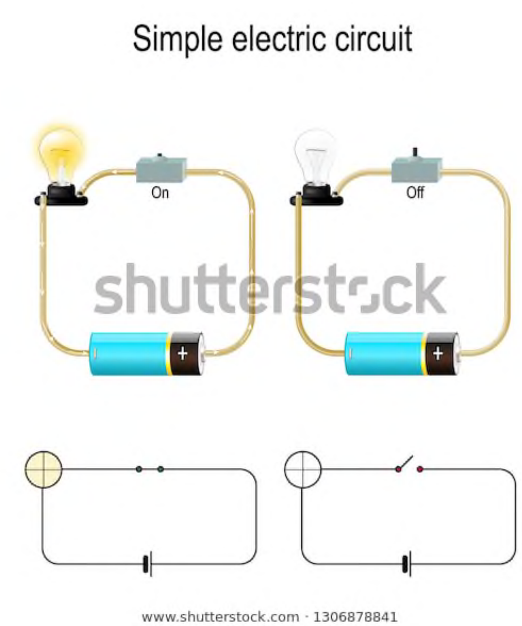
Electrodynamics





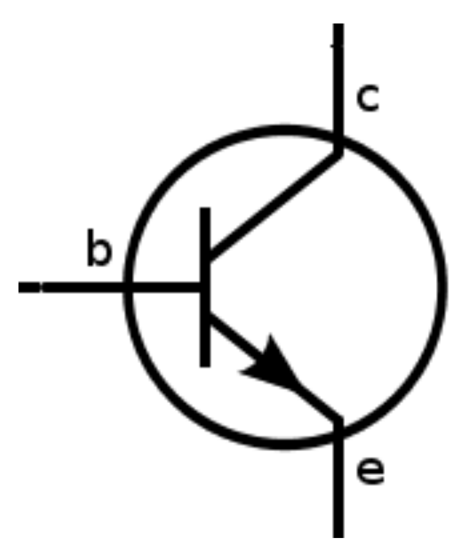
- One of the fundamental forces of nature is ***Electricity and Magnetism***.
    - What keeps Atoms together.
    - Responsible for all ***Chemistry***.
    - Foundation of ***Electronics***.
        - Electrons have an ***electric charge***.
            - Produces an ***Electric Field***.
            - Feel a force when they experience another ***Electric Field.***
        - Charges move (a ***Current***) freely in conductors
            - Wires serves as electron pipes… like water pipers.
            - Electric potential (***Voltage***) ~ pressure in pipe. Moves electrons around.
            - Other components: ***capacitors, resistors, inductors, transistors***…
        - ***Digital Electronics***:
            - “0”: No electrons flowing.
            - “1”: Electrons flowing.
            - “Clock”: electrons are pushed through system at a regular rate.





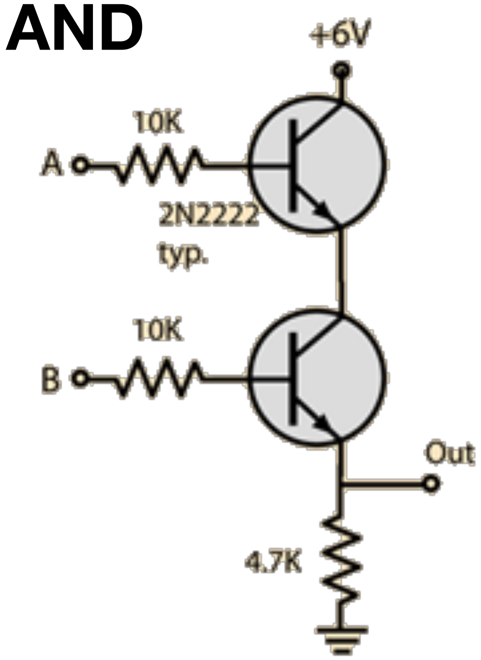
Transistor

- *Base:* The base is responsible for controlling whether current is allowed to flow through the transistor when power is applied.
- *Collector:* When there is power to the base, the collector current is allowed to flow towards the emitter.
- *Emitter:* The emitter takes the electric current that the collector is allowed to send, to be used on other parts of your circuit.
- → A digital switch

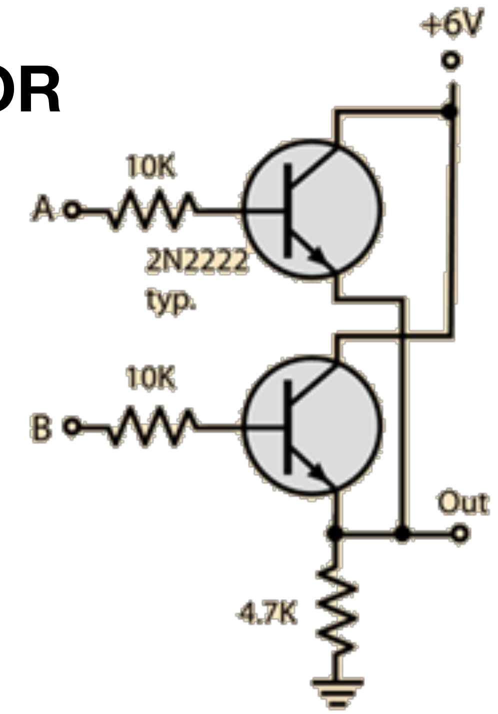


Logic Gates

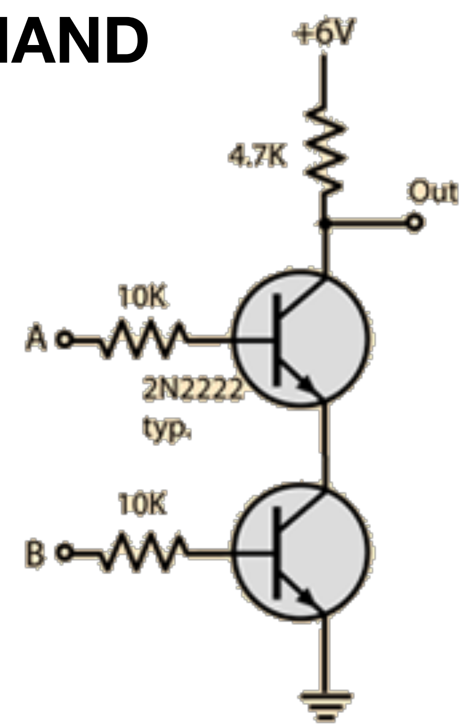
AND



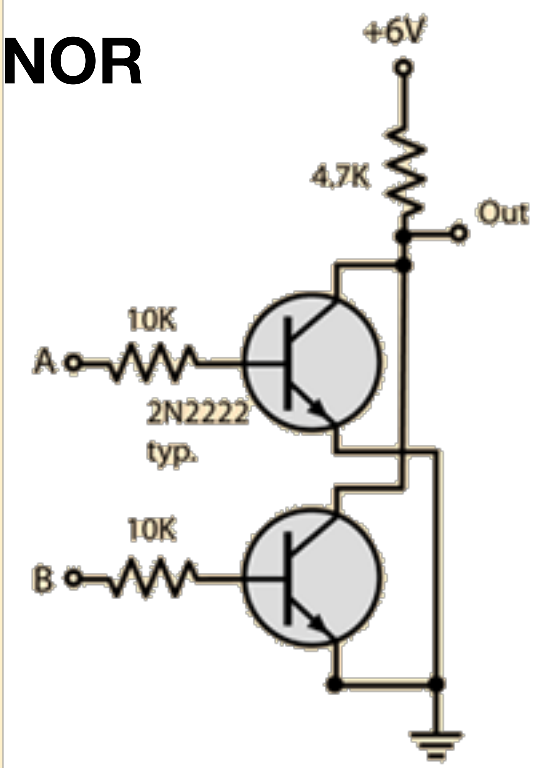
OR

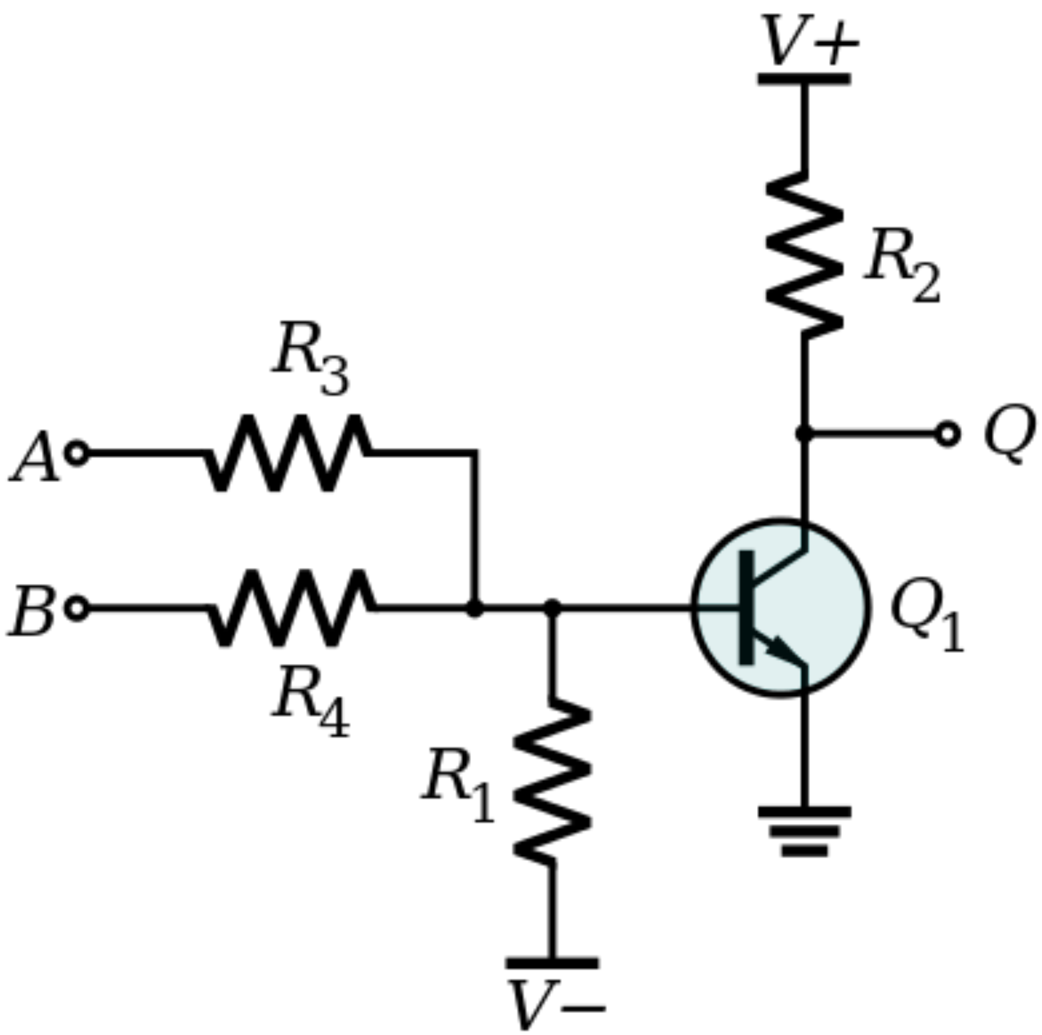


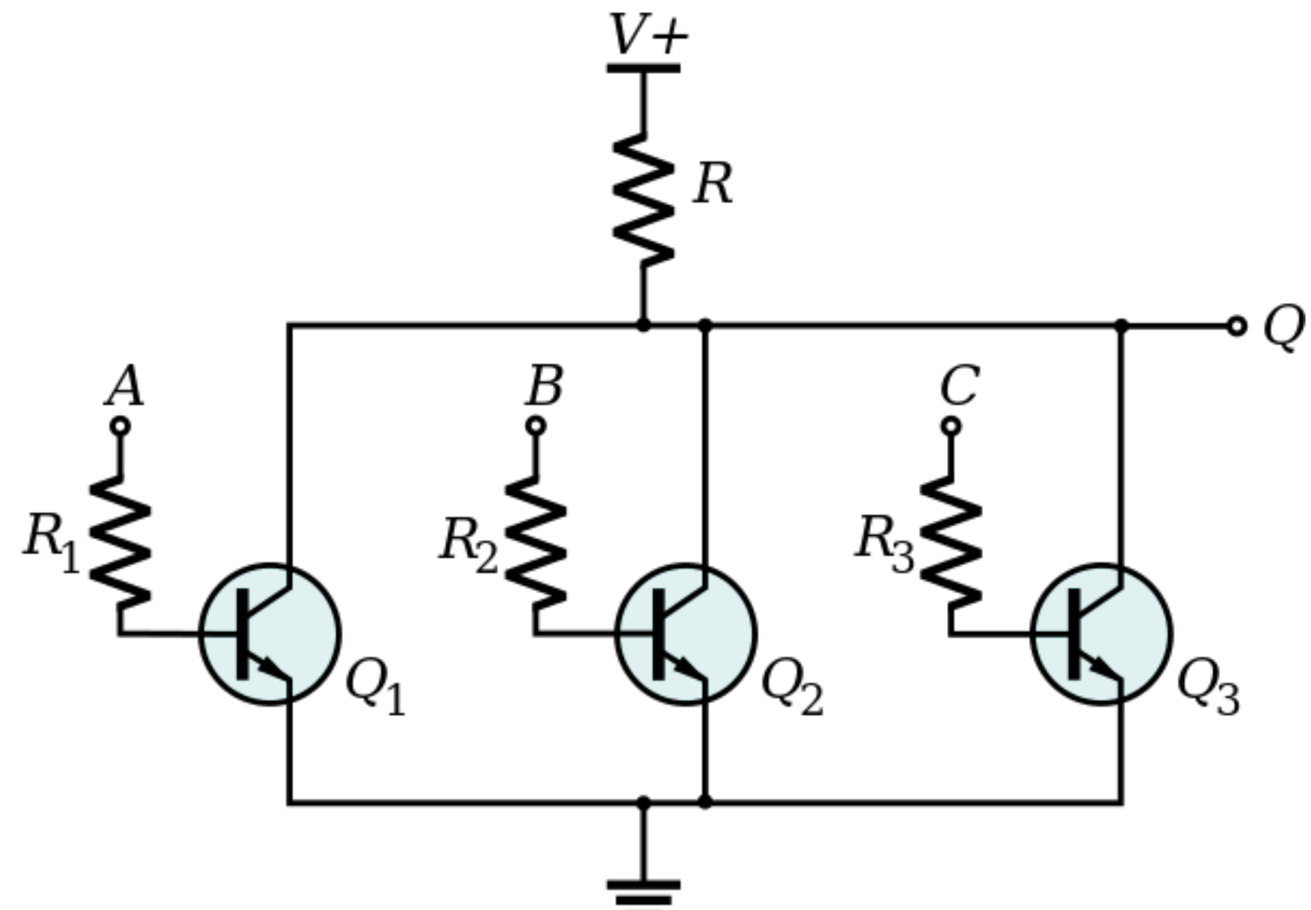
NAND



NOR

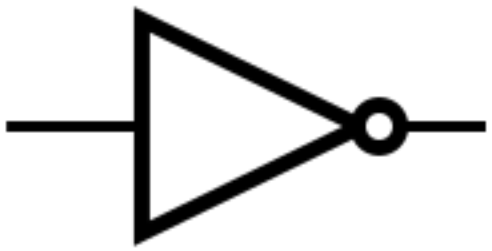



V+
R2
R3
A
Q
B
R4
Q1
R1
V−


V+
R
Q
A
B
C
R1
R2
R3
Q1
Q2
Q3

Boolean Operations

NOT



INPUT	OUTPUT
A	NOT A
0	1
1	0

AND

INPUT		OUTPUT
A	B	A AND B
0	0	0
0	1	0
1	0	0
1	1	1

NAND

NPUT		OUTPUT
A	B	A NAND B
0	0	1
0	1	1
1	0	1
1	1	0

OR

INPUT		OUTPUT
A	B	A OR B
0	0	0
0	1	1
1	0	1
1	1	1

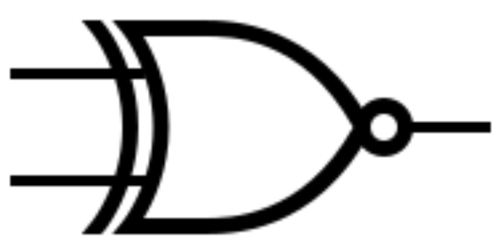
XOR

INPUT		OUTPUT
A	B	A XOR B
0	0	0
0	1	1
1	0	1
1	1	0

NOR

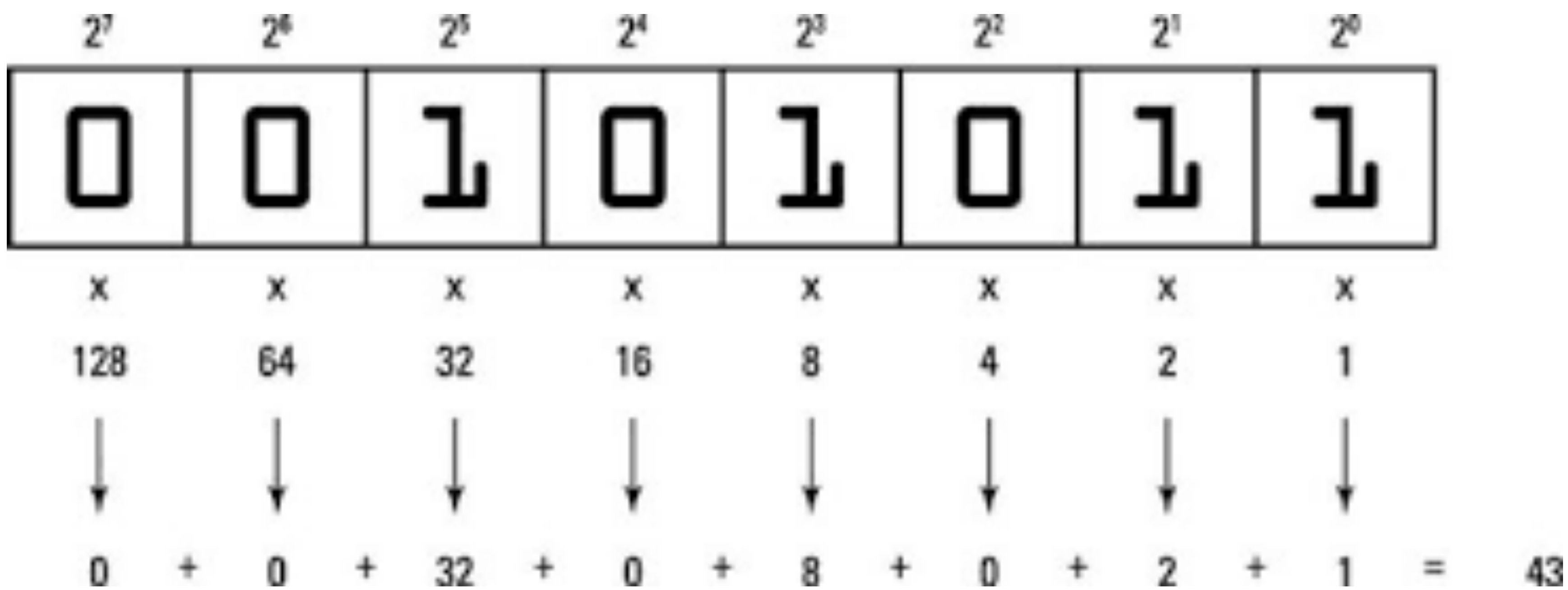
INPUT		OUTPUT
A	B	A NOR B
0	0	1
0	1	0
1	0	0
1	1	0

XNOR



INPUT		OUTPUT
A	B	A XNOR B
0	0	1
0	1	0
1	0	0
1	1	1

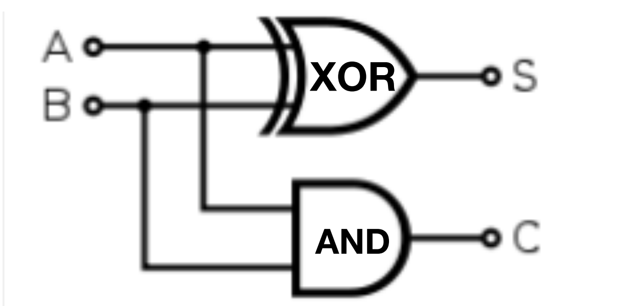
Binary



Number	Binary equivalent
0	000000
1	000001
2	000010
3	000011
4	000100
5	000101
6	000110
7	000111
8	001000
9	001001
10	001010
11	001011
12	001100
13	001101
14	001110
15	001111

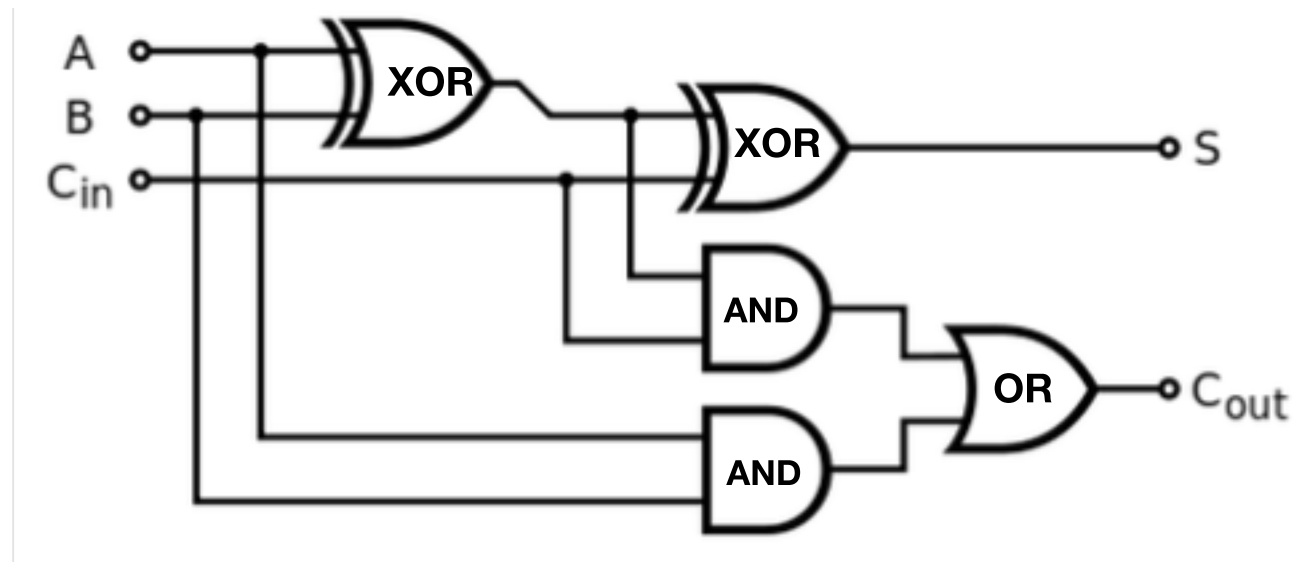
Adder

Half Adder



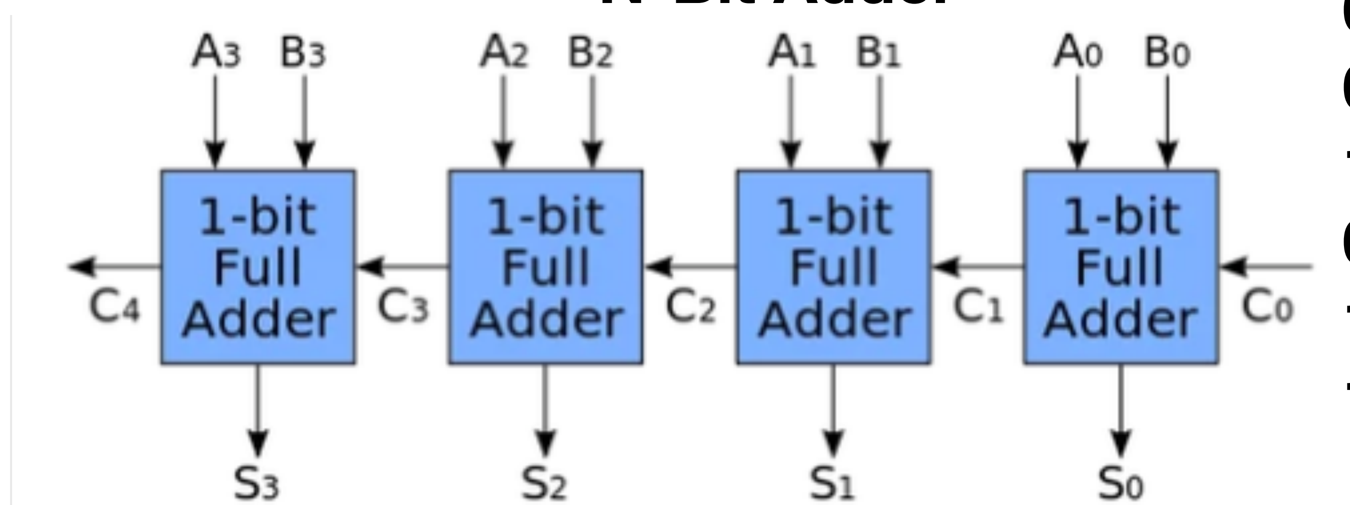
0+0=00
0+1=01
1+0=01
1+1=10

Full Adder



INPUT		OUTPUT
A	B	A XOR B
0	0	0
0	1	1
1	0	1
1	1	0

N-Bit Adder

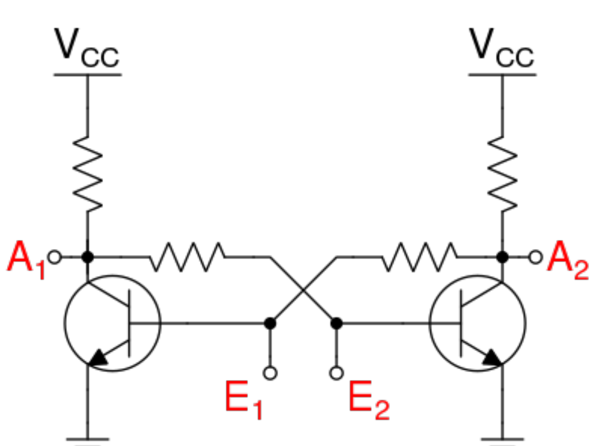


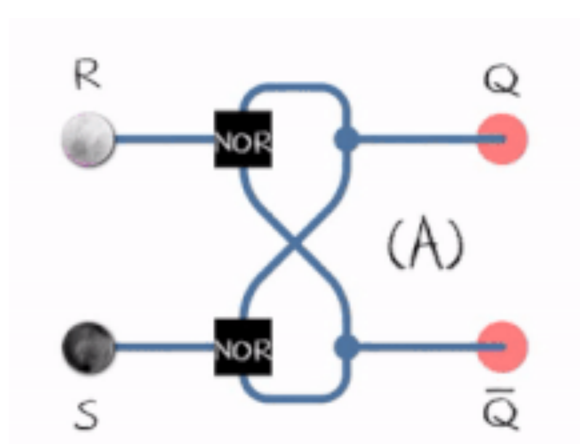
0+0+0=00
1+0+0=01
0+1+0=01
0+0+1=01
1+1+0=10
0+1+1=10
1+0+1=10
1+1+1=11

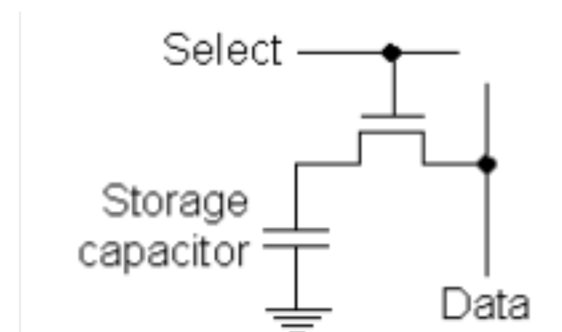
https://gizmodo.com/how-computer-chips-work-1645654993

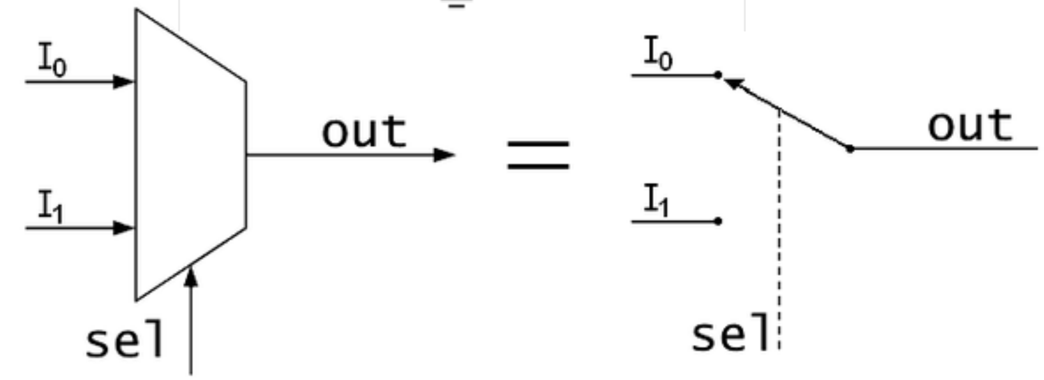
Other Circuits

- *Flip-flop:* Circuit that can "store" a value. Its output will depend on what value was written to it earlier.
- *Multiplexer:* selects between two inputs, I_0 and I_1, and outputs I_0 if the command is 0, and I_1 if it is 1
  - Use it to select different instructions (e.g. + or -).
- Random Access Memory: 1024-bit Multiplexer + 1024 Flop-flops = 1 KB



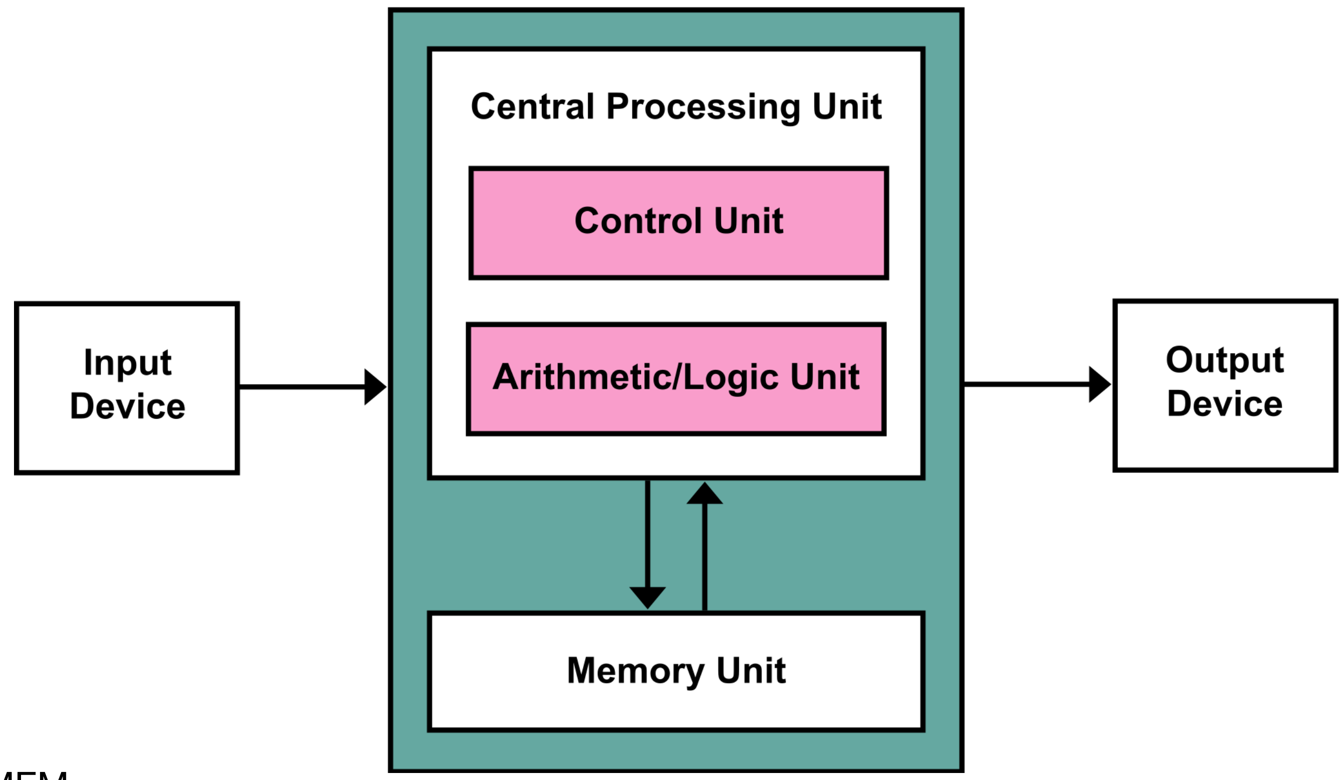




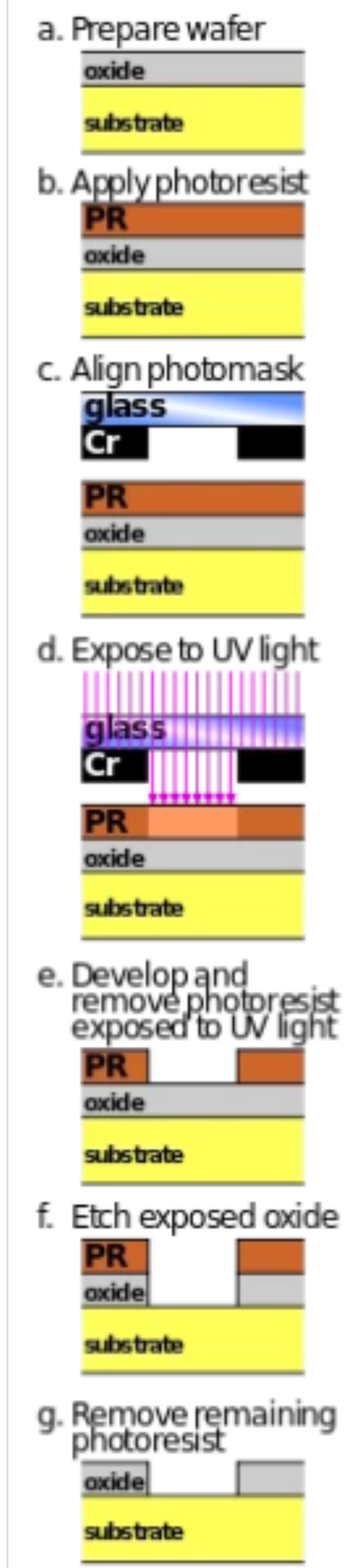


Von Neumann Architecture

- ***Memory array:*** (MEM) holds all the "commands" (instructions) and "numbers" (data).
- ***Control Unit:***
    - ***Program counter***: select which instruction to execute from MEM. It normally just increases by 1 in each step.
    - Instruction Multiplexer
- ***Arithmetic block:*** multiplexers connecting to different binary different operations (+, -, …), with input / output
    - Generate inputs to our arithmetic block from MEM.
- [***Registers:*** hold input/output of arithmetic block]
- Instructions
    - Two types: data instructions and control instructions.
    - Each data instruction contains four things:
        - two addresses specifying which two numbers to pick from MEM
        - one command saying what operation to perform
        - and another location saying where to put the result back.
    - The control instructions put another address back into the "program counter."



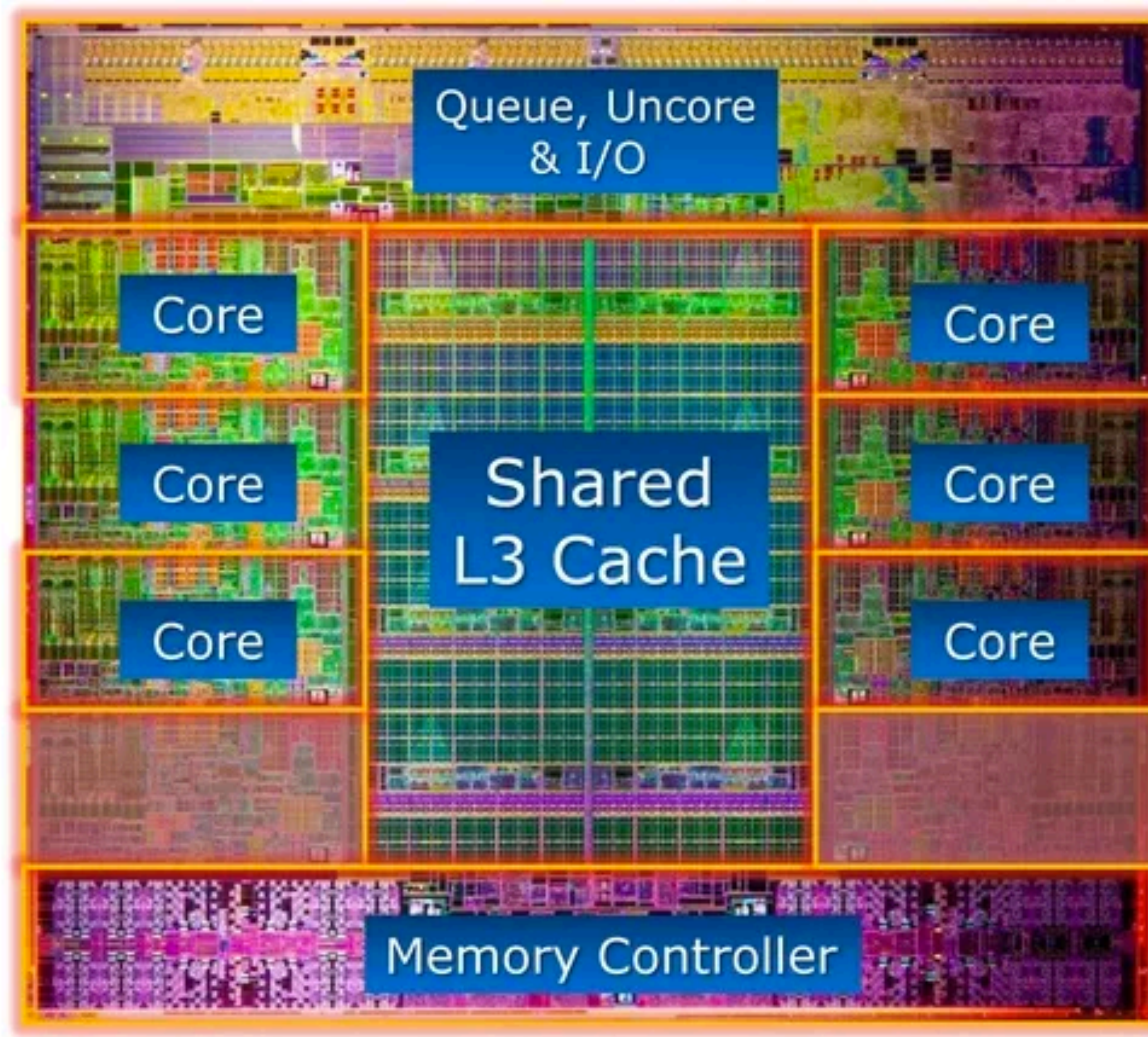
Scilicon Electronics



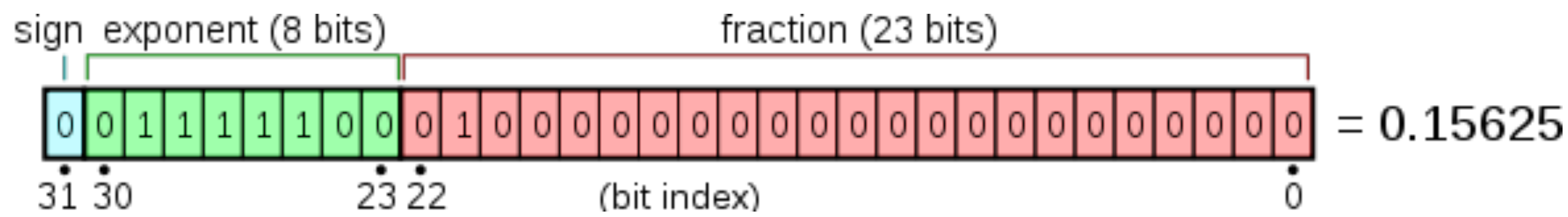
- Modern processors have billions of transistors in precisely arranged and connected.
- Photolithography: pattern is an image that is focused on silicon covered with layers photo-sensitive material, that can be subsequently etched away or have metal deposited on, leaving a pattern.

Modern Processors

- Variable clock rates (in GHz).
- Biggest constraints: energy consumption and heat dissipation.
- Large amounts of memory (GBs), not on processor.
- Cache: small part of memory, mirrored inside/closer to processor to accelerate memory access.
    - Multi-level: Exchange size vs proximity/speed
- Out-of-order processing
- Many cores



Floating Point



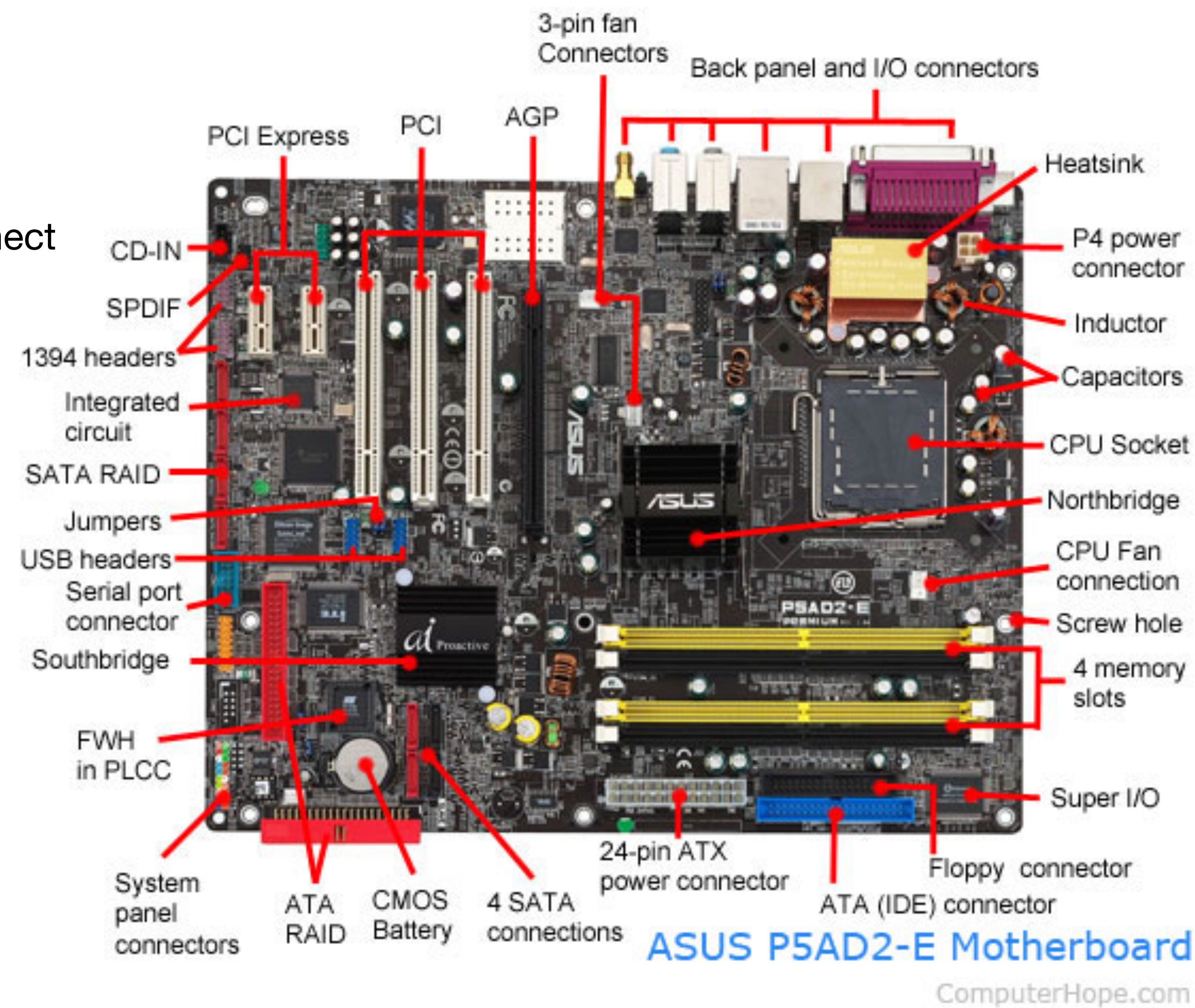
Floating Point Operation per Second (FLOPS) =
cores
x
cycles/second
x
FLOP/cycle

FLOPs per cycle for various processors [edit]

Microarchitecture	ISA	FP64	FP32	FP16
Intel Atom (Bonnell, Saltwell, Silvermont and Goldmont)	SSE3 (64-bit)	2	4	0
Intel Core (Merom, Penryn) Intel Nehalem[6] (Nehalem, Westmere)	SSE4 (128-bit)	4	8	0
Intel Sandy Bridge (Sandy Bridge, Ivy Bridge)	AVX (256-bit)	8	16	0
Intel Haswell[6] (Haswell, Devil's Canyon, Broadwell) Intel Skylake (Skylake, Kaby Lake, Coffee Lake, Whiskey lake, Amber lake)	AVX2 & FMA (256-bit)	16	32	0
Intel Xeon Phi (Knights Corner)	SSE & FMA (256-bit)	16	32	0
Intel Skylake-X Intel Xeon Phi (Knights Landing, Knights Mill)	AVX-512 & FMA (512-bit)	32	64	0
AMD Bobcat	AMD64 (64-bit)	2	4	0
AMD Jaguar AMD Puma	AVX (128-bit)	4	8	0
AMD K10	SSE4/4a (128-bit)	4	8	0
AMD Bulldozer[6] (Piledriver, Steamroller, Excavator)	AVX (128-bit) Bulldozer-Steamroller AVX2 (128-bit) Excavator FMA3 (Bulldozer)[7] FMA3/4 (Piledriver-Excavator)	4	8	0
AMD Zen (Ryzen 1000 series, Threadripper 1000 series, Epyc Naples) AMD Zen+[6][8][9][10] (Ryzen 2000 series, Threadripper 2000 series)	AVX2 & FMA (128-bit, 256-bit decoding)[11]	8	16	0
AMD Zen 2[12] (Ryzen 3000 series, Threadripper 3000 series, Epyc Rome)	AVX2 & FMA (256-bit)	16	32	0
ARM Cortex-A7, A9, A15	ARMv7	1	8	0
ARM Cortex-A32, A35, A53, A55, A72, A73, A75	ARMv8	2	8	0
ARM Cortex-A57[6]	ARMv8	4	8	0
ARM Cortex-A76, A77	ARMv8	8	16	0
Qualcomm Krait	ARMv8	1	8	0
Qualcomm Kryo (1xx - 3xx)	ARMv8	2	8	0
Qualcomm Kryo (4xx)	ARMv8	8	16	0
Samsung Exynos M1 and M2	ARMv8	2	8	0
Samsung Exynos M3 and M4	ARMv8	3	12	0
IBM PowerPC A2 (Blue Gene/Q)	?	8	8 (as FP64)	0
Hitachi SH-4[13][14]	SH-4	1	7	0
Nvidia Fermi (only GeForce GTX 465-480, 560 Ti, 570-590)	PTX	1/4 (locked by driver, 1 in hardware)	2	0
Nvidia Fermi (only Quadro 600-2000)	PTX	1/8	2	0
Nvidia Fermi (only Quadro 4000-7000, Tesla)	PTX	1	2	0
Nvidia Kepler (GeForce (except Titan and Titan Black), Quadro (except K6000), Tesla K10)	PTX	1/12 (for GK110: locked by driver, 2/3 in hardware)	2	0
Nvidia Kepler (GeForce GTX Titan and Titan Black, Quadro K6000, Tesla (except K10))	PTX	2/3	2	0
Nvidia Maxwell Nvidia Pascal (all except Quadro GP100 and Tesla P100)	PTX	1/16	2	1/32

Motherboard

- Central Processing Unit
- Random Access Memory
- Basic Input/Output System (BIOS)
- Off processor Cache
- Expansion Bus: Peripheral Component Interconnect (PCI)
- Chipset: control data flow in/out of CPU
    - Northbridge: CPU / memory
    - Southbridge: CPU / IO
- IO Controllers:
    - Disk: ATA, SATA, RAID
    - Peripherals: USB, …
    - Network: Ethernet, WiFi
- CPU Clock

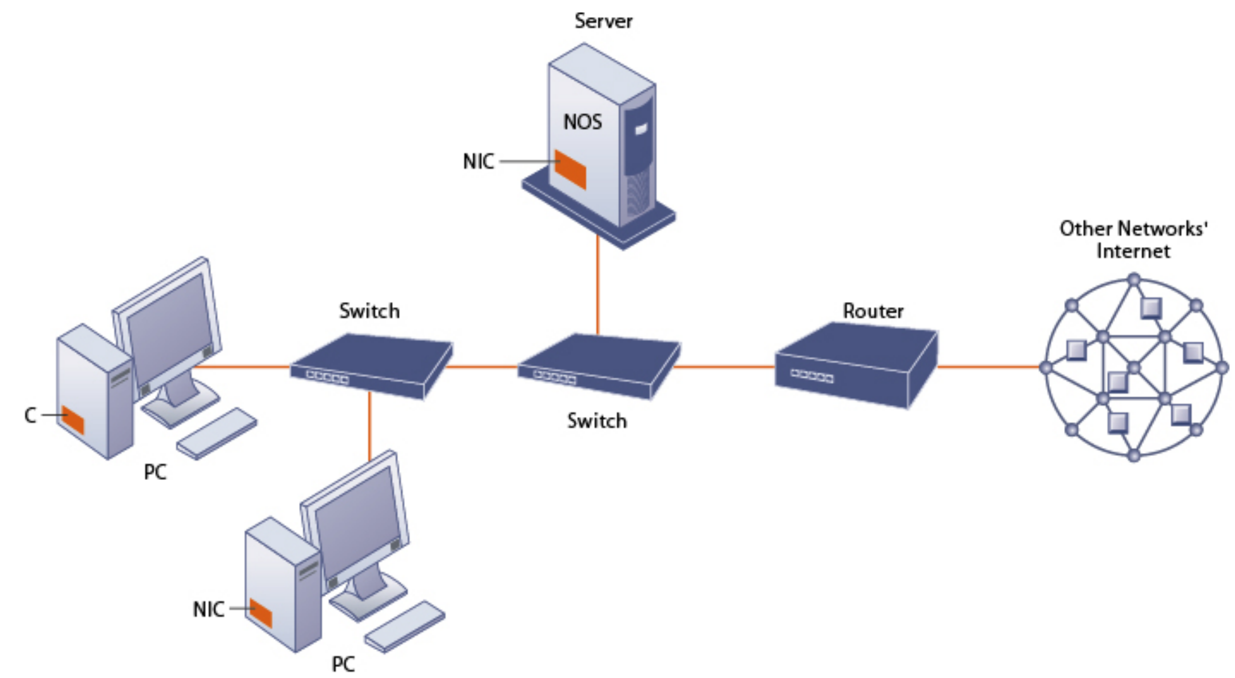


Computer

- Case
- Power supply
- Fan
- Motherboard
    - CPU
        - Heat sink / Fan
    - RAM
    - Graphics Processing Unit (GPU)
    - USB, Ethernet, etc connectors
- Storage: Hard Drive or Silicon Disk Drive

Network

- Local Area Network (LAN) / Wide Area Networks (WAN)
- Signals sent via coaxial cable, twister pair, fiber optics, …
- Components: adapter, switch (connects computers), router (connects networks), wireless…
- Open Systems Interconnection model Layers
  - Physical: bits. Rates now approaching 100 Gb.
  - Ethernet:
    - Every component has a unique address (48-bit MAC address)
    - Data broken into frames, with source/destination address and error checking data.
  - Network: for example Internet Protocol (IP)
    - Packets sent via IP address
    - Addresses kept in Domain Name System (DNS): Match name → address.



- Transport:
  - How data is exchanged, broken up, transmitted, routed, …
  - Transmission Control Protocol (TCP): Services listen / communicate on ports.

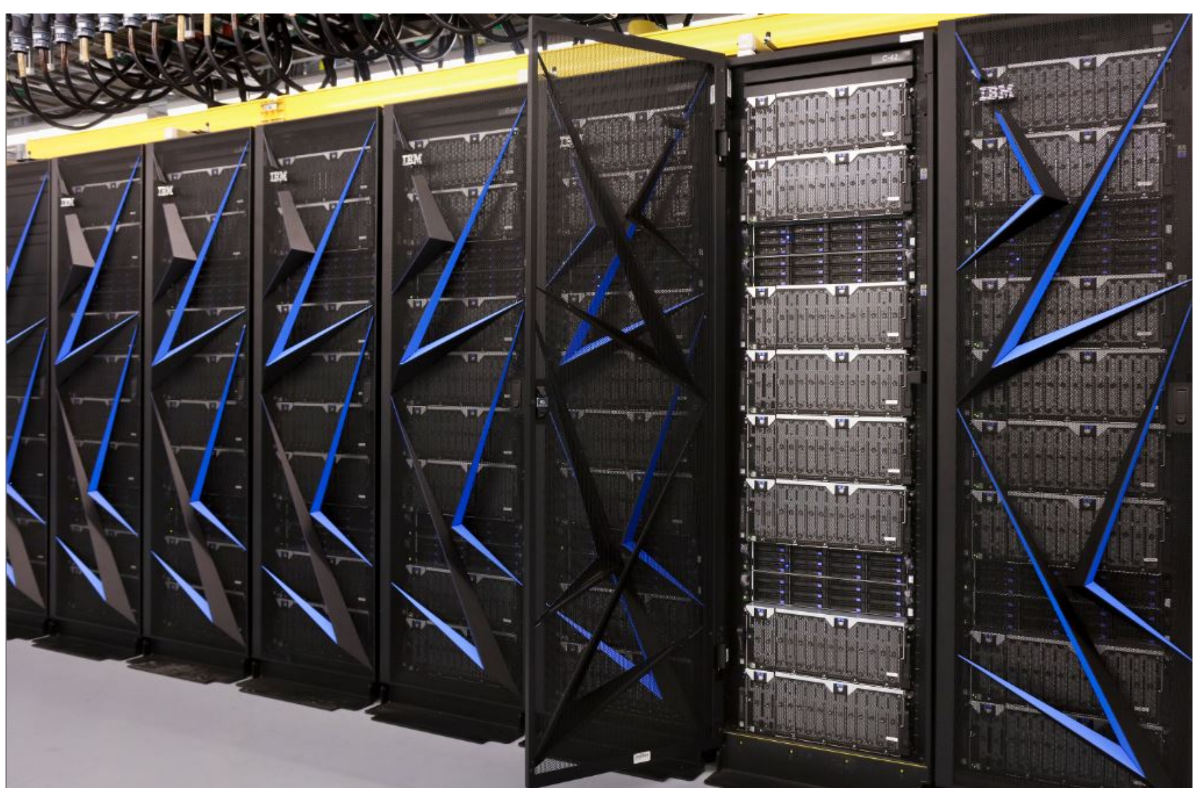
OSI model

Layer			Protocol data unit (PDU)	Function[6]
Host layers	7	Application	Data	High-level APIs, including resource sharing, remote file access
	6	Presentation		Translation of data between a networking service and an application; including character encoding, data compression and encryption/decryption
	5	Session		Managing communication sessions, i.e., continuous exchange of information in the form of multiple back-and-forth transmissions between two nodes
	4	Transport	Segment, Datagram	Reliable transmission of data segments between points on a network, including segmentation, acknowledgement and multiplexing
Media layers	3	Network	Packet	Structuring and managing a multi-node network, including addressing, routing and traffic control
	2	Data link	Frame	Reliable transmission of data frames between two nodes connected by a physical layer
	1	Physical	Symbol	Transmission and reception of raw bit streams over a physical medium

TOP 10 Sites for November 2019

For more information about the sites and systems in the list, click on the links or view the complete list.

1-100 | 101-200 | 201-300 | 301-400 | 401-500



Rank	System	Cores	Rmax (TFlop/s)	Rpeak (TFlop/s)	Power (kW)
1	**Summit** - IBM Power System AC922, IBM POWER9 22C 3.07GHz, NVIDIA Volta GV100, Dual-rail Mellanox EDR Infiniband , IBM DOE/SC/Oak Ridge National Laboratory United States	2,414,592	148,600.0	200,794.9	10,096
2	**Sierra** - IBM Power System AC922, IBM POWER9 22C 3.1GHz, NVIDIA Volta GV100, Dual-rail Mellanox EDR Infiniband , IBM / NVIDIA / Mellanox DOE/NNSA/LLNL United States	1,572,480	94,640.0	125,712.0	7,438
3	**Sunway TaihuLight** - Sunway MPP, Sunway SW26010 260C 1.45GHz, Sunway , NRCPC National Supercomputing Center in Wuxi China	10,649,600	93,014.6	125,435.9	15,371
4	**Tianhe-2A** - TH-IVB-FEP Cluster, Intel Xeon E5-2692v2 12C 2.2GHz, TH Express-2, Matrix-2000 , NUDT National Super Computer Center in Guangzhou China	4,981,760	61,444.5	100,678.7	18,482
5	**Frontera** - Dell C6420, Xeon Platinum 8280 28C 2.7GHz, Mellanox InfiniBand HDR , Dell EMC Texas Advanced Computing Center/Univ. of Texas United States	448,448	23,516.4	38,745.9	
6	**Piz Daint** - Cray XC50, Xeon E5-2690v3 12C 2.6GHz, Aries interconnect , NVIDIA Tesla P100 , Cray/HPE Swiss National Supercomputing Centre (CSCS) Switzerland	387,872	21,230.0	27,154.3	2,384
7	**Trinity** - Cray XC40, Xeon E5-2698v3 16C 2.3GHz, Intel Xeon Phi 7250 68C 1.4GHz, Aries interconnect , Cray/HPE DOE/NNSA/LANL/SNL United States	979,072	20,158.7	41,461.2	7,578
8	**AI Bridging Cloud Infrastructure (ABCI)** - PRIMERGY CX2570 M4, Xeon Gold 6148 20C 2.4GHz, NVIDIA Tesla V100 SXM2, Infiniband EDR , Fujitsu National Institute of Advanced Industrial Science and Technology (AIST) Japan	391,680	19,880.0	32,576.6	1,649
9	**SuperMUC-NG** - ThinkSystem SD650, Xeon Platinum 8174 24C 3.1GHz, Intel Omni-Path , Lenovo Leibniz Rechenzentrum Germany	305,856	19,476.6	26,873.9	
10	**Lassen** - IBM Power System AC922, IBM POWER9 22C 3.1GHz, Dual-rail Mellanox EDR Infiniband, NVIDIA Tesla V100 , IBM / NVIDIA / Mellanox DOE/NNSA/LLNL United States	288,288	18,200.0	23,047.2	