Introduction to Scientific Computing I

Lecture 2

Amir Farbin

Announcements

- Laptops

What do *I* do ?

Was the Universe an Accident?

Artificial Intelligence may find the answer in data from the Large Hadron Collider

Amir Farbin

UNIVERSITY OF TEXAS ARLINGTON

ATLAS EXPERIMENT

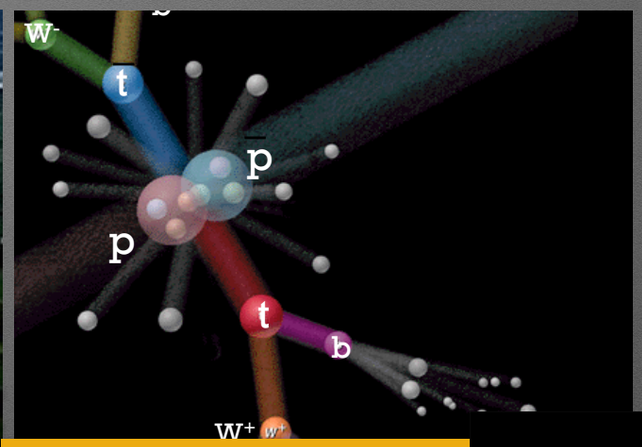
DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

What is HEP ?

Large Hadron Collider (LHC)

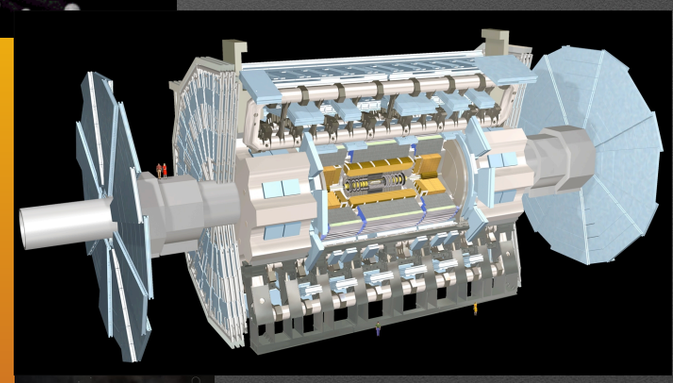
Largest Machine Ever Built

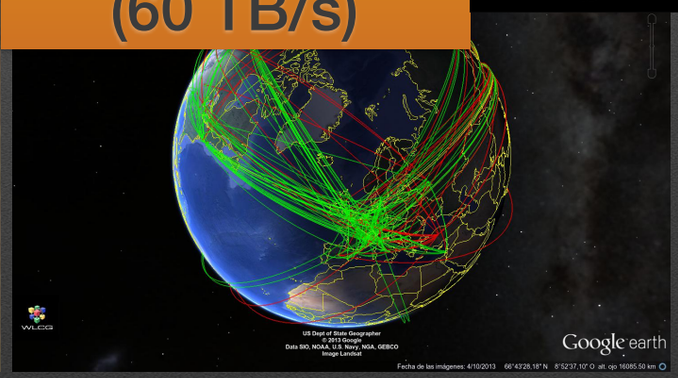
10^{11} Protons Collide 40 Million Times per Second



Create New Particles
Only 1 in 10^{11} are "interesting"

Record with 5 Story 100M Channel "Camera" (60 TB/s)





Processed by 300k Cores Around the World

Higgs Discovery - Nobel Prize Physics 2013

Physics Letters B 716 (2012) 1–29

Contents lists available at SciVerse ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC ☆

ATLAS Collaboration *

This paper is dedicated to the memory of our ATLAS colleagues who did not live to see the full impact and significance of their contributions to the experiment.

ARTICLE INFO

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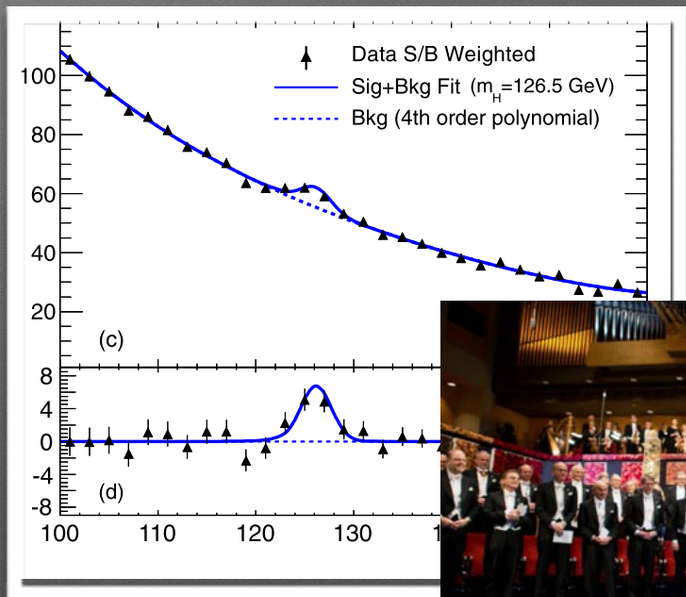
ABSTRACT

A search for the Standard Model Higgs boson in proton–proton collisions with the ATLAS detector at the LHC is presented. The datasets used correspond to integrated luminosities of approximately 4.8 fb^{-1} collected at $\sqrt{s} = 7$ TeV in 2011 and 5.8 fb^{-1} at $\sqrt{s} = 8$ TeV in 2012. Individual searches in the channels $H \to ZZ^{(*)} \to 4\ell$, $H \to \gamma\gamma$ and $H \to WW^{(*)} \to e\nu\mu\nu$ in the 8 TeV data are combined with previously published results of searches for $H \to ZZ^{(*)}$, $WW^{(*)}$, $b\bar{b}$ and $\tau^+\tau^-$ in the 7 TeV data and results from improved analyses of the $H \to ZZ^{(*)} \to 4\ell$ and $H \to \gamma\gamma$ channels in the 7 TeV data. Clear evidence for the production of a neutral boson with a measured mass of 126.0 ± 0.4 (stat) ± 0.4 (sys) GeV is presented. This observation, which has a significance of 5.9 standard deviations, corresponding to a background fluctuation probability of 1.7×10^{-9}, is compatible with the production and decay of the Standard Model Higgs boson.



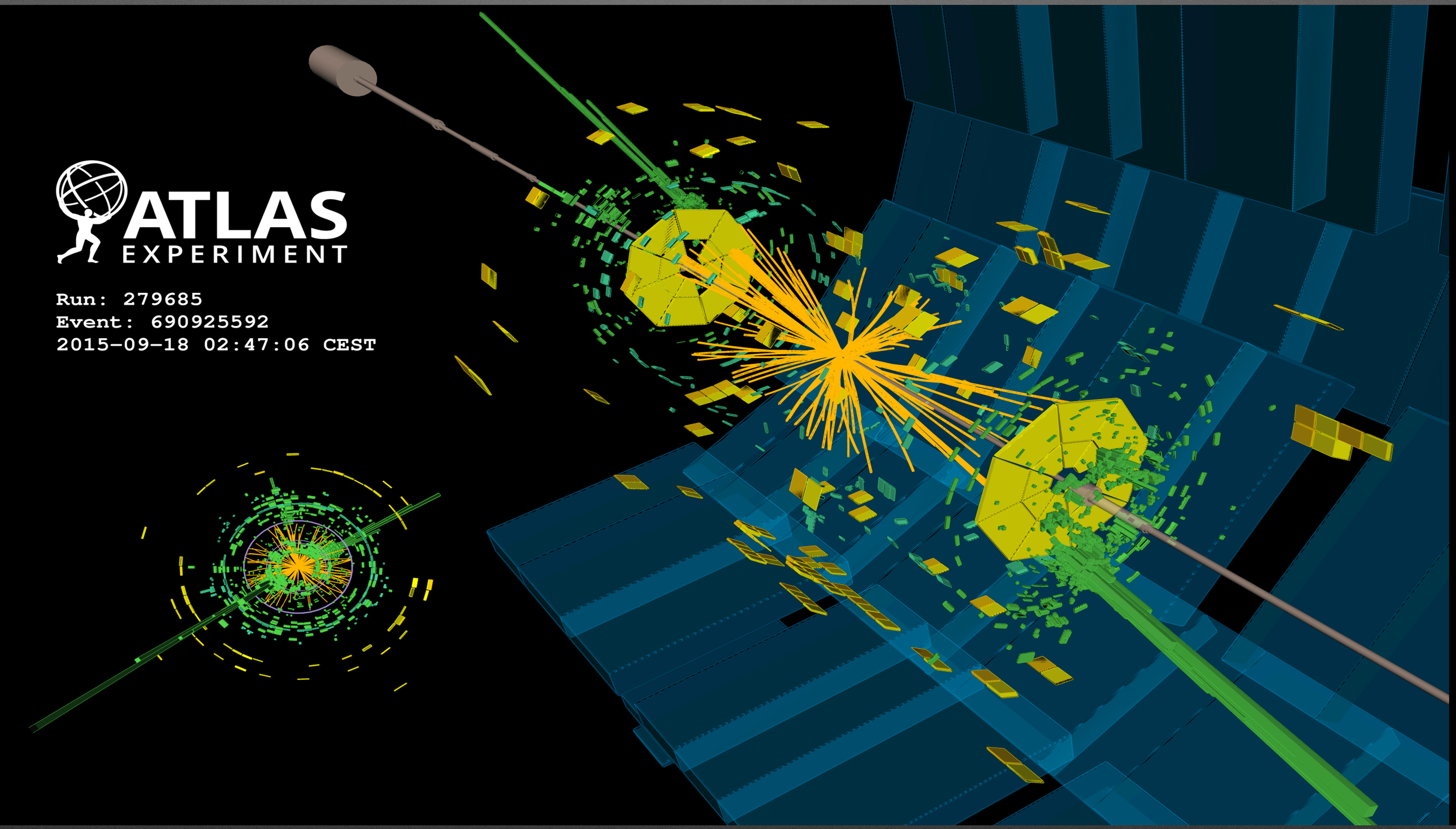
Last Piece of the Standard Model

Best Tested Theory… Ever.

Not Done… Higgs is Light! Possibilities:

- *Fine-tuned Theory*: Accident or Multiverse + Anthropic Principle
- *Mechanism*: Supersymmetry, Extra-Dimensions, Sub-structure
  - Focus of LHC
- *Design?*

Deep Learning in High Energy Physics



- Requires lots of computing
- Upgrade to LHC will give us 100x the data.
  - We won’t have 100x the computing power or storage.
- Use Artificial Intelligence and newest processors…

Animal Brains

- The brain takes in sensory data… ***builds hierarchical models of the world***.
- So effectively, a ***representation*** of the input is assembled in the brain.
  - Eyes see a limited window… but…
  - Location Cells
  - Imagining locations

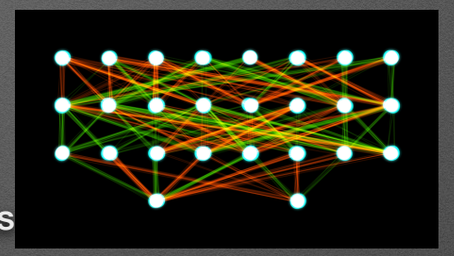
Brief History of AI

Artificial Intelligence

- Goal: Systems that reason and act as well as or better than humans
- Heuristic AI (1990's)
- Machine Learning AI
  - Knowledge learned from data
- Neural Networks ~ Brain inspired computing (1943)
  - Universal Computation Theorem (1989)
  - Multi-layer hidden networks (a.k.a. Deep) (1965)
  - Vanishing Gradient Problem (1991)

Deep Learning Renaissance (> 2007 - now)

- Driven by:
  - New NN Innovation
  - Big Data
  - Graphical Processing Units

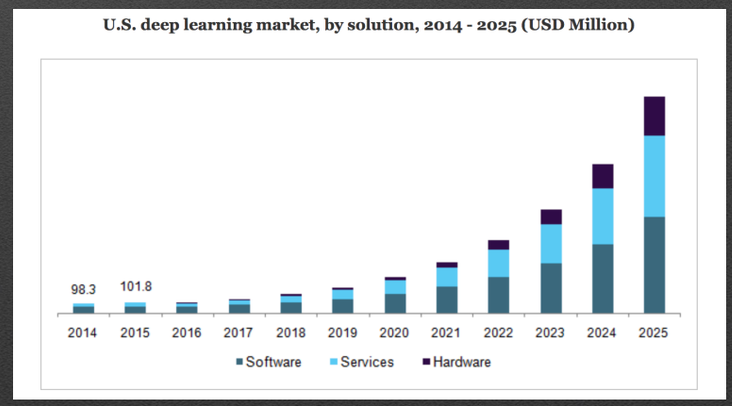


- Amazing Feats

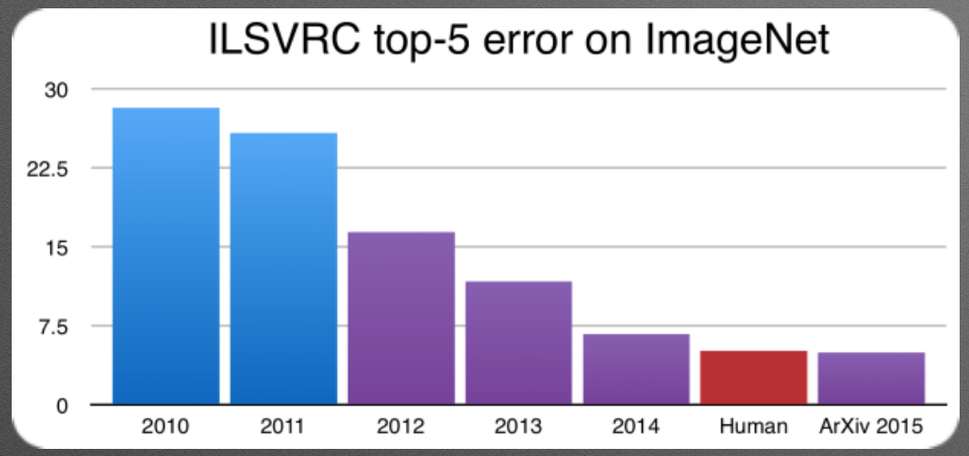
WIRED STAFF SCIENCE 06.26.12 11:15 AM

GOOGLE'S ARTIFICIAL BRAIN LEARNS TO FIND CAT VIDEOS

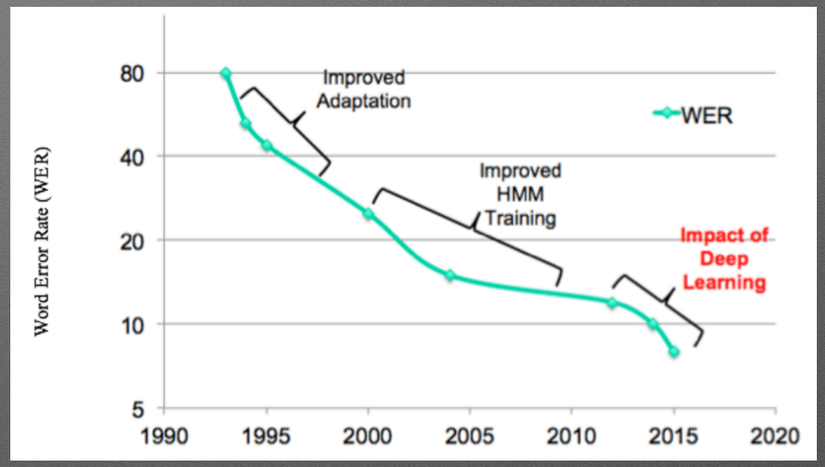
- Market Growth
- Industry Adoption



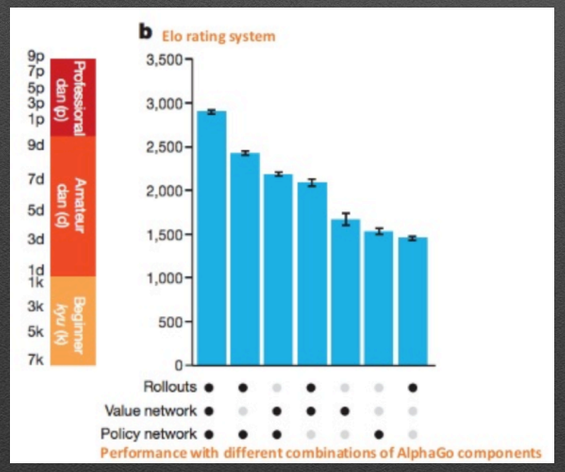
Amazing Feats : Some Examples



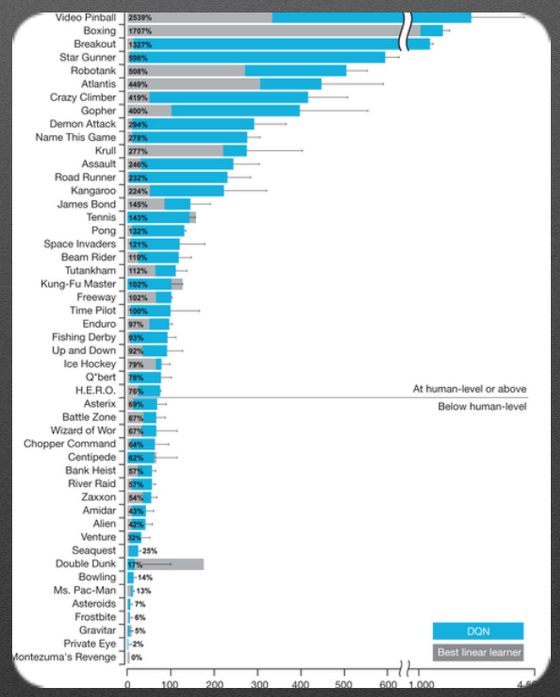
ImageNet Outperforms humans



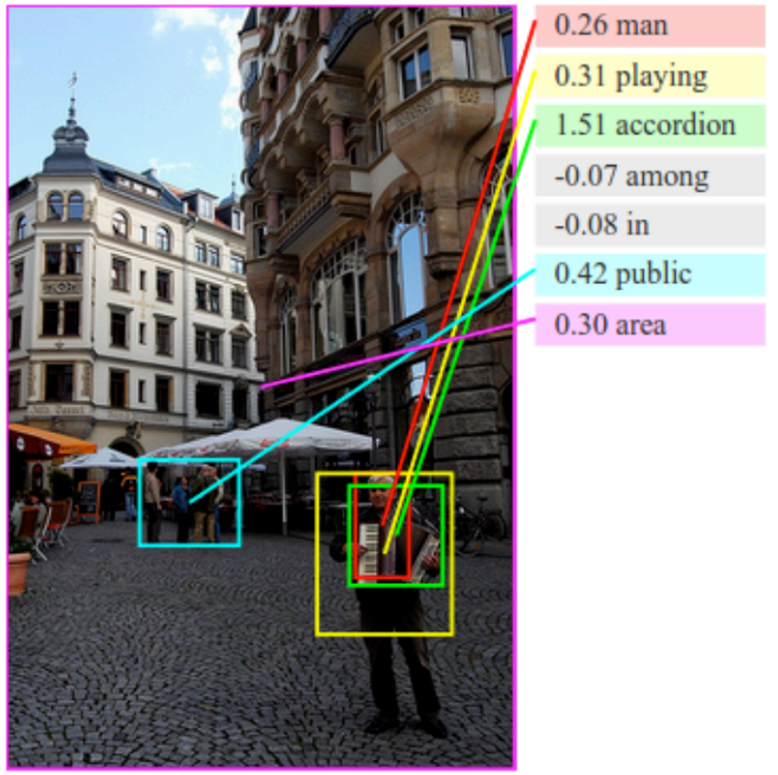
Rapid Advances in Speech Recognition

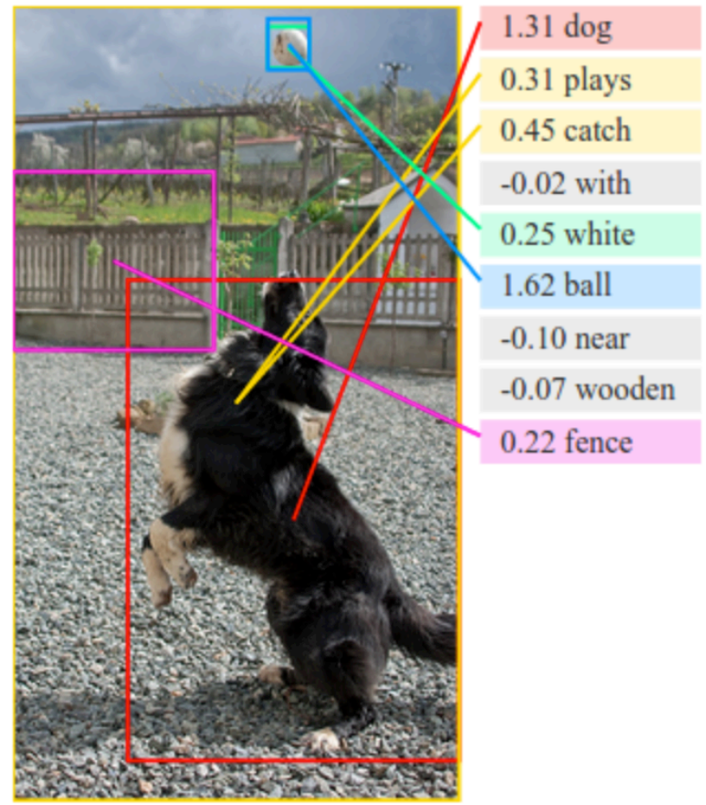


AlphaGo beats Lee Sedol



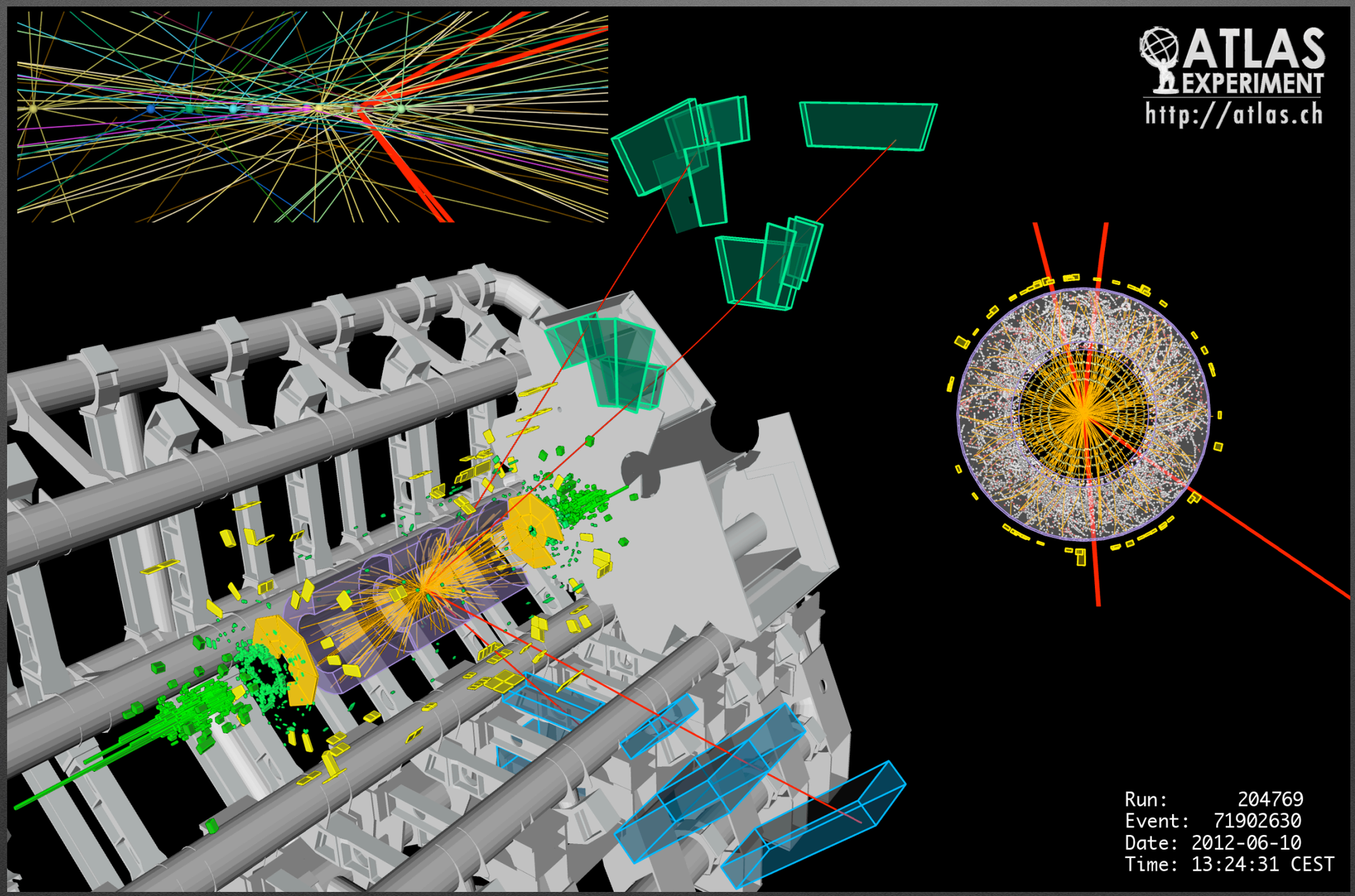
Human Level control in playing Atari games





Deep Learning can be used to tell a story with context through data

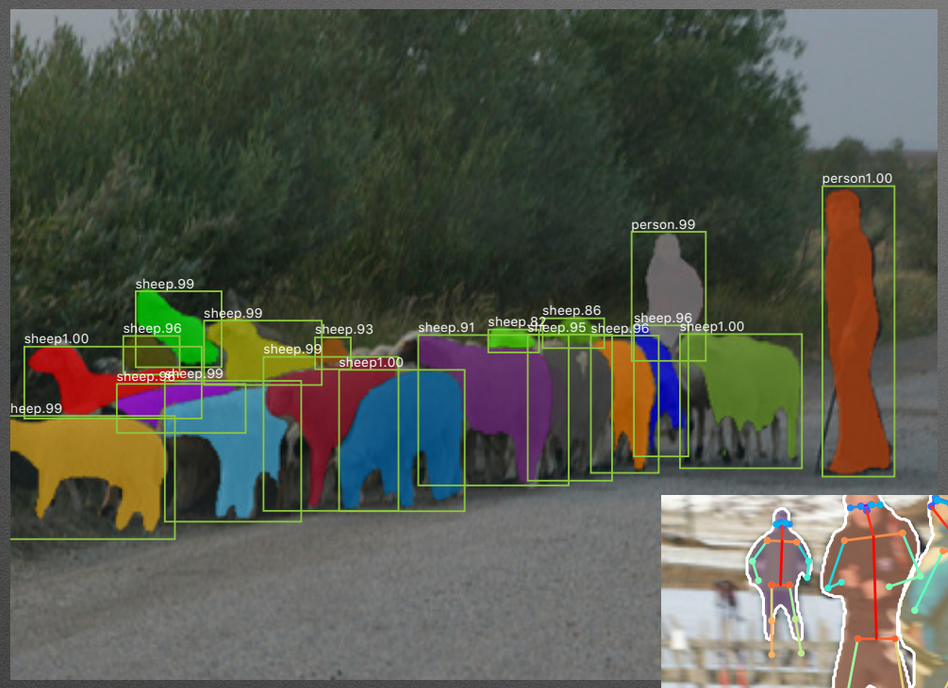
Used in HEP to understand what physics is happening

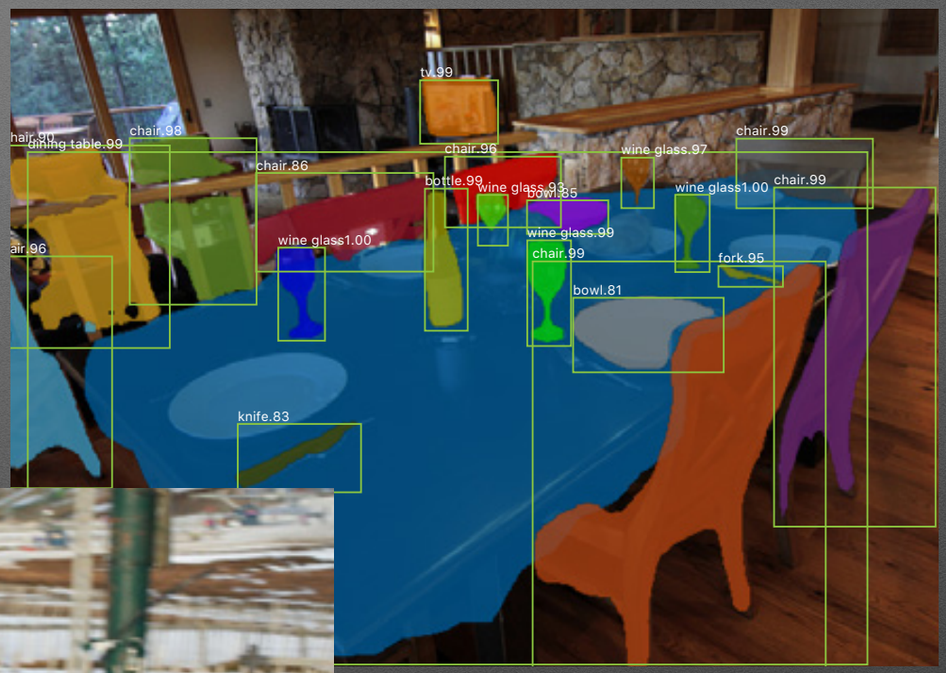


$H \rightarrow ZZ \rightarrow 4\ell$

We can use deep learning object tagging techniques in the data to find the decaying particle

Amazing Feats : Some More Examples





https://arxiv.org/pdf/1703.06870.pdf

Why go Deep?

Better Algorithms

- Better results
- Solution where there is none
- Make sense of complicated data

Easier Development

- Feature Learning, not Feature Engineering
- Save time and cost

Faster Algorithms

- DNNs Faster than traditional Algs
- Neuromorphic processors

Why Physicists ?

High Energy Physicists (HEP) ideally suited

- HEP Systems and Machine Learning and Deep Learning Systems confront similar challenges
- Decades of Experience at the Data Frontier
- Bridge between science and industry
- HEP scientists are also engineers by training

MOVE OVER, CODERS— PHYSICISTS WILL SOON RULE SILICON VALLEY

… it's happening across Silicon Valley. …, ***the things that just about every internet company needs to do are more and more suited to the skill set of a physicist***.

new wave of data science and AI is something that suits physicists right down to their socks.

"There is something very natural about a physicist going into machine learning … more natural than a computer scientist."

Physicists know how to handle data … building these enormously complex systems requires its own breed of abstract thought.

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.
- Imagine zooming out from a picture, start from individual spec of paint … all the way to the full picture.

Electrodynamics

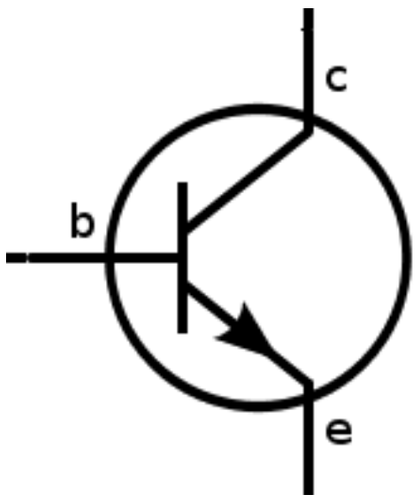
- One of the fundamental forces of nature is ***Electricity and Magnetism***.
    - What keeps Atoms together.
    - Responsible for all ***Chemistry***.
    - Foundation of ***Electronics***.
        - Electrons have an ***electric charge***.
        - Produce and ***Electric Field***.
        - Feel a force when they experience an ***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.

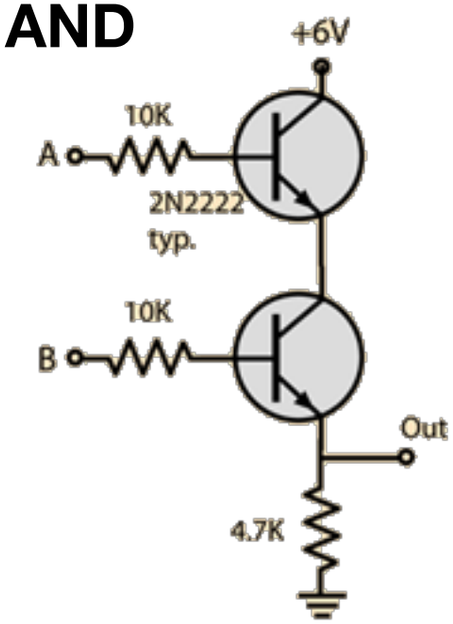
- *Collector:* When there is power to the base, the collector current is allowed to flow towards the emitter.

- *Emitter:* The emitter takes the electric current that the collector is allowed to send, to be used on other parts of your circuit.

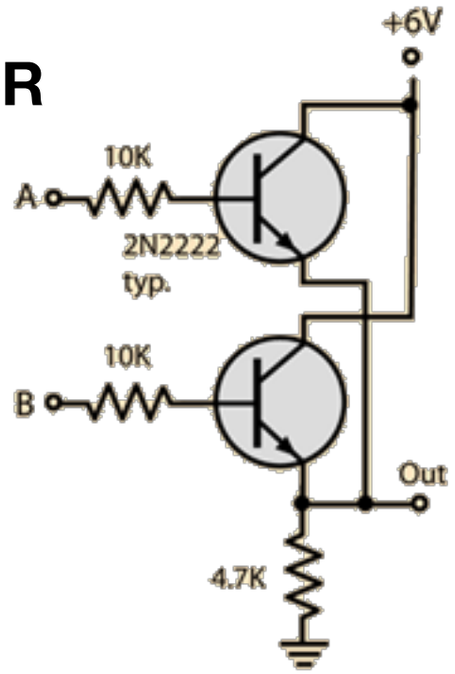


Logic Gates

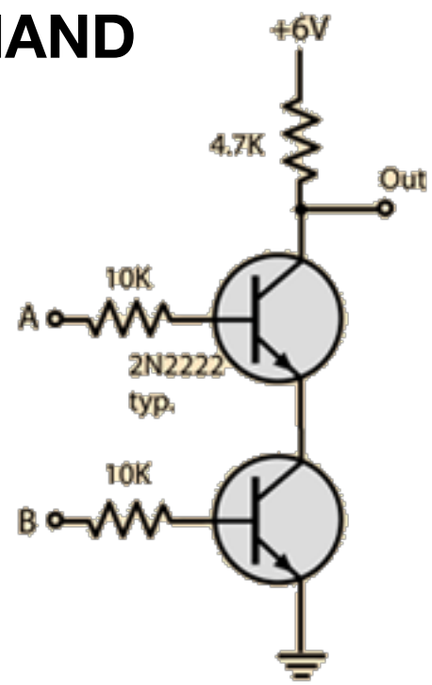
AND



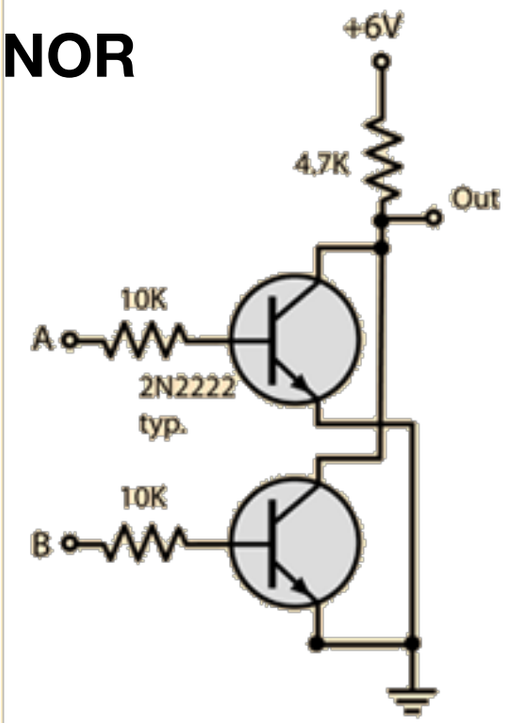
OR



NAND

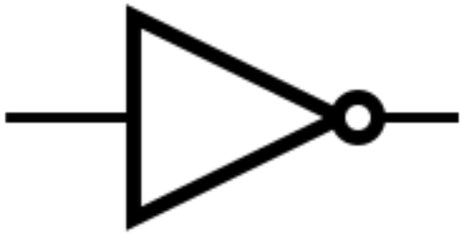


NOR



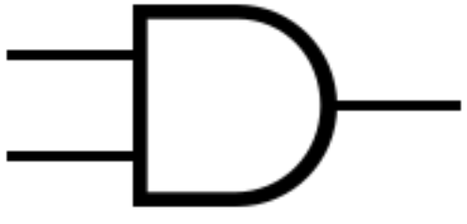
Boolean Operations

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

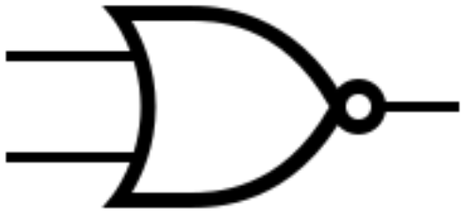
OR

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

XOR

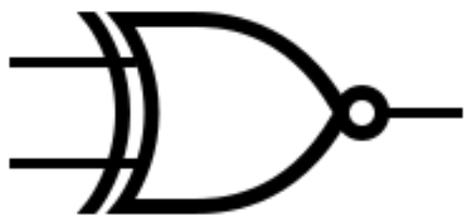
INPUT		OUTPUT
A	B	A XOR B
0	0	0
0	1	1
1	0	1
1	1	0

NOR



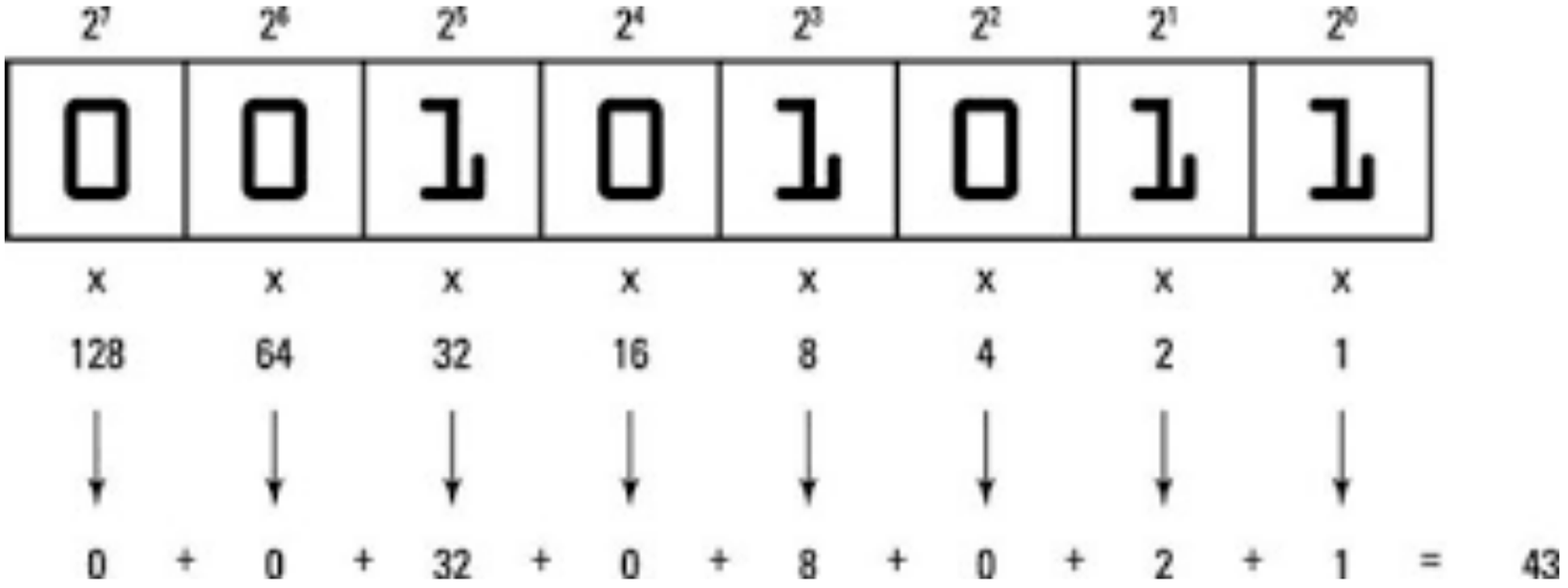
INPUT		OUTPUT
A	B	A NOR B
0	0	1
0	1	0
1	0	0
1	1	0

XNOR



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

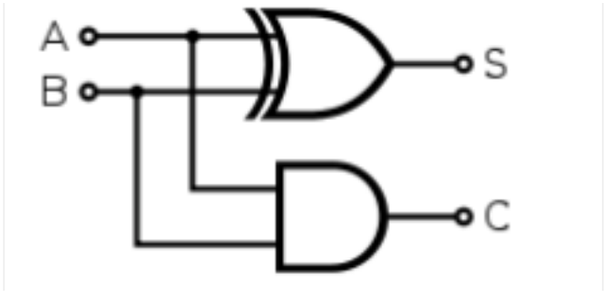
Binary



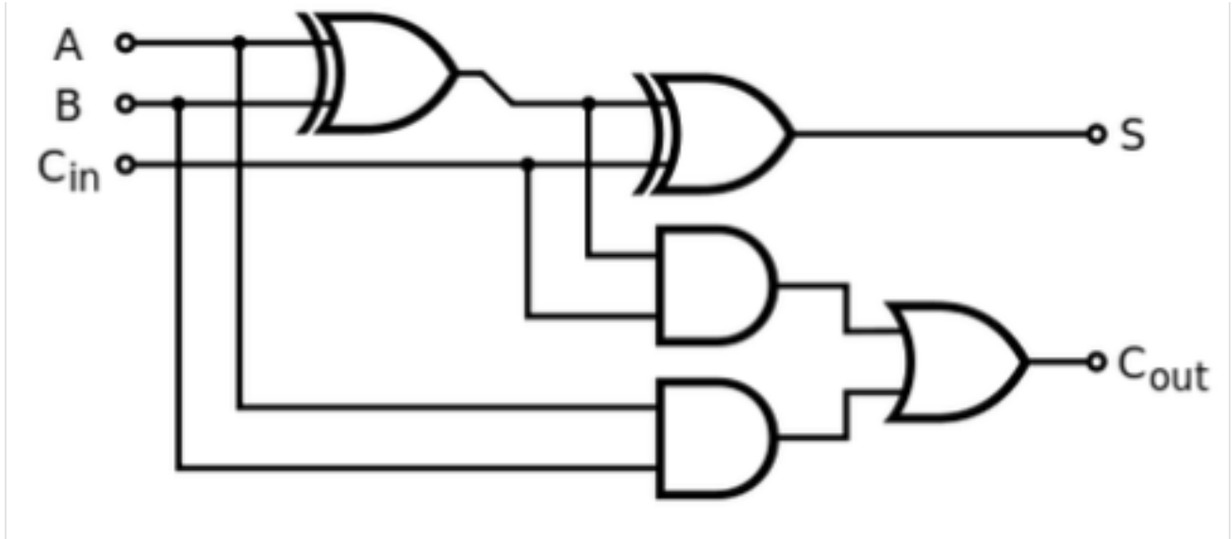
Number	Binary equivalent
0	000000
1	000001
2	000010
3	000011
4	000100
5	000101
6	000110
7	000111
8	001000
9	001001
10	001010
11	001011
12	001100
13	001101
14	001110
15	001111

Adder

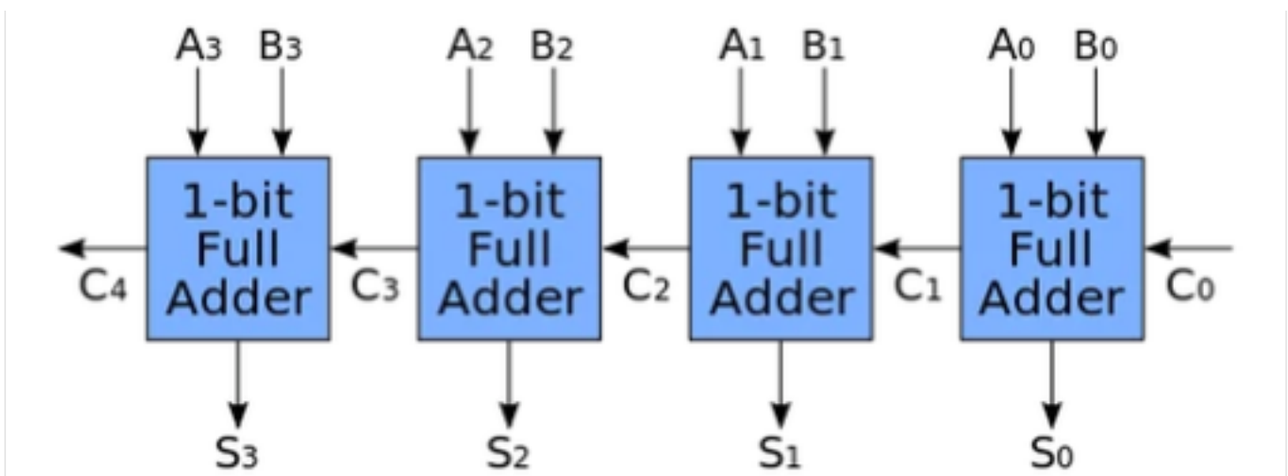
Half Adder



Full Adder



N-Bit Adder



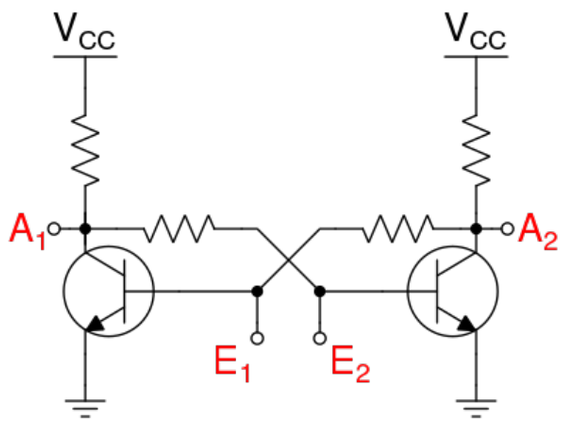
https://gizmodo.com/how-computer-chips-work-1645654993

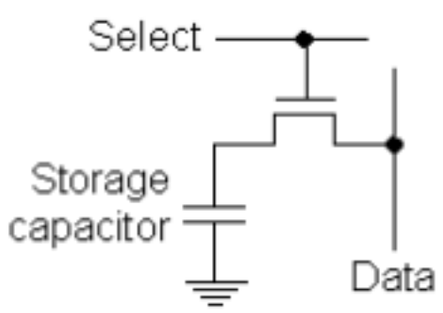
Other Circuits

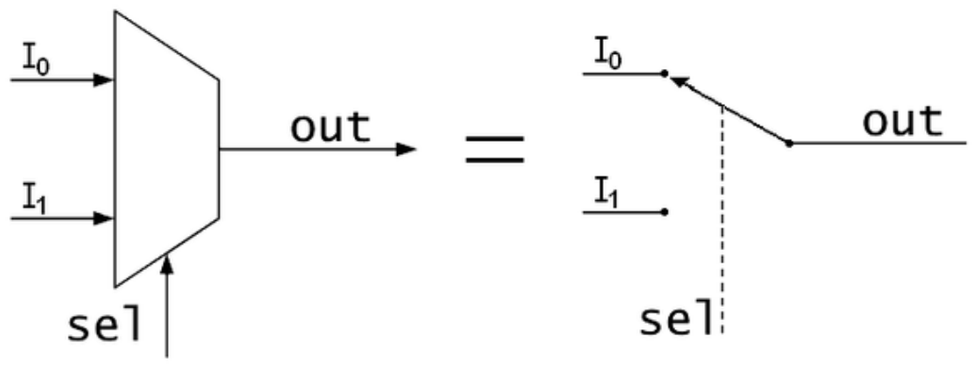
- *Flip-flop:* Circuit that can "store" a value. Its output will depend on what value was written to it earlier.

- *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

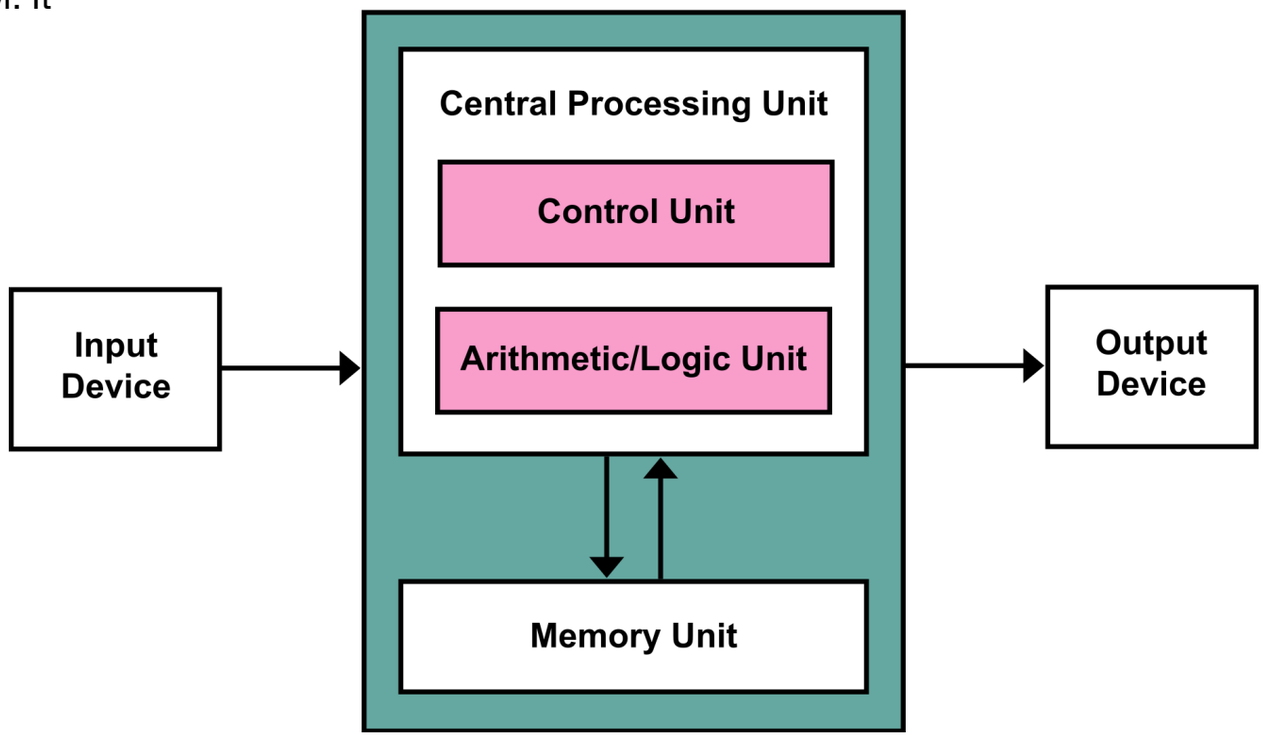






Von Neumann Architecture

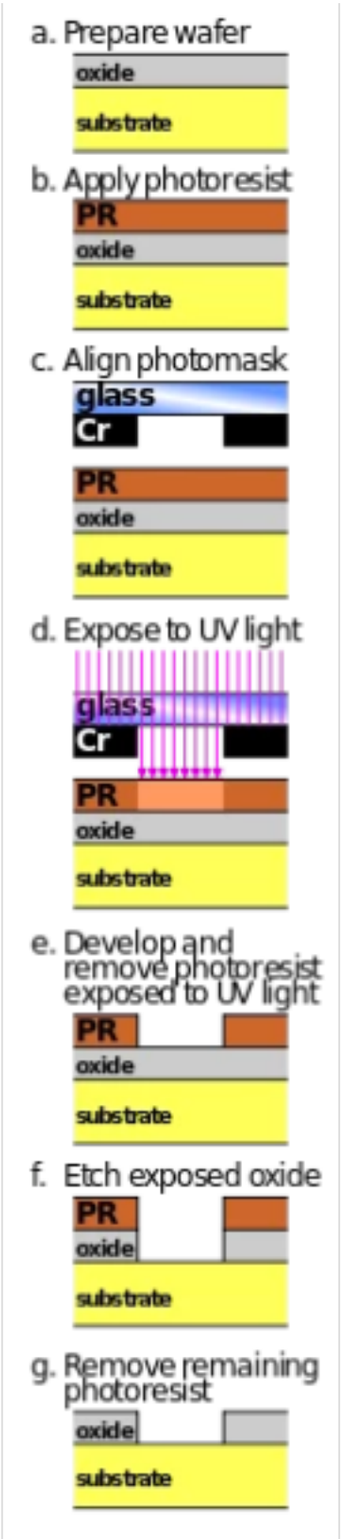
- ***Memory array:*** (MEM) holds all the "commands" (instructions) and "numbers" (data).
- ***Control Unit:***
    - ***Program counter***: select which instruction to execute from MEM. It normally just increases by 1 in each step.
    - Instruction Multiplexer
- ***Arithmetic block:*** multiplexers connecting to different binary different operations (+, -, …), with input / output
    - Generate inputs to our arithmetic block from MEM.
- 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

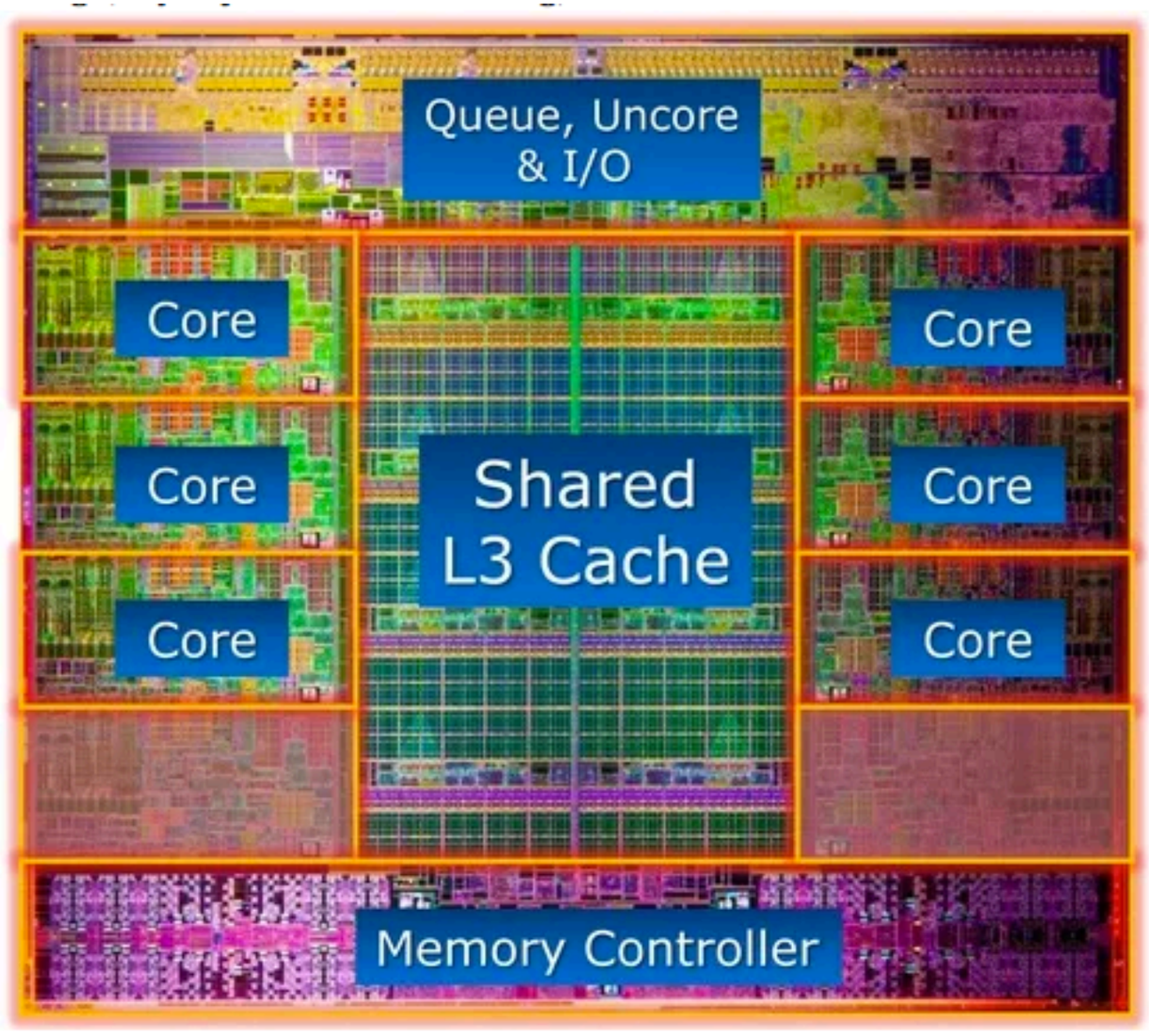
- Modern processors have billions of transistors in precisely arranged and connected.

- 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.



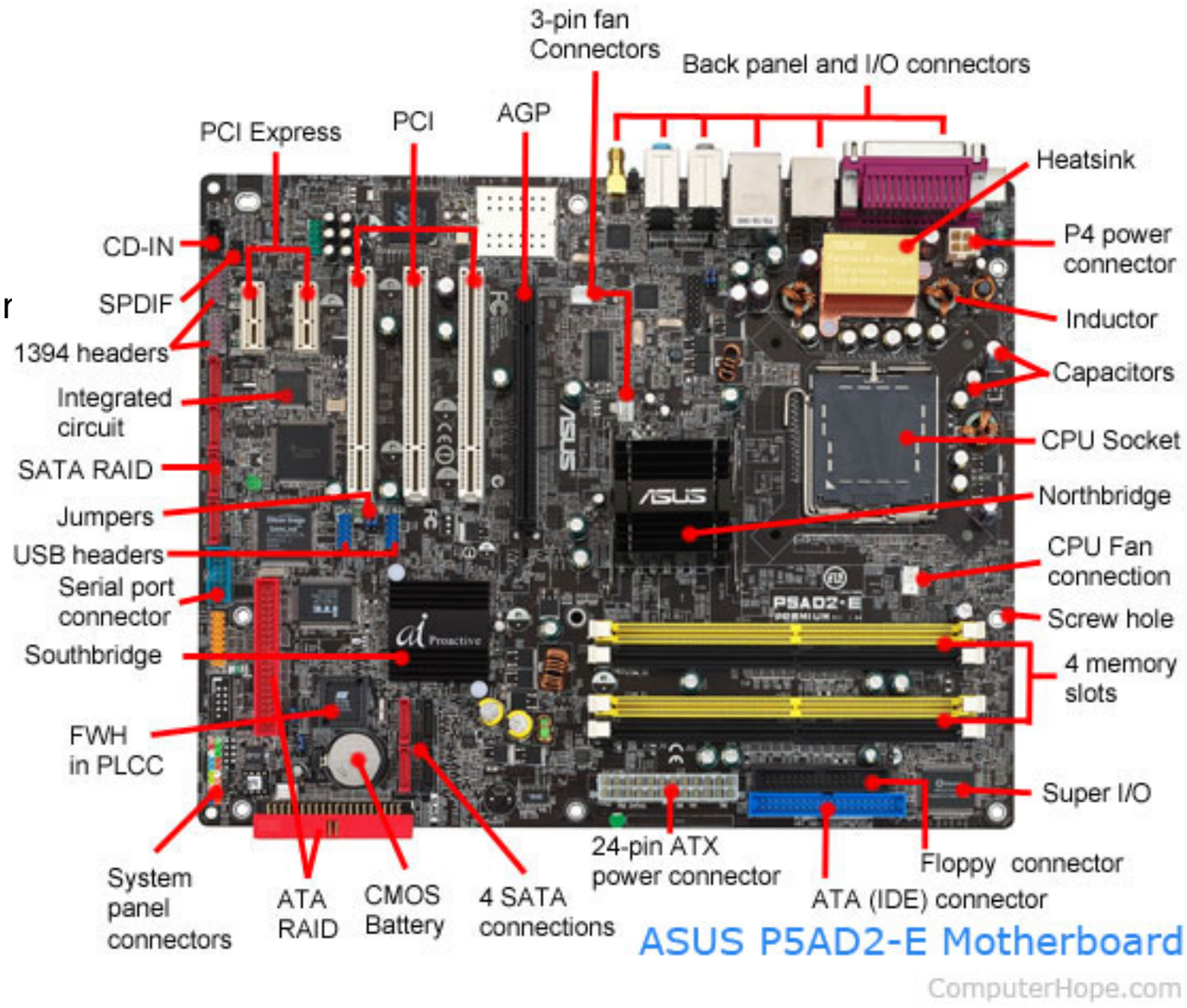
Modern Processors

- 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



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 (connec networks), wireless…
- Layers
    - Ethernet: (physical)
        - Rates now approaching 100 Gb
        - 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.