Introduction to Neuroinformatics

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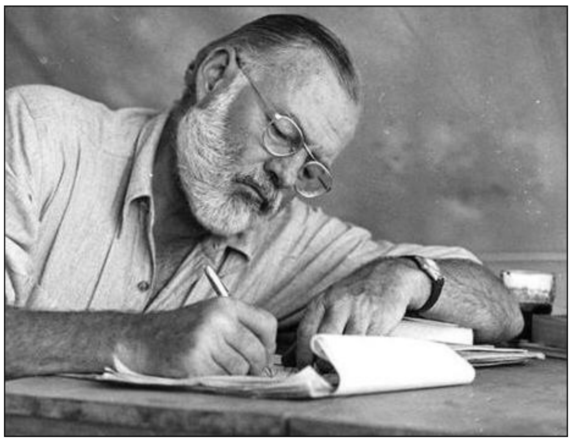
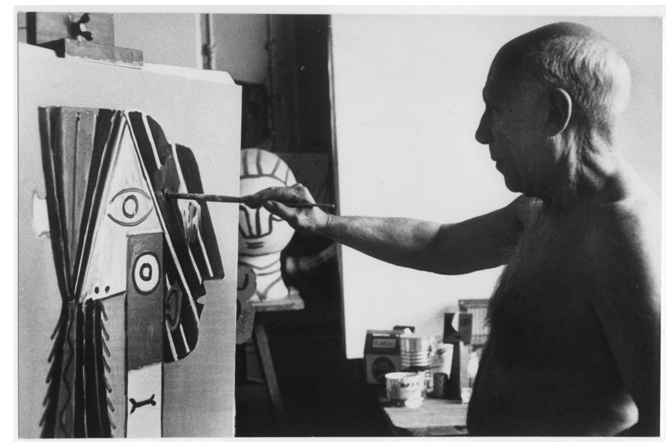
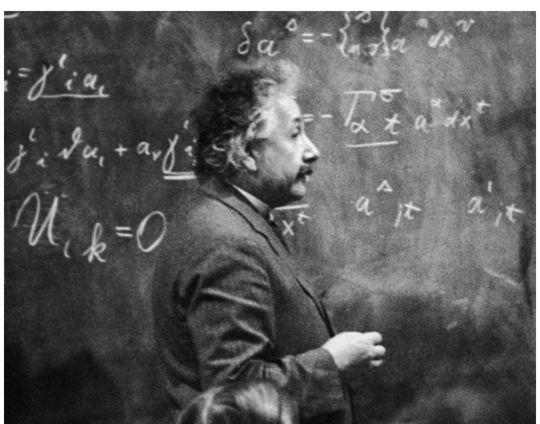
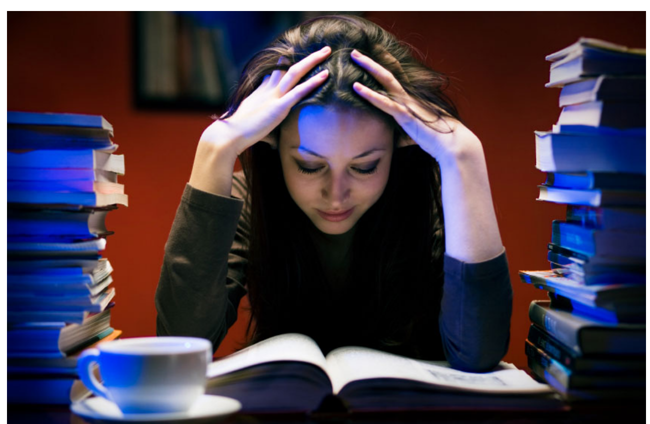
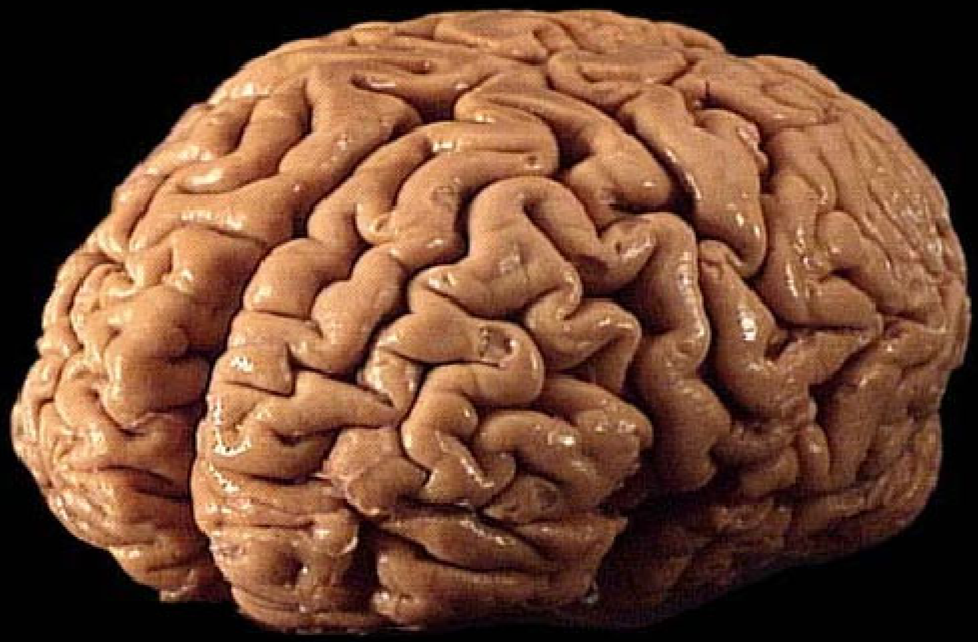



unicef









Average human brain:
~1.5 kg
~1.1-1.2 l volume

Why do we have a brain?

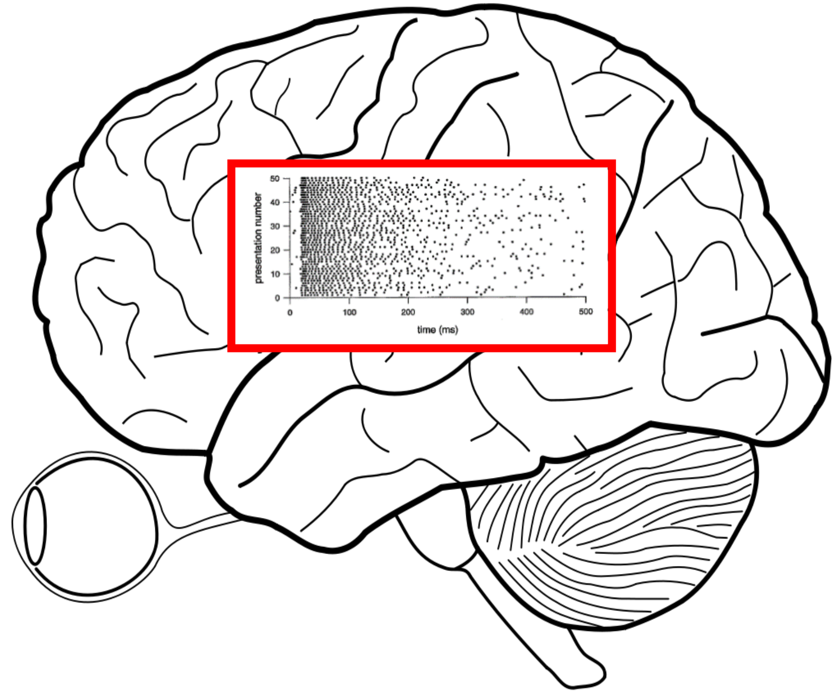
(according to Daniel Wolpert)

Giant Sequoia

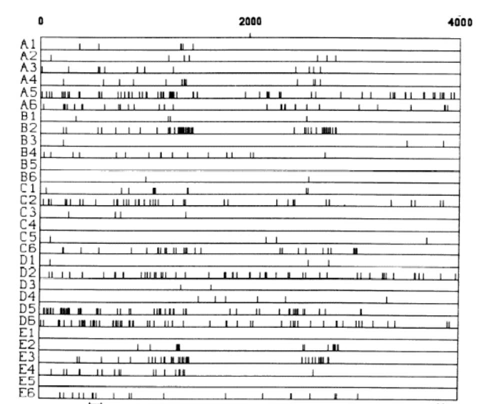
Sea squirt

Stimuli in the Environment

Encoding

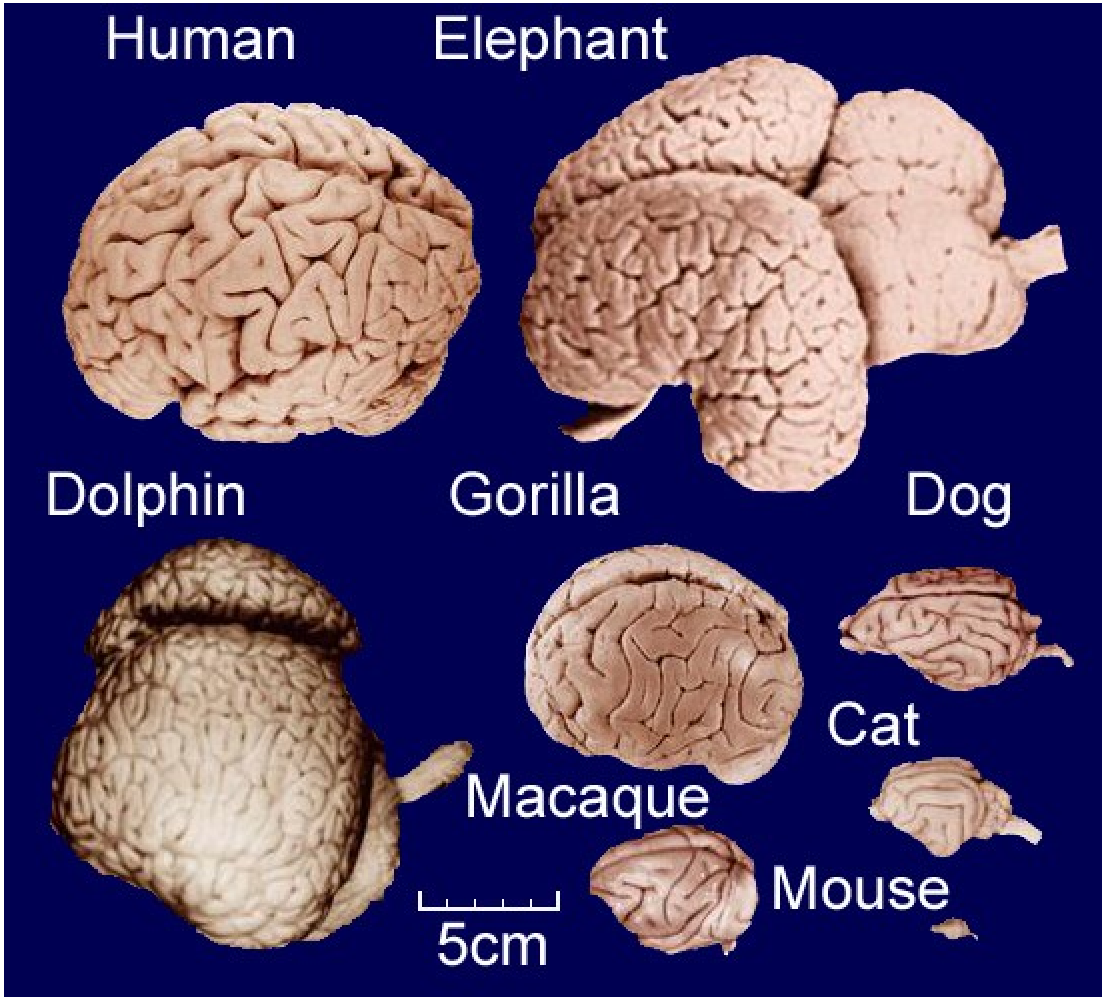


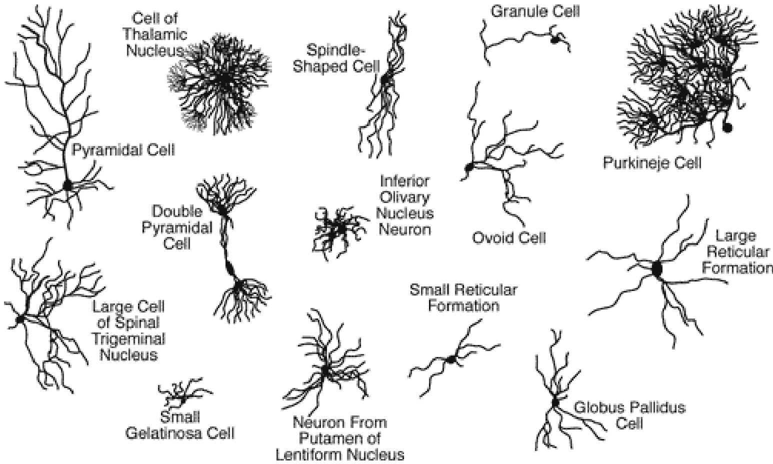
Neuronal Representation
Perception
Sensory Integration
Memory / maintenance



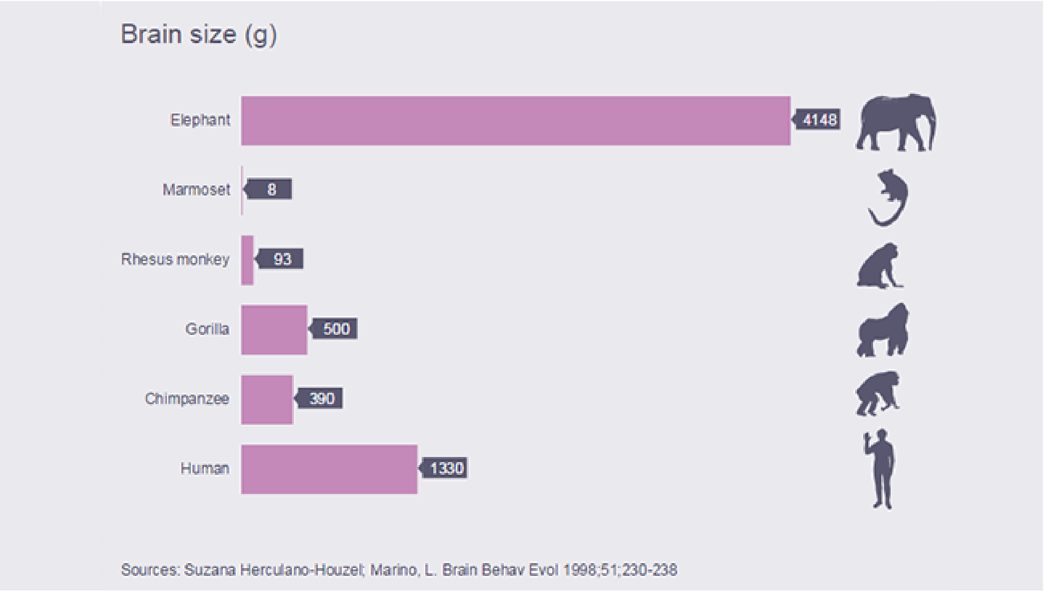
Decoding

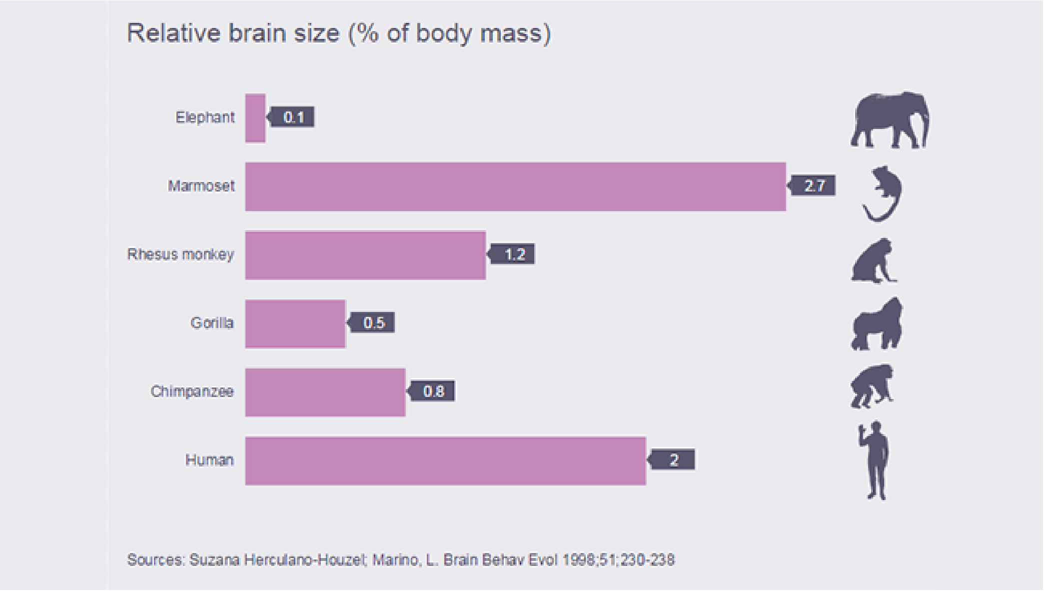
Movement
Actions
Decisions
Behavior

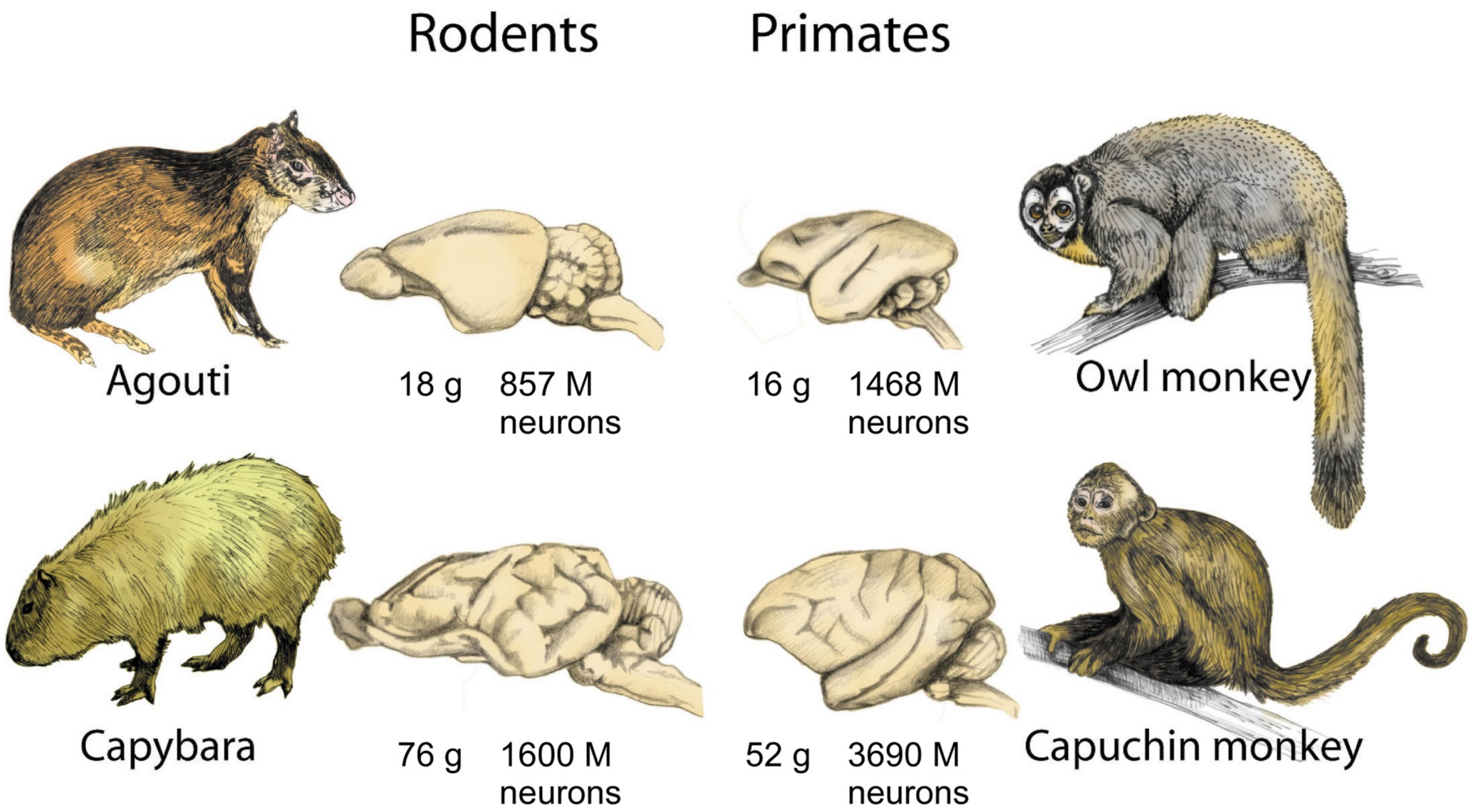




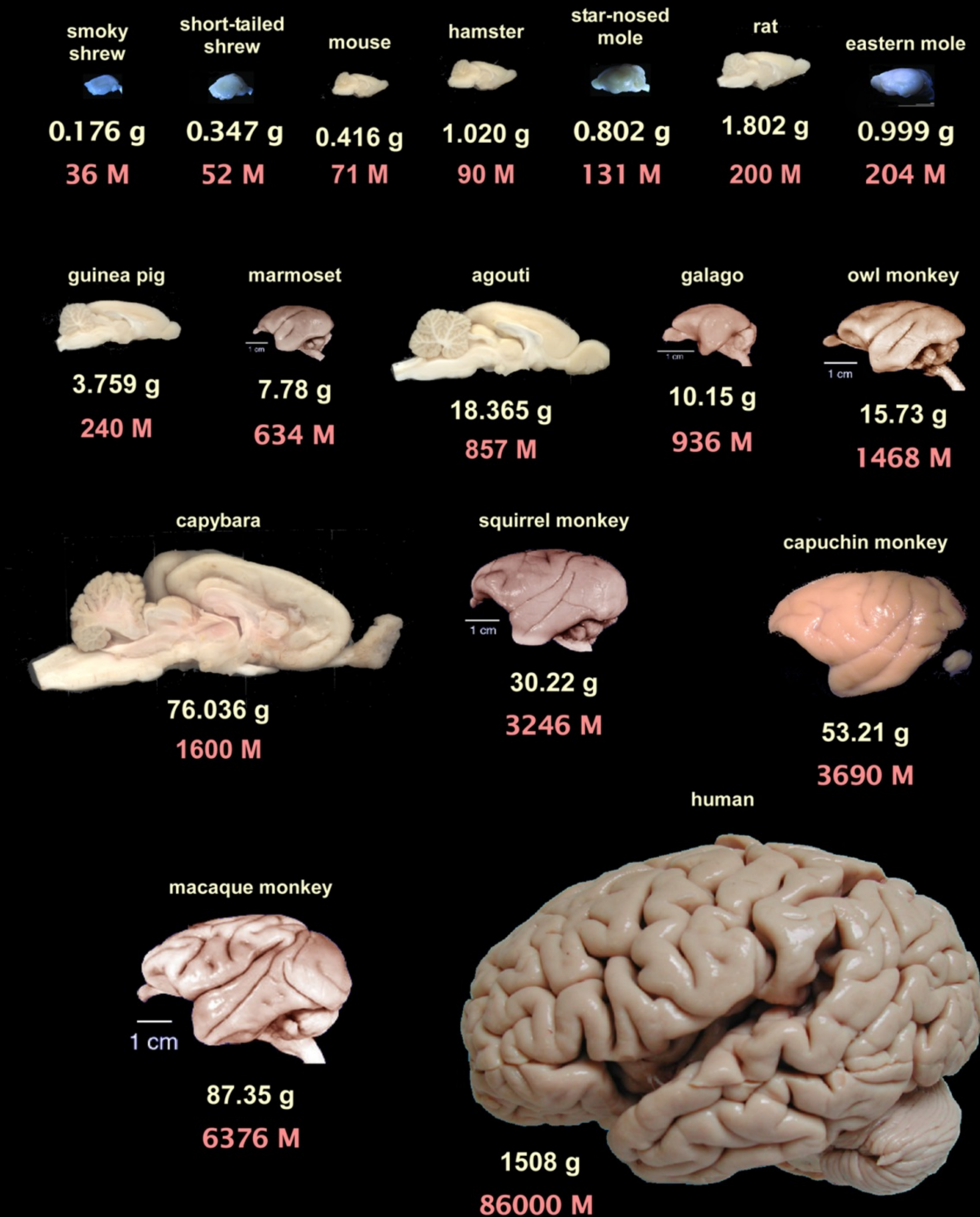
Human brains are large, but by far not the largest (elephants, whales, …)
The cells (neurons) that make up brains are very similar between species


Brain size (g)
Elephant
4148
Marmoset
8
Rhesus monkey
93
Gorilla
500
Chimpanzee
390
Human
1330
Sources: Suzana Herculano-Houzel; Marino, L. Brain Behav Evol 1998;51;230-238

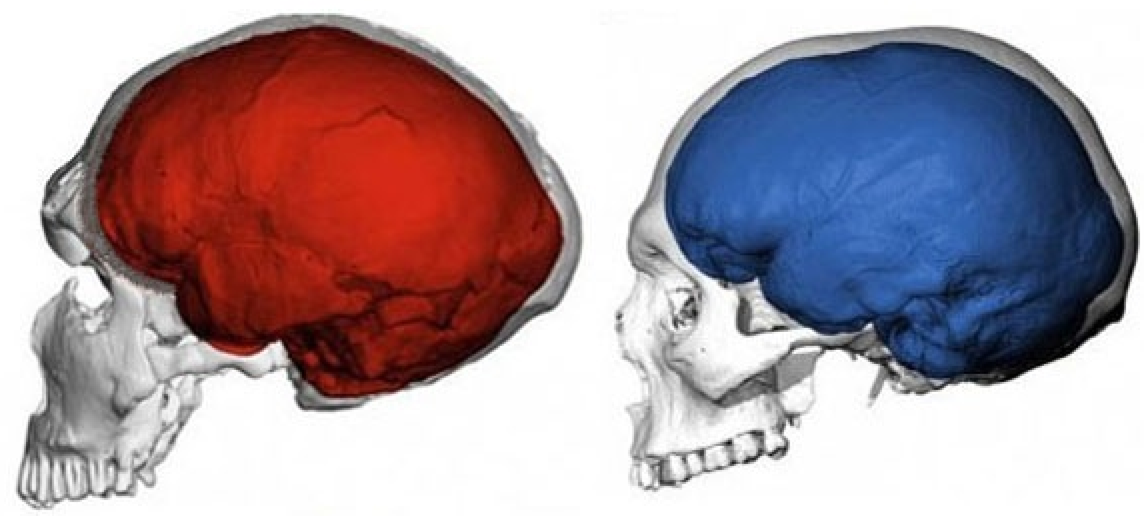

Relative brain size (% of body mass)
Elephant
0.1
Marmoset
2.7
Rhesus monkey
1.2
Gorilla
0.5
Chimpanzee
0.8
Human
2
Sources: Suzana Herculano-Houzel; Marino, L. Brain Behav Evol 1998;51;230-238



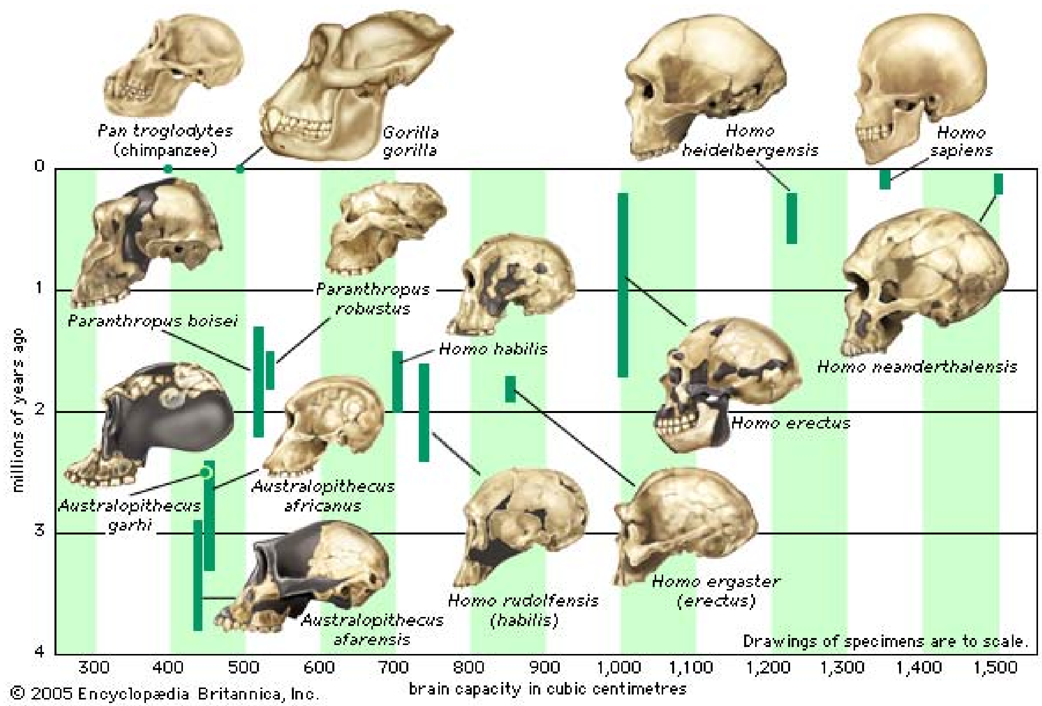
Herculano-Houzel, 2009

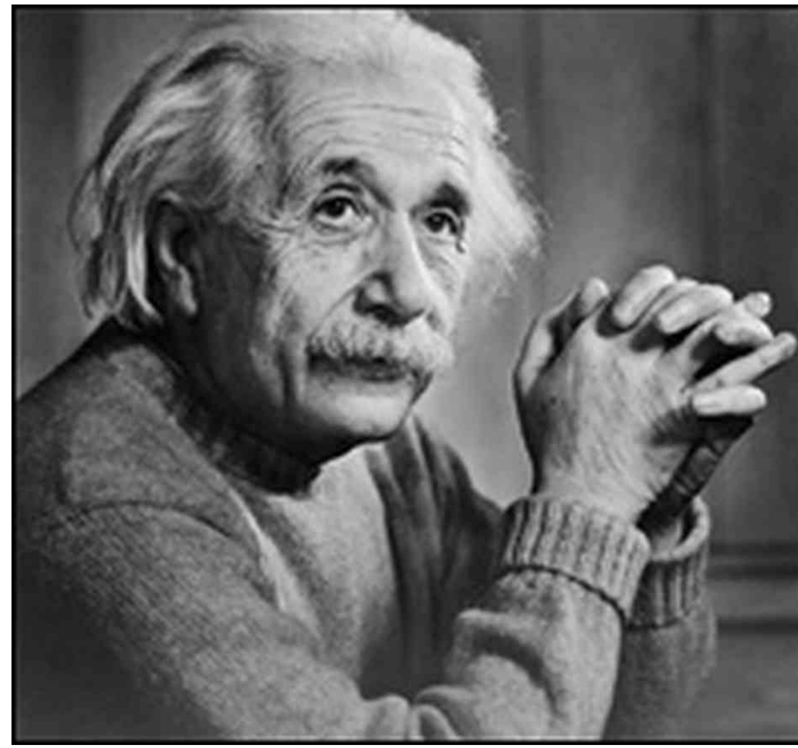


Herculano-Houzel, 2009

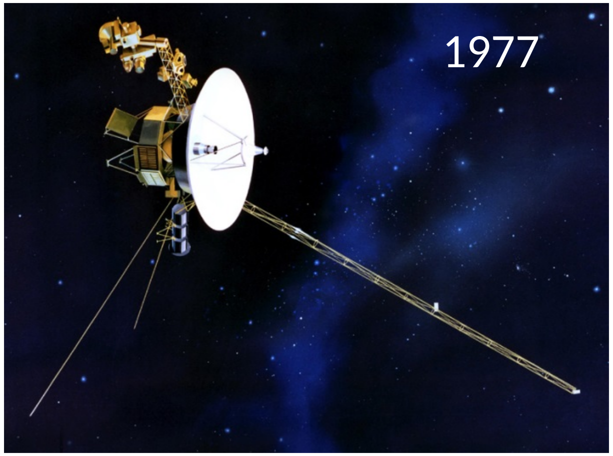


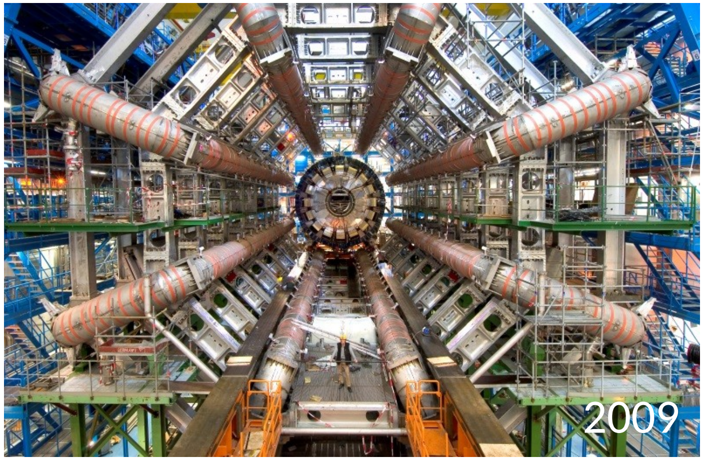
Neanderthal (left), Homo sapiens (right)






~200,000 BC


1977

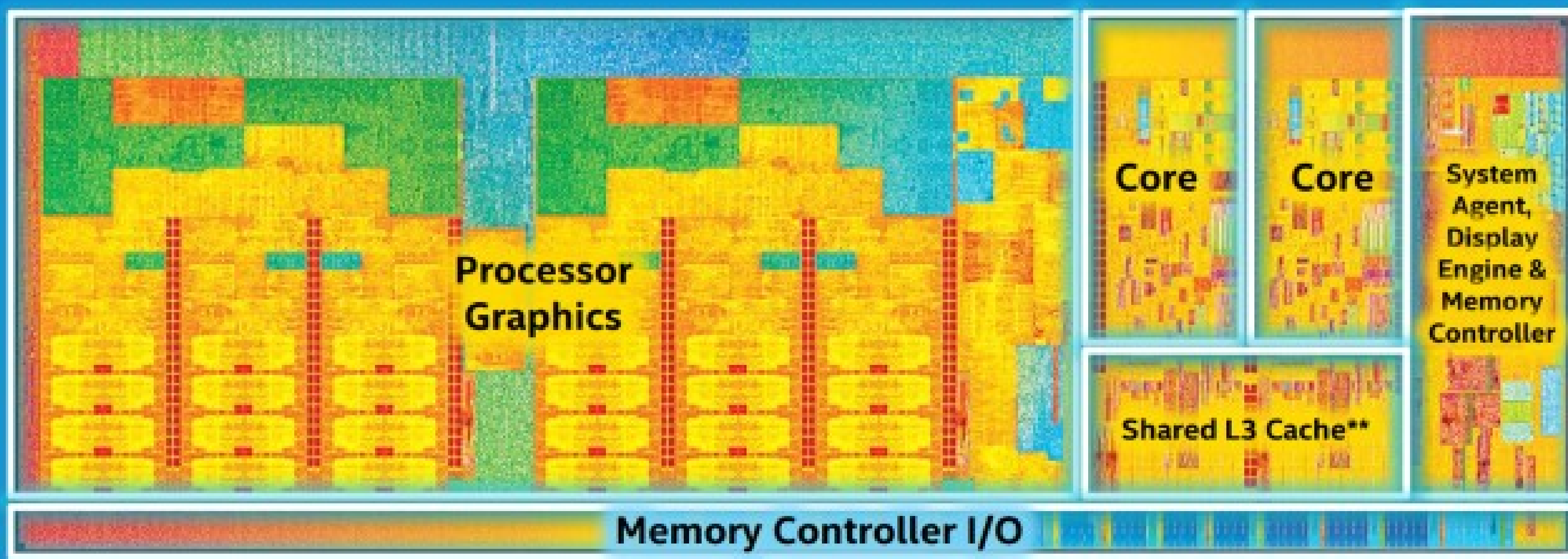

2009


~2500 BC


A380 AIRBUS
A380
2007

5th Gen Intel® Core™ Processor Die Map

Intel® HD Graphics 6000 or Intel® Iris™ Graphics 6100

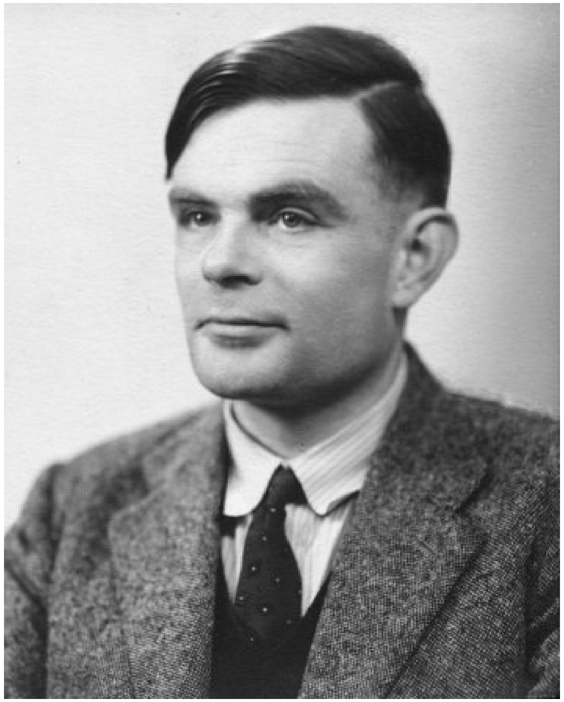


Dual Core Die Shown Above | Transistor Count: 1.9 Billion | Die Size: 133 mm²

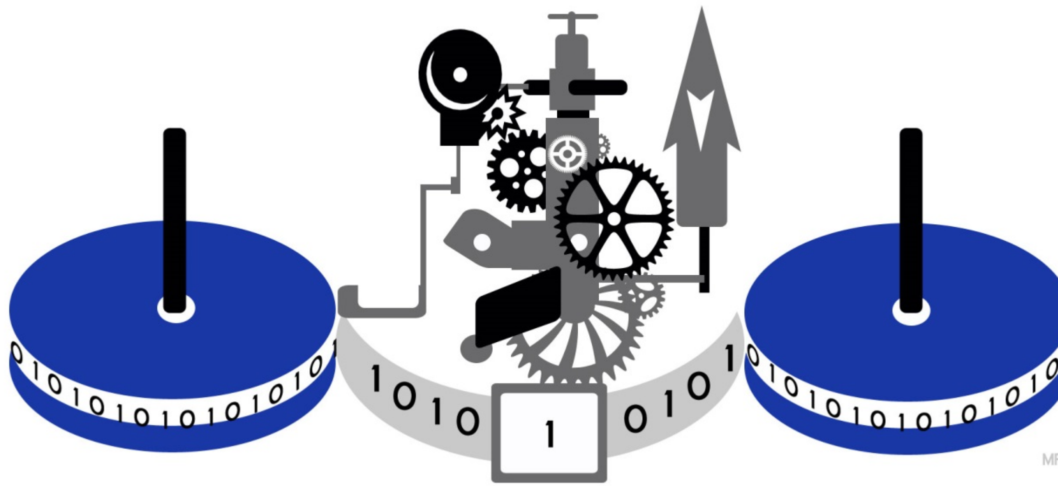
4th Gen Core Processor (U series): 1.3B

4th Gen Core Processor (U series): 181mm²

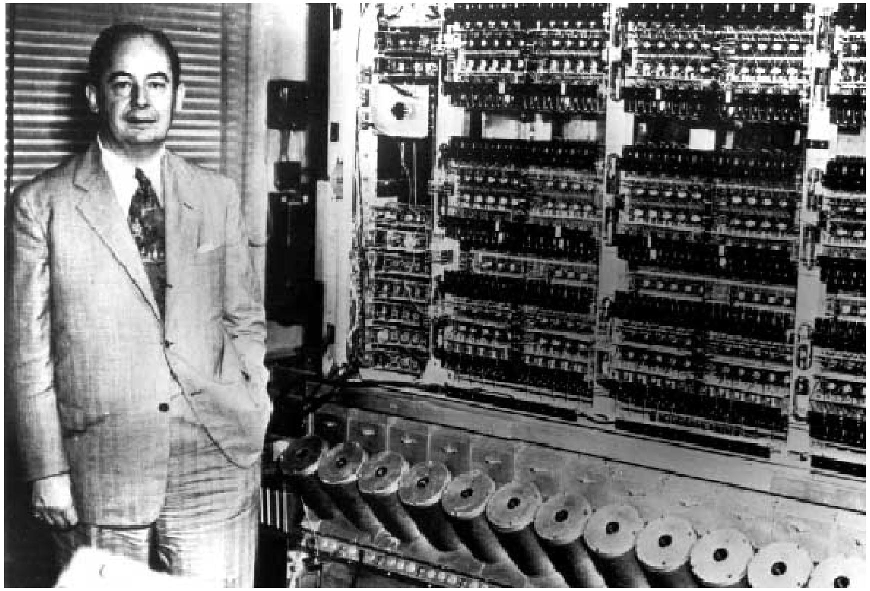
** Cache is shared across both cores and processor graphics

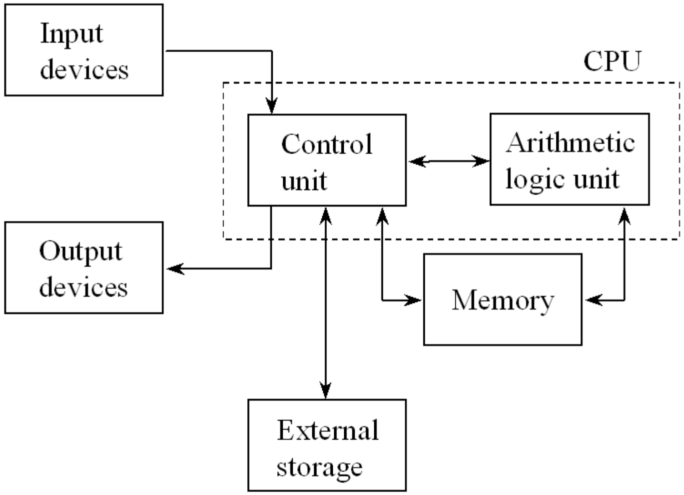


Alan Turing (1912-1954)

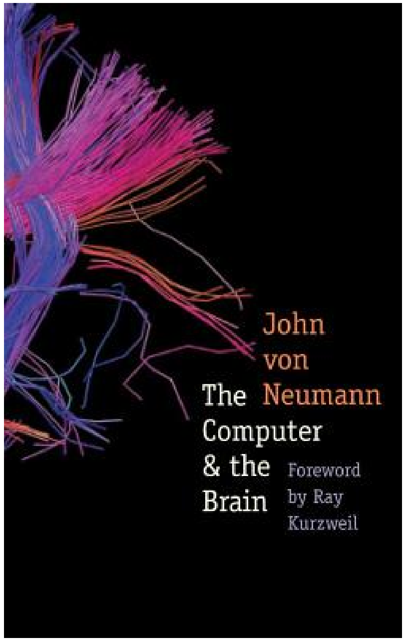


Turing Machine





John von Neumann (1903 – 1957)



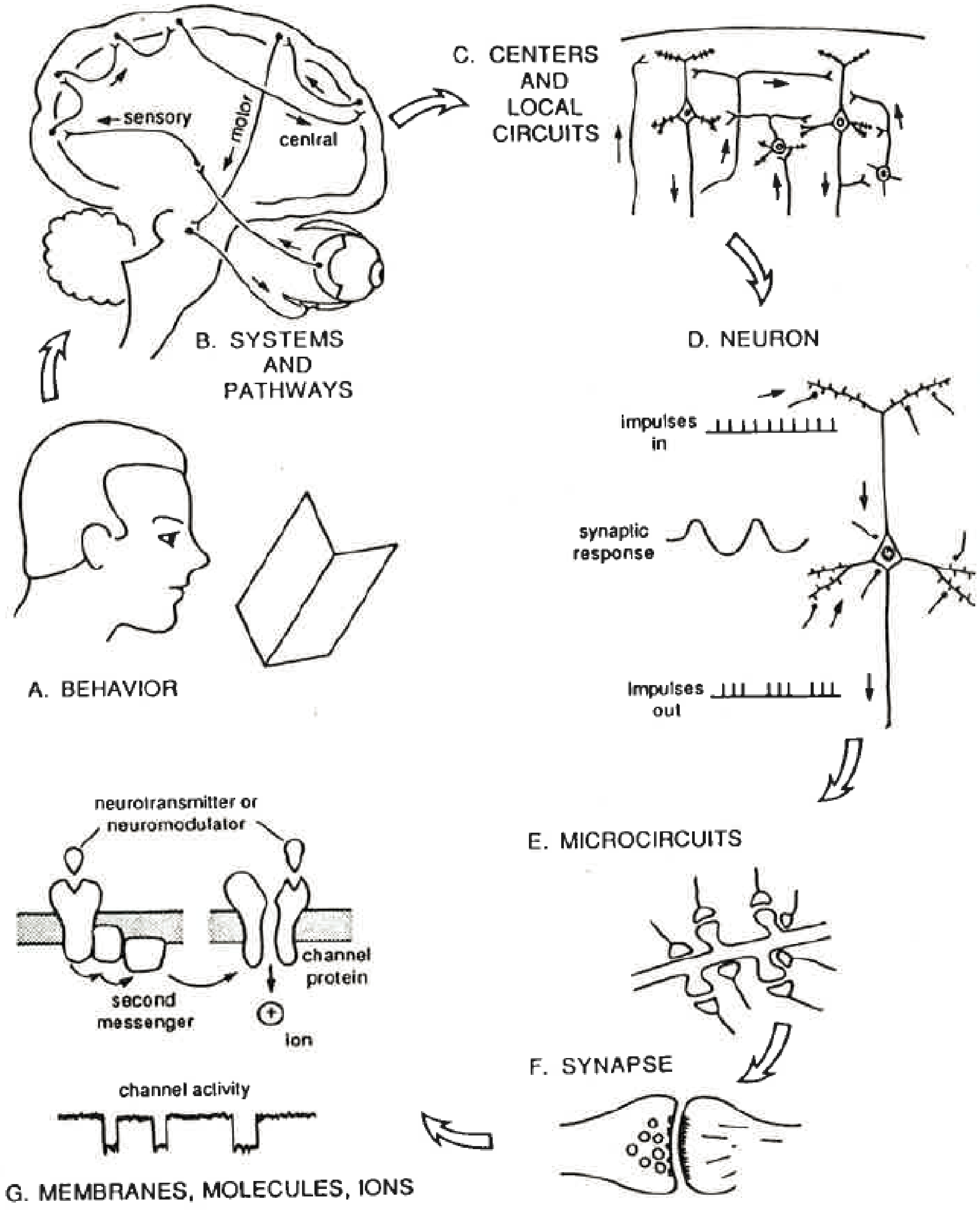
How is a brain different / similar to a computer?

Similar

- Process information
- Logical operations
- Memory
- Use electrical (digital) signaling
- Can learn from inputs
- Consume energy
- …

Different

- Massive parallelism
- Separation of memory and processing
- Constantly adapting
- Chemical signaling
- Unreliable units
- Analog computation
- Robust to damage
- Very energy efficient
- …



Shepherd, 1988

What this course will be about?

- Information processing in the brain: neurons, synapses, nervous system organization
- Analytical descriptions of neural computations
- Learning and plasticity
- Encoding information in the brain
- Theoretical neural network models
- Engineering brain-like computers

Lecturers

Valerio Mante

Benjamin Grewe

Matthew Cook

Giacomo Indiveri

Daniel Kiper

Wolfger von der Behrens

Teaching Assistants:

Karla Burelo

Vanessa Leite

Nicoletta Risi

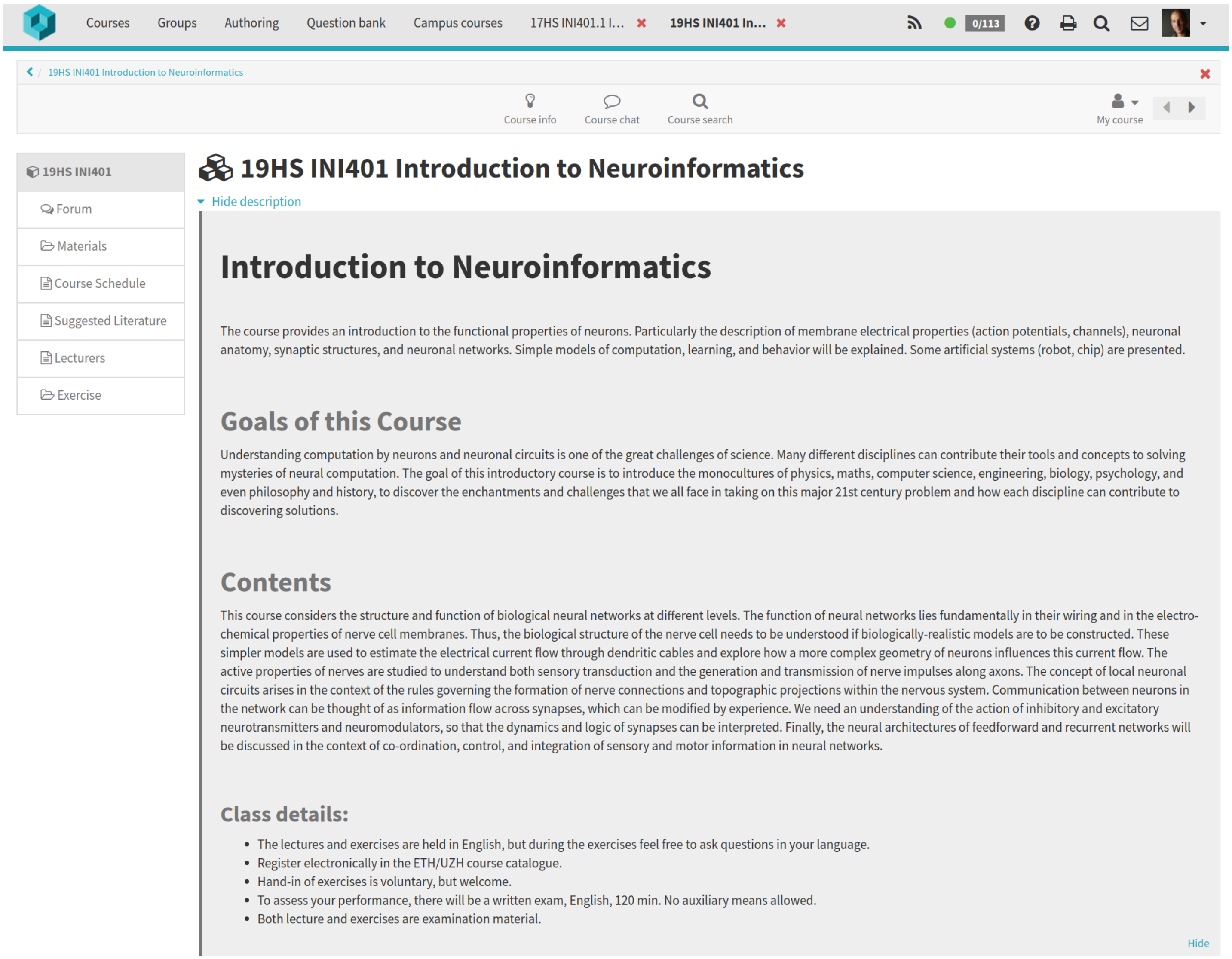
Logistics

- Lecture: Thursdays 08:15-9:00, 9:15-10:00
- Exercises: Thursdays 10:15-11:00

- 2 rooms: ETH HG G3 (lecture)
  - ETH HG F3(excercises)

- Written Exam
  - Multiple choice, 2 hours
  - ETH exam session (January-February 2018)
  - Exact date will be announced
  - One exam for UZH and ETH students
  - (Most likely) on ETH Hönggerberg campus

OLAT E-Learning System



Introduction to Neuroinformatics

The course provides an introduction to the functional properties of neurons. Particularly the description of membrane electrical properties (action potentials, channels), neuronal anatomy, synaptic structures, and neuronal networks. Simple models of computation, learning, and behavior will be explained. Some artificial systems (robot, chip) are presented.

Goals of this Course

Understanding computation by neurons and neuronal circuits is one of the great challenges of science. Many different disciplines can contribute their tools and concepts to solving mysteries of neural computation. The goal of this introductory course is to introduce the monocultures of physics, maths, computer science, engineering, biology, psychology, and even philosophy and history, to discover the enchantments and challenges that we all face in taking on this major 21st century problem and how each discipline can contribute to discovering solutions.

Contents

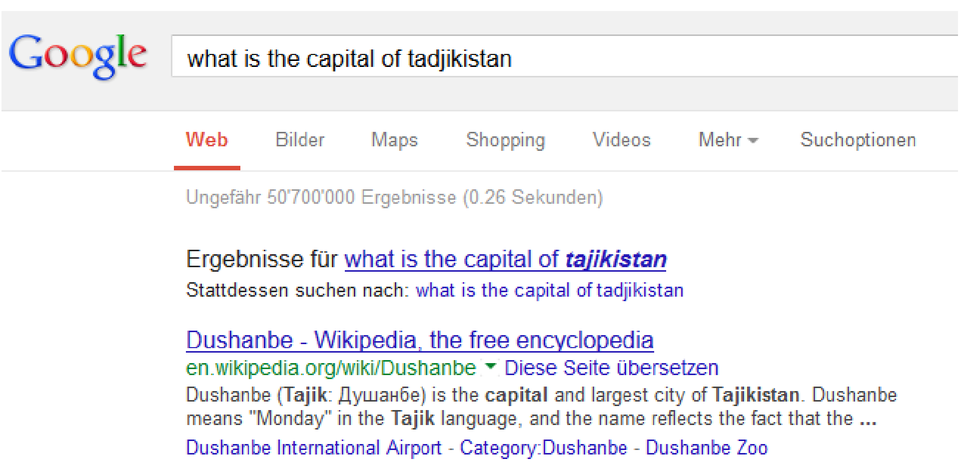
This course considers the structure and function of biological neural networks at different levels. The function of neural networks lies fundamentally in their wiring and in the electro-chemical properties of nerve cell membranes. Thus, the biological structure of the nerve cell needs to be understood if biologically-realistic models are to be constructed. These simpler models are used to estimate the electrical current flow through dendritic cables and explore how a more complex geometry of neurons influences this current flow. The active properties of nerves are studied to understand both sensory transduction and the generation and transmission of nerve impulses along axons. The concept of local neuronal circuits arises in the context of the rules governing the formation of nerve connections and topographic projections within the nervous system. Communication between neurons in the network can be thought of as information flow across synapses, which can be modified by experience. We need an understanding of the action of inhibitory and excitatory neurotransmitters and neuromodulators, so that the dynamics and logic of synapses can be interpreted. Finally, the neural architectures of feedforward and recurrent networks will be discussed in the context of co-ordination, control, and integration of sensory and motor information in neural networks.

Class details:

- The lectures and exercises are held in English, but during the exercises feel free to ask questions in your language.
- Register electronically in the ETH/UZH course catalogue.
- Hand-in of exercises is voluntary, but welcome.
- To assess your performance, there will be a written exam, English, 120 min. No auxiliary means allowed.
- Both lecture and exercises are examination material.

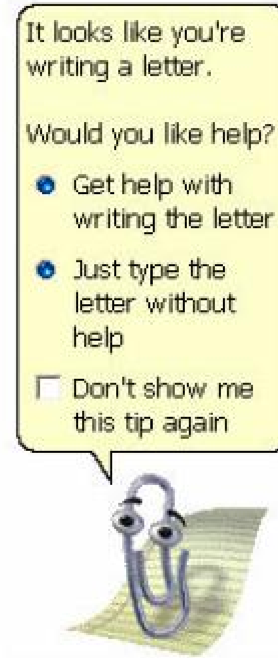
Hide

Computers are smart



… are they?


Sprint
12:11 PM
6%
What can I help you with?
“ I need a dinner reservation for Valentine's Day ”
I found a number of restaurants fairly close to you:
West State Road
Burger King
1 review
0.3 miles
Wrights Road
McDonald's
0 reviews
0.4 miles
Know your meme at FAILKING.COM


It looks like you're writing a letter.
Would you like help?
Get help with writing the letter
Just type the letter without help
Don't show me this tip again

Hard and Easy Problems

"The main lesson of thirty-five years of AI research is that the hard problems are easy and the easy problems are hard."

– Steven Pinker

"It is comparatively easy to make computers exhibit adult level performance on intelligence tests or playing checkers, and difficult or impossible to give them the skills of a one-year-old when it comes to perception and mobility."

– Hans Moravec











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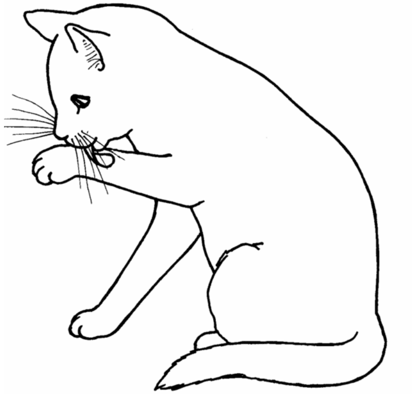
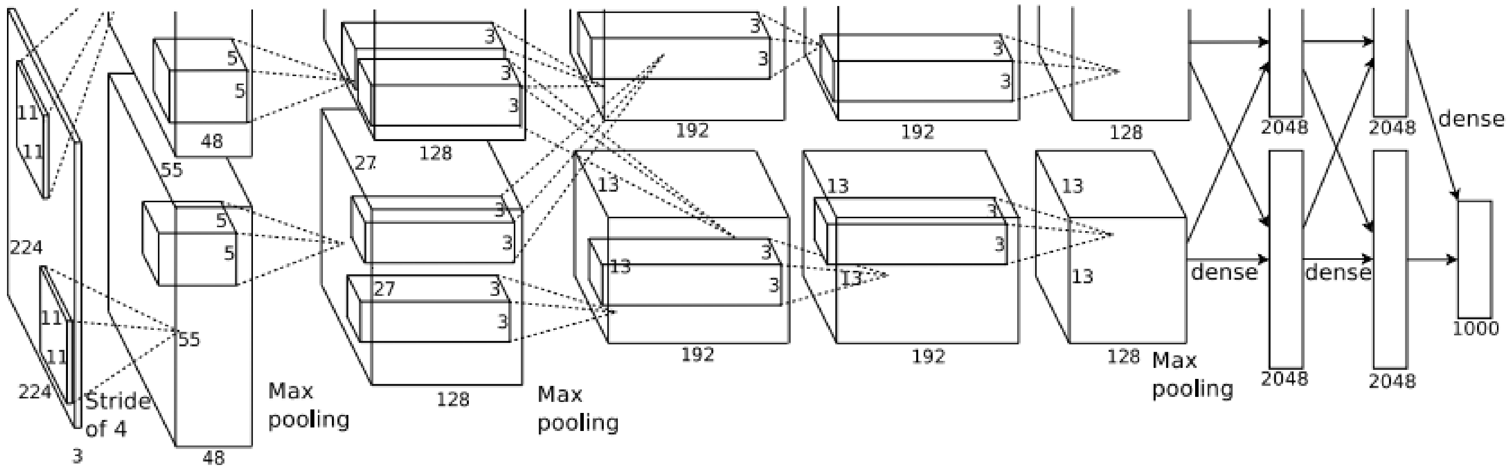
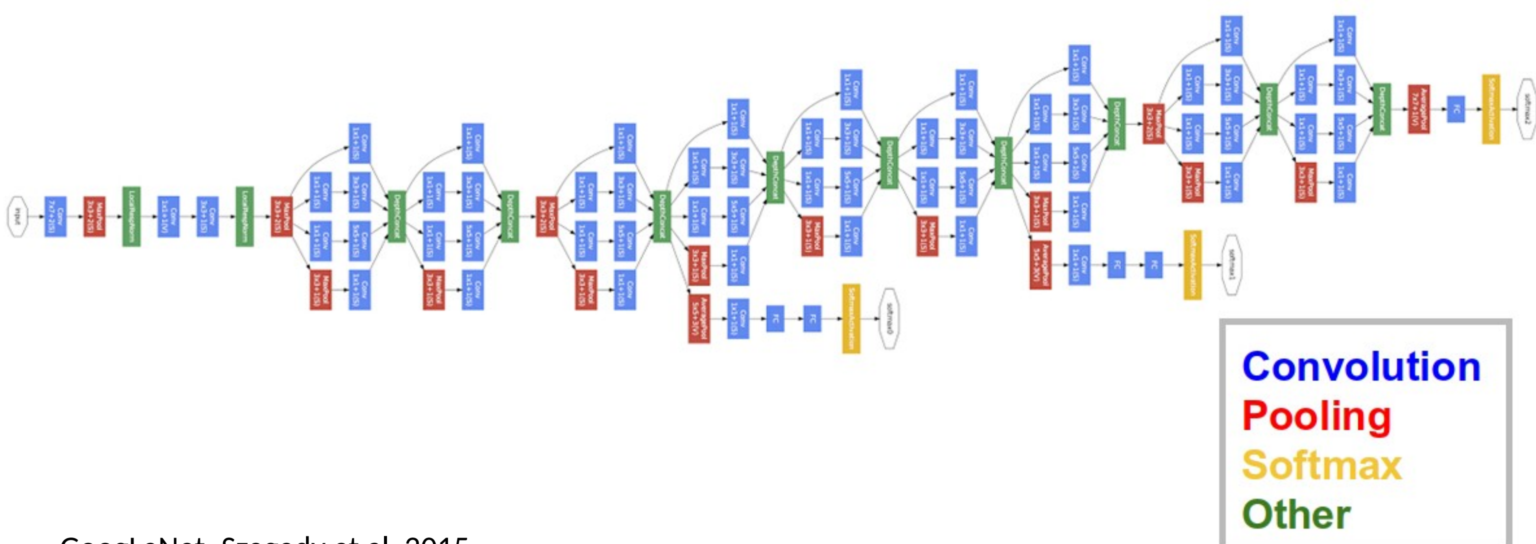


Deep Neural Networks

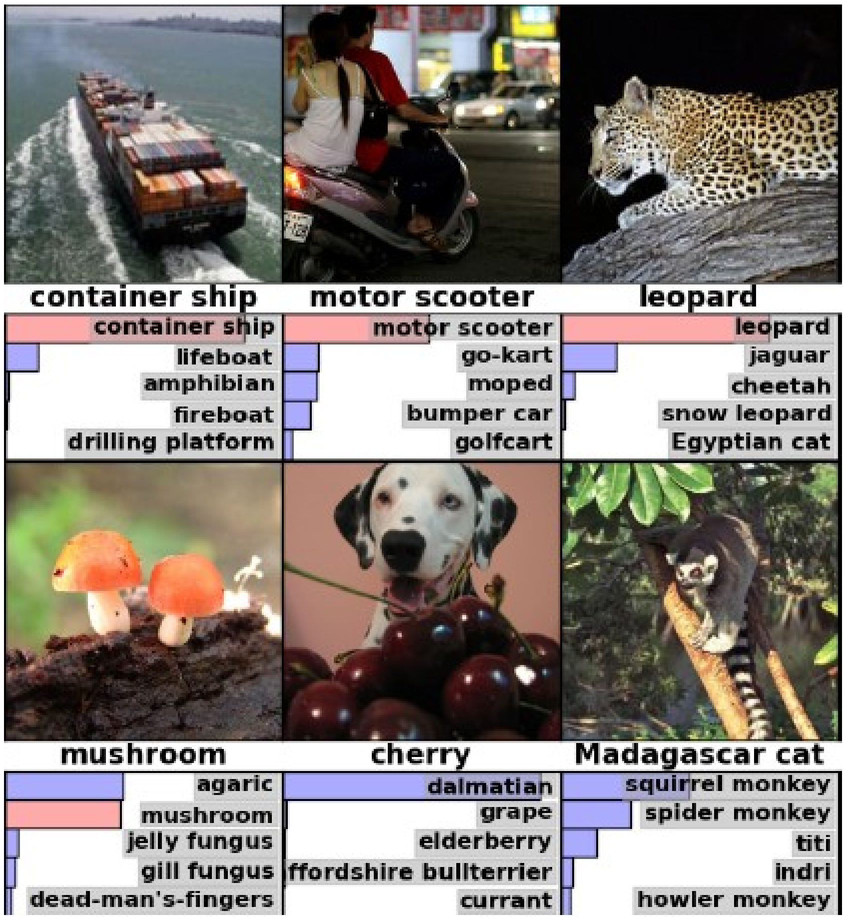


Krizhevsky et al. 2012



GoogLeNet: Szegedy et al. 2015

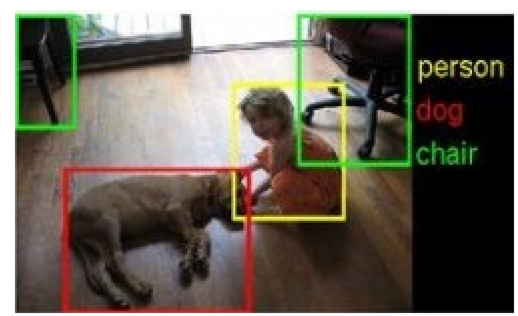
Recognizing Images with Deep Neural Networks



AlexNet: network with 650,000 neurons and 60 million connections

Current record: only 4.9% errors (humans: 5.1%)

Training (using 15 Million images from 20,000 classes) learns on high-performance computers for 3-4 weeks (!)



Krizhevsky et al. 2012; He et al. 2015

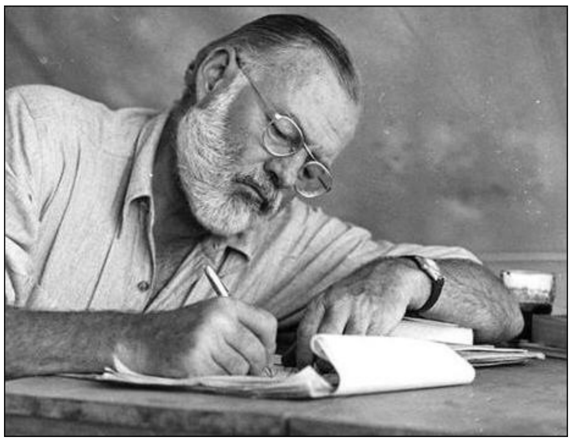
Deep Learning can Describe Images

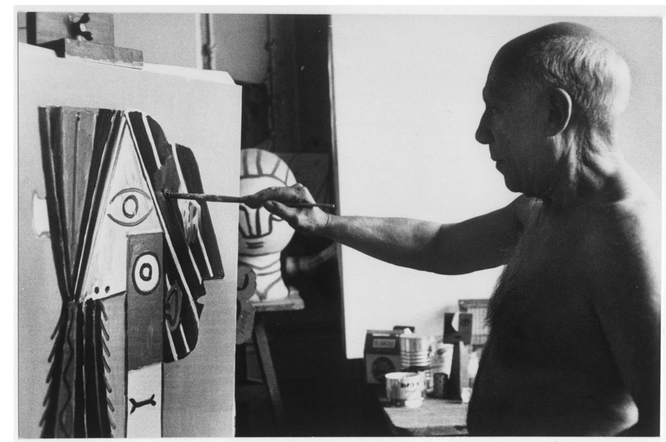
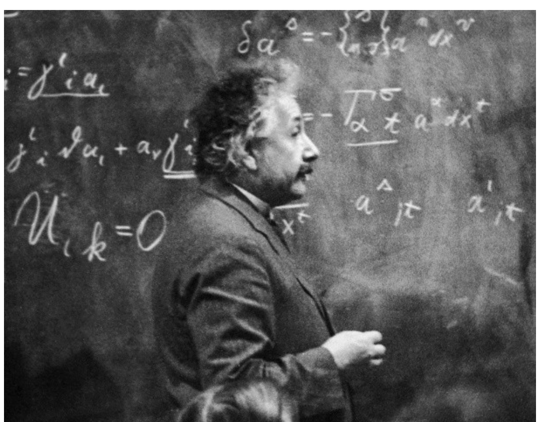
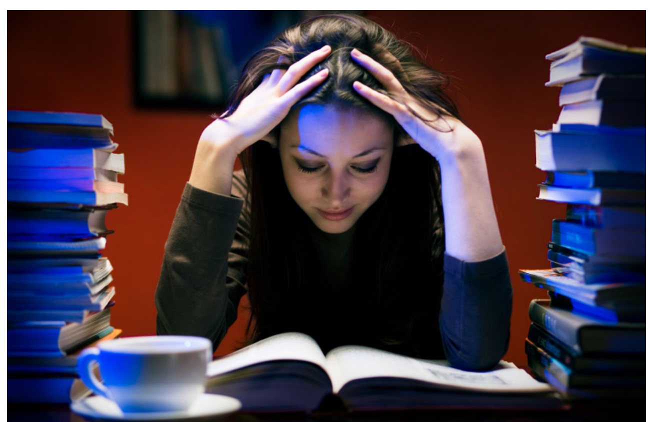
Xu et al. 2015

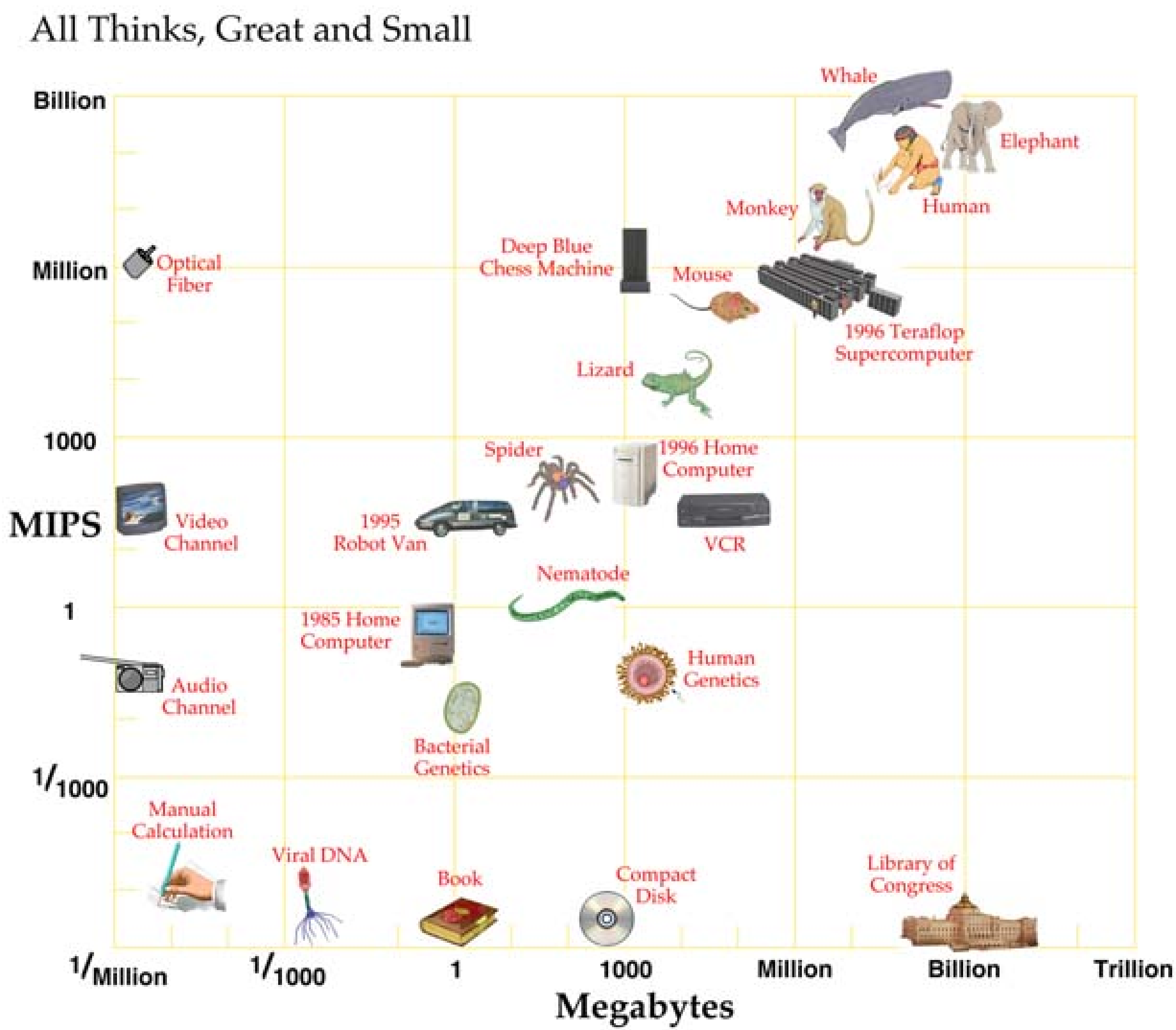
Not always perfect…

Vinyals et al. 2015

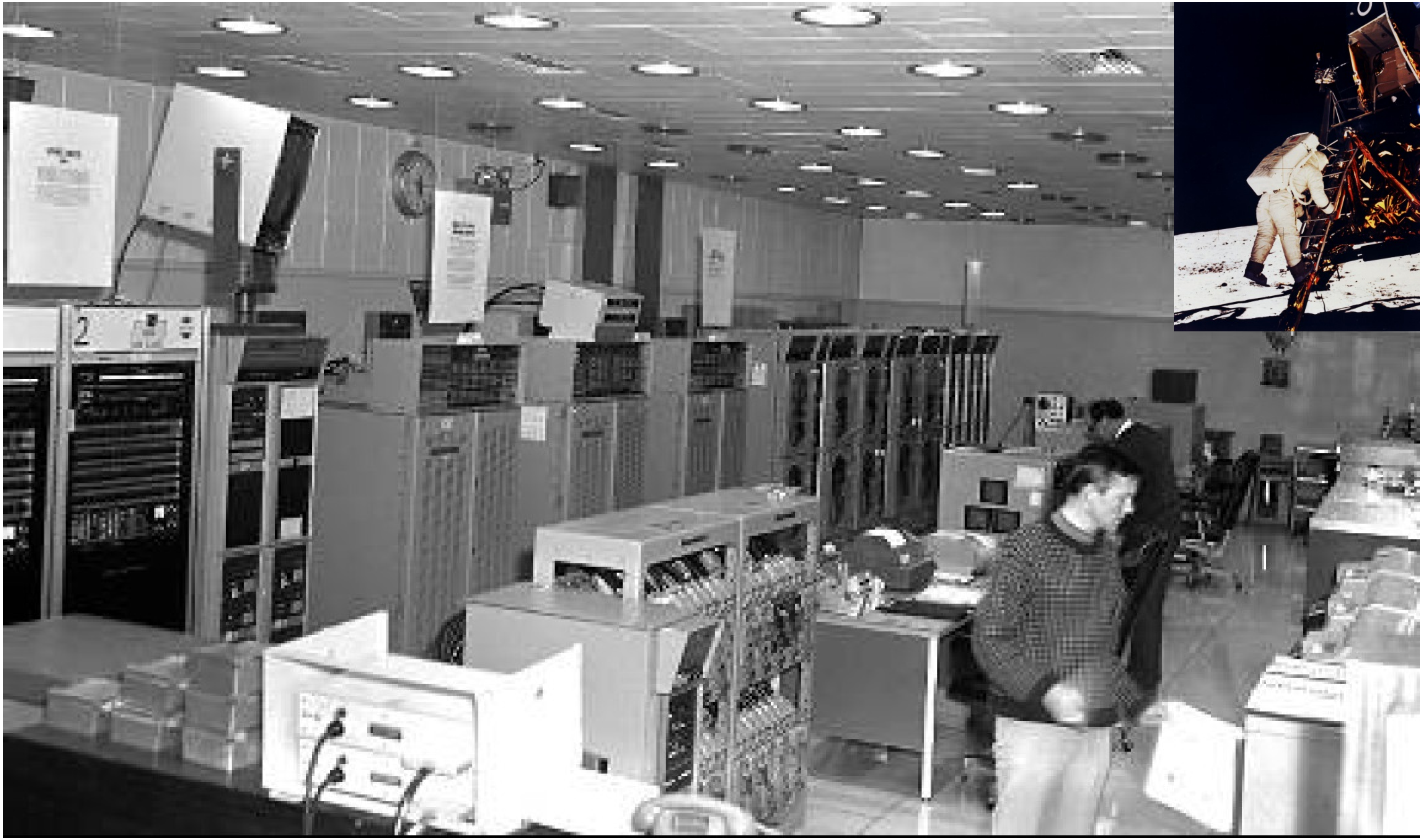


unicef




Moravec, 1997



2 Univac 642B, 10kFlop, 64kB each (Apollo Goddard Command Center ~ mid 1960's)

IBM Bluegene/P 'Dawn' (2009) --- prototype for Bluegene/Q 'Sequoia'
0.5 PFlop, 10^5 nodes (4x10^5 cores), 1PB, 10MW

Sunway TaihuLight (China), world’s fastest supercomputer

93 petaFLOPS, 40960 nodes, 10.6 Mio. cores, 1.31 PB Memory, Power Usage: 15 MW

An 83,000-Processor Supercomputer Can Only Match 1% of Your Brain

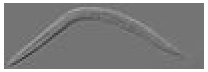
2013-08-13 12:35:45+00:00

(0 comments)

You've undoubtedly heard over and over again about what an absurdly complex entity the human brain is. But a new breakthrough by Japanese and German scientists might finally drive the point home. Taking advantage of the almost 83,000 processors of one of the world's most powerful supercomputers, the team was able to mimic just one percent of one second's worth of human brain activity—and even that took 40 minutes.

Enter the Fujitsu K computer, which while no longer the world's fastest (it was the top-ranked supercomputer in the world in 2011, and now sits in the four-hole), is still a massively powerful beast. To mimic this relatively minuscule amount of brainpower, researchers used the Fujitsu K to connect a total of 1.73 billion virtual nerve cells by 10.4 trillion virtual synapses (with 24 bytes of memory in each synapse). In total, this added up to around one petabyte of memory, which is the equivalent of about 250,000 standard PCs. And remember, all that's still just one percent of what your brain does every single day, in the time it takes to blink a few times.

Number of Nerve Cells



C. Elegans
302

Fruit fly
100,000

Honey Bee
960,000

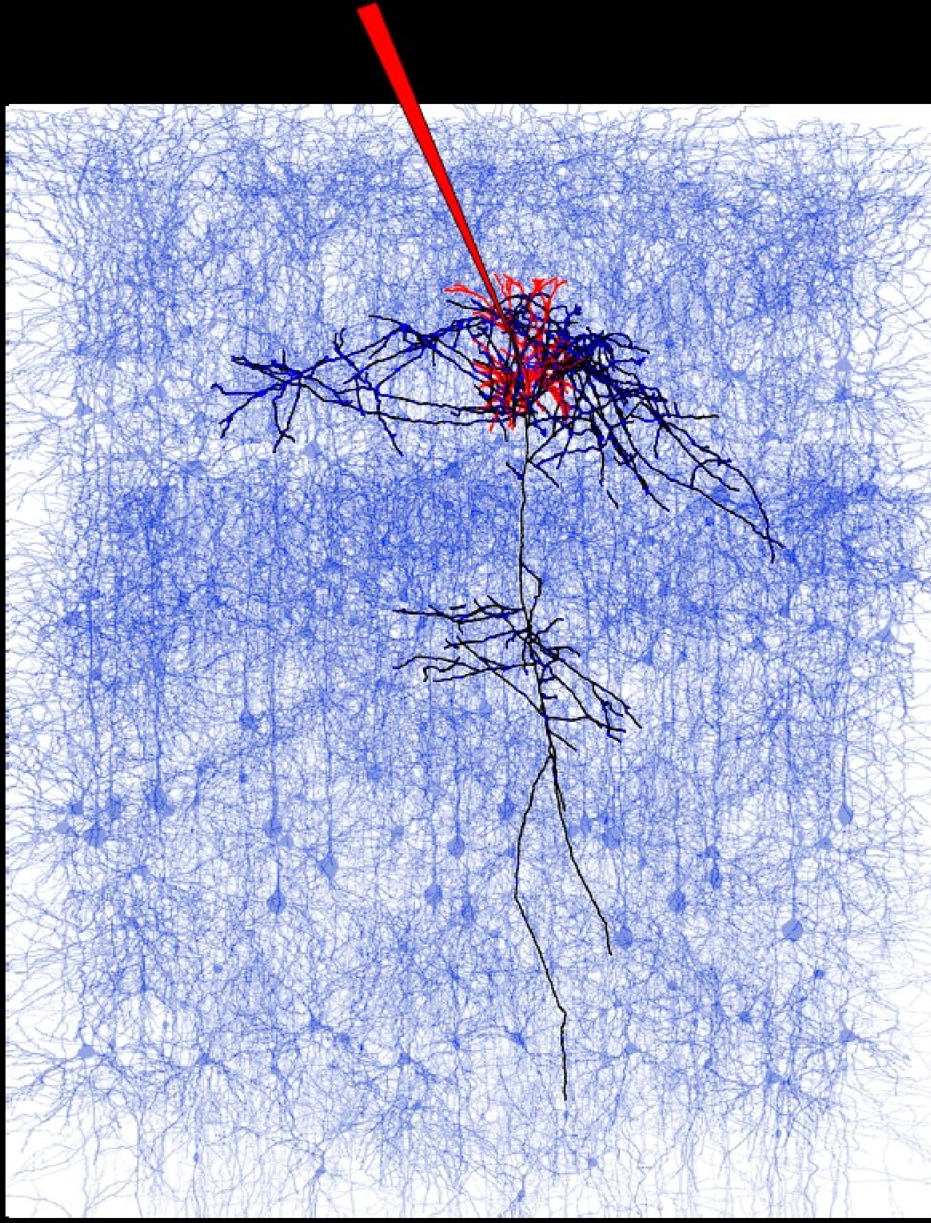
Frog
16 Mio.

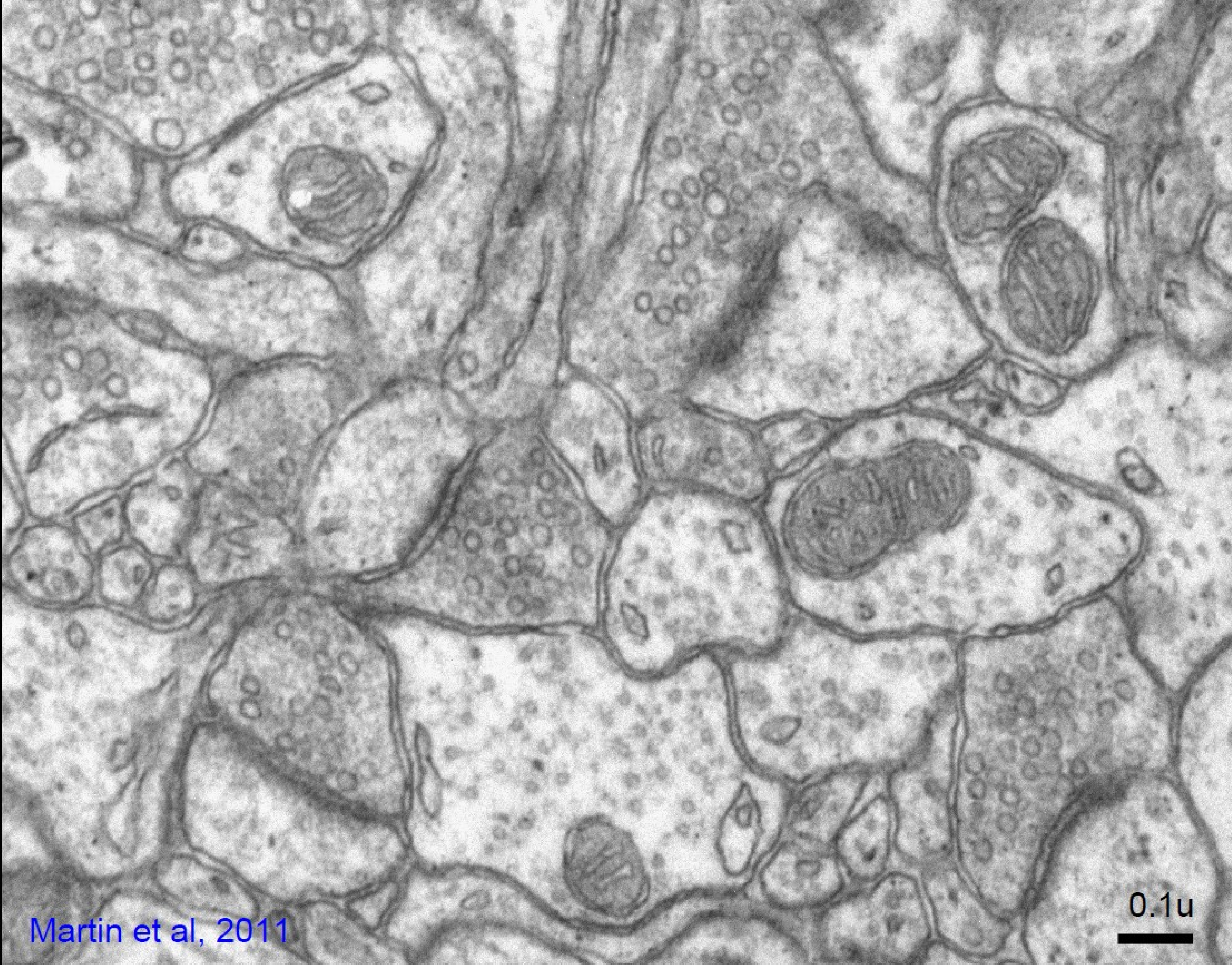
Mouse
75 Mio.

Cat
1 Billion

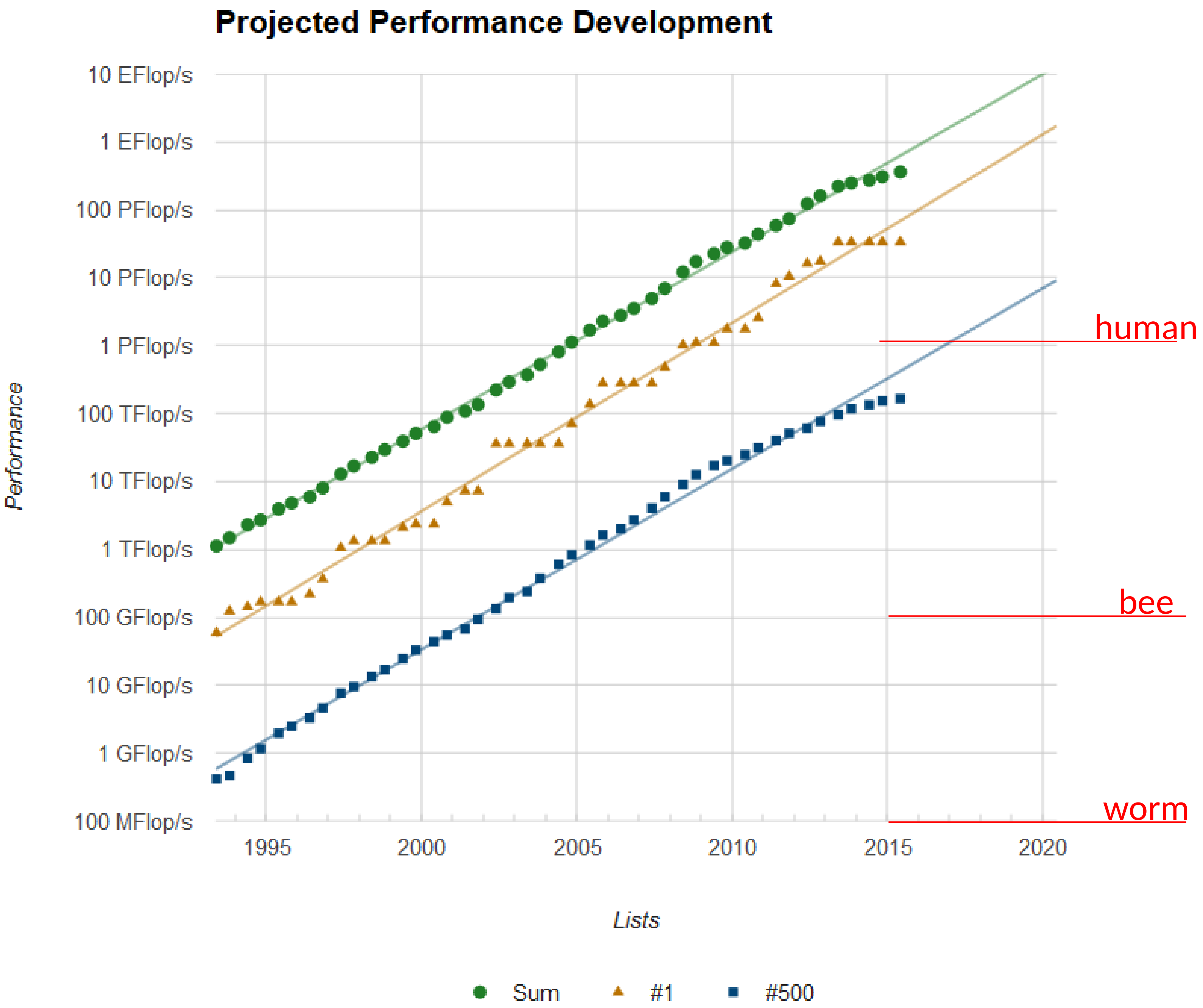
Chimpanzee
6.7 Billion

Human
~85 Billion



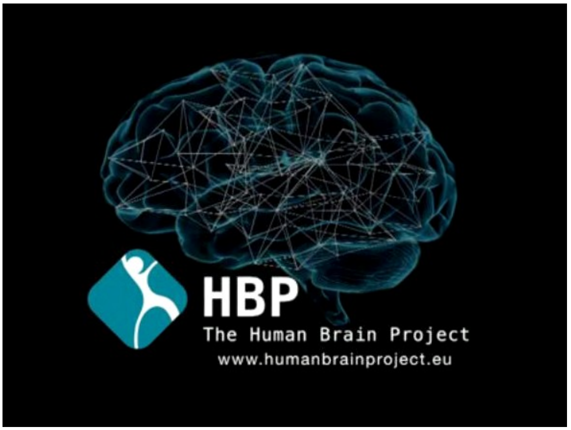


Martin et al, 2011



www.top500.org

Human Brain Project



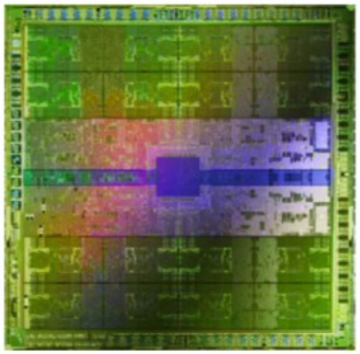
1 billion Euro, 10-year project, started 2013, hosted at EPFL Lausanne

Goal: simulation of the entire human brain on supercomputers

The era of «Big Brain Projects»

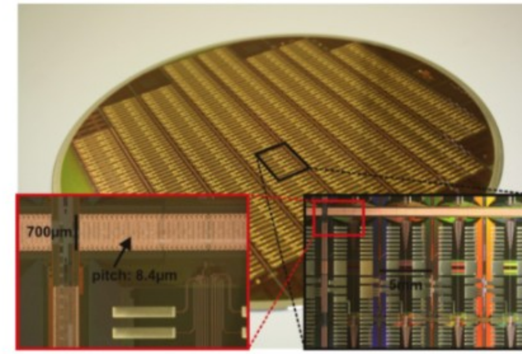
- Connectome projects
- BRAIN initiative
- Allen Brain Institute
- …

Neuromorphic Chips

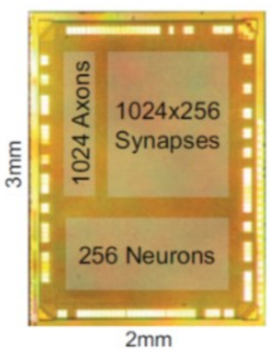


SW simulated neural networks (CPUs, GPUs).

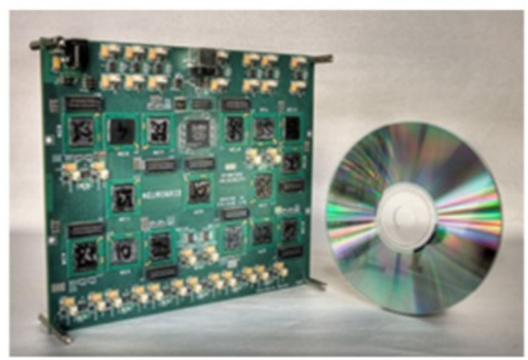
Real-time ARM-based neural network simulator (SpiNNaker).



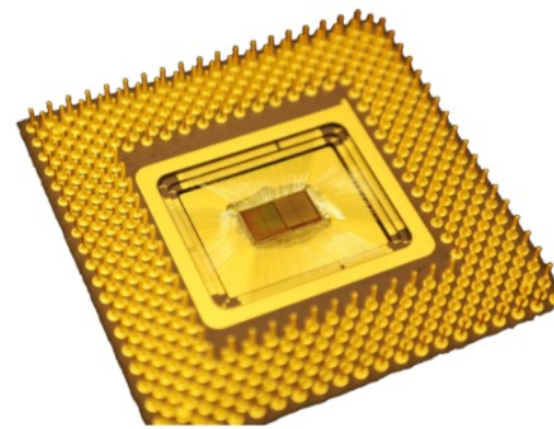
Wafer-scale analog neural accelerators (BrainScaleS).



Fully digital *cognitive computing* chips (TrueNorth).

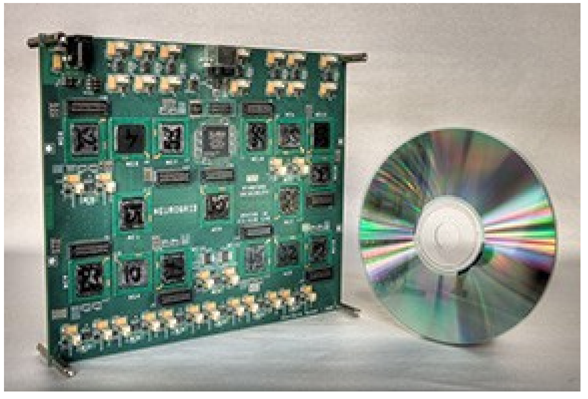


Real-time neuromorphic large-scale system (NeuroGrid).



Real-time on-line learning neuromorphic chips (ROLLS)

Neurogrid



Hosted at Stanford University (K. Boahen)

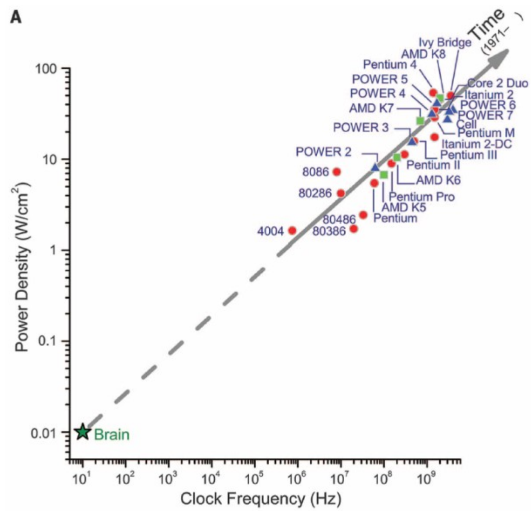
Emulation of 1 Mio. neurons, 6 billion synapses, in mixed analog and digital hardware

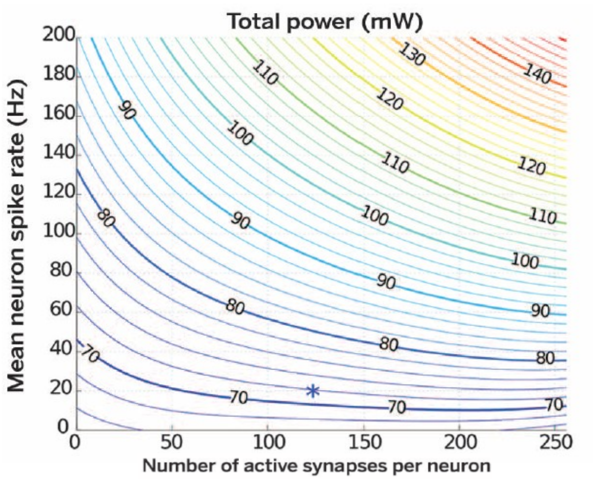
Real-time performance

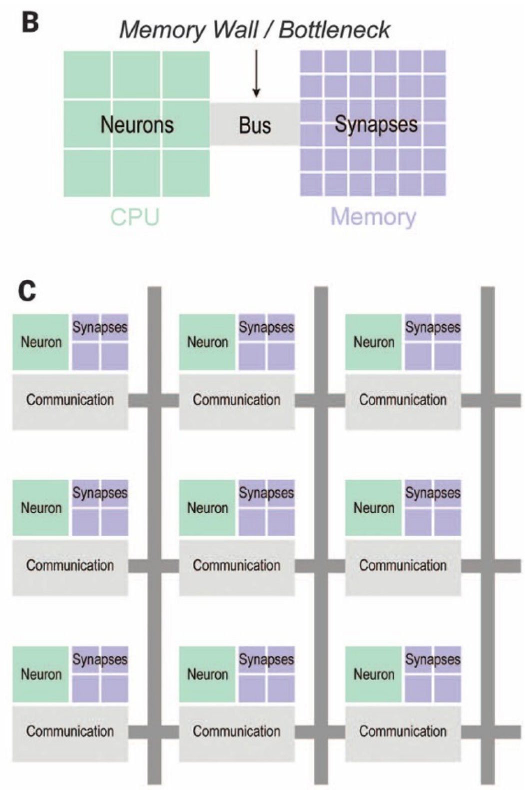
5W energy consumption – 100,000 times less than a supercomputer

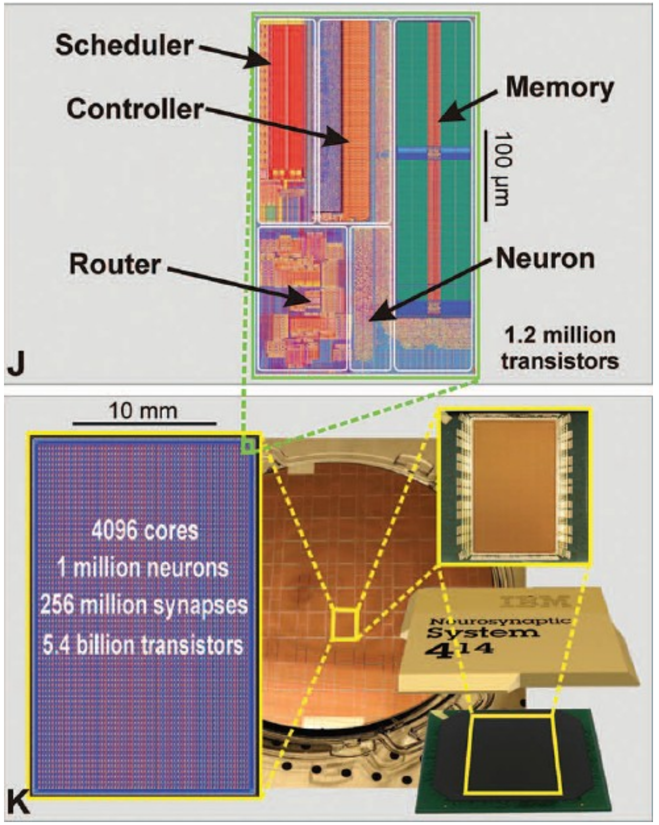
✉ **Neuromorphic Engineering**

IBM TrueNorth



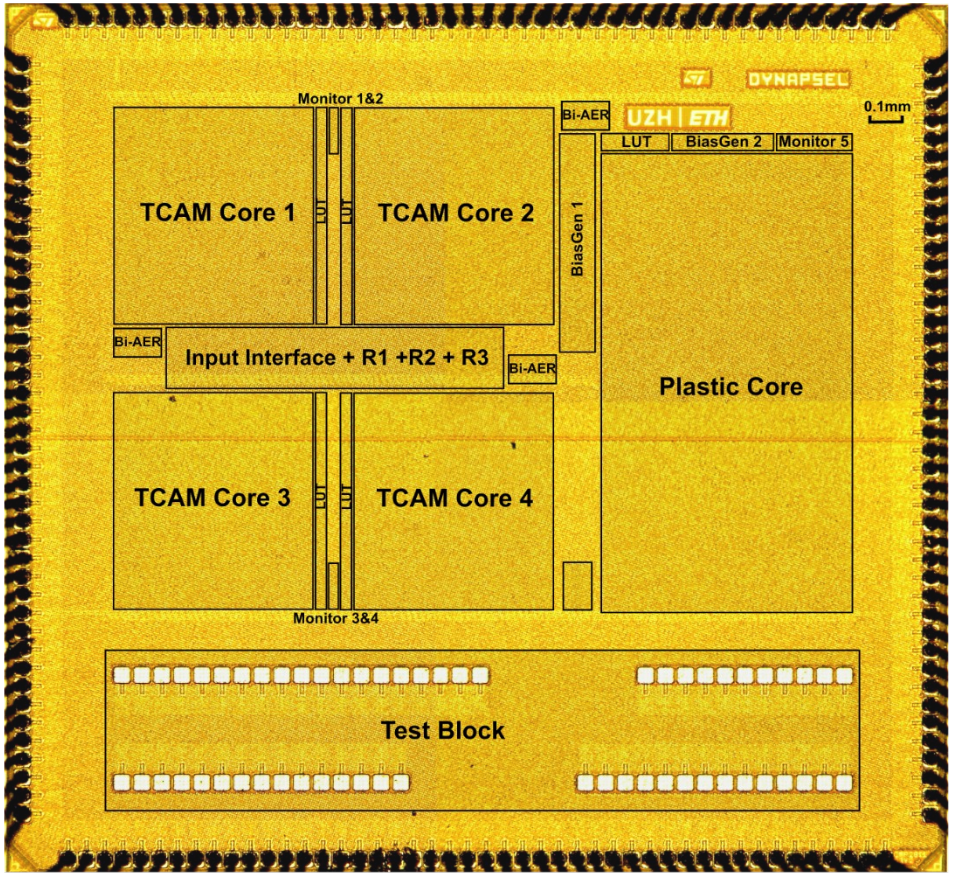






Merolla et al. 2014

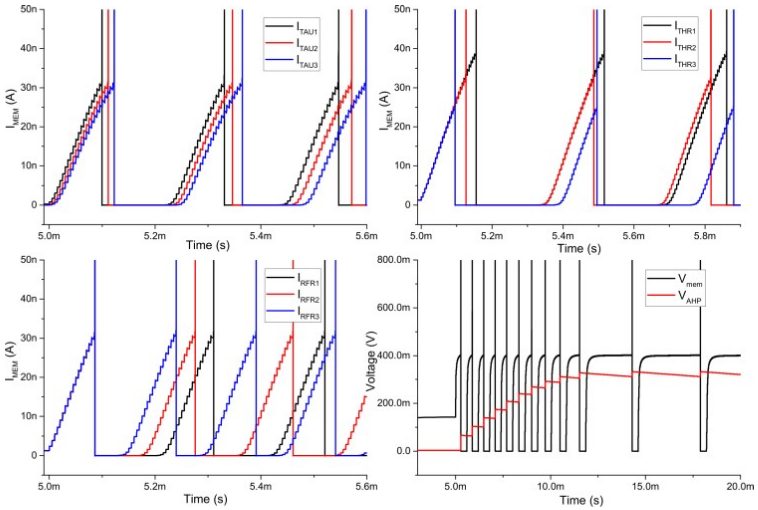
Dynap-SEL

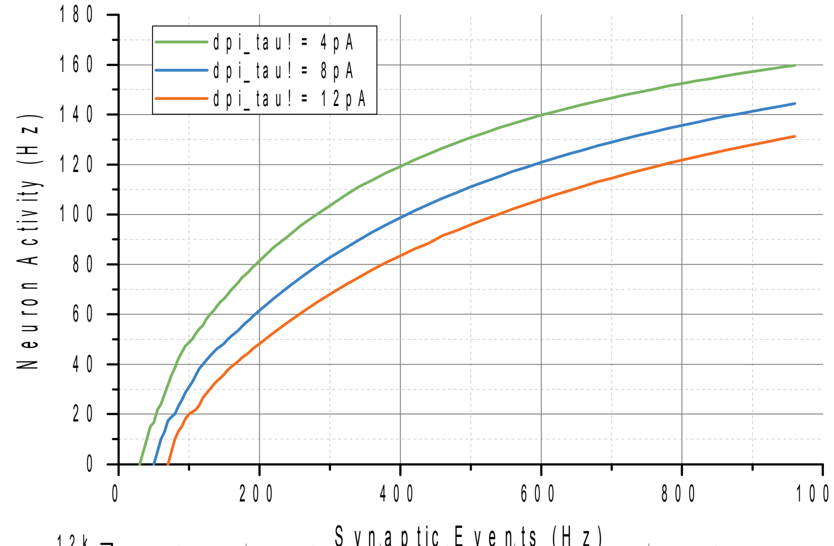


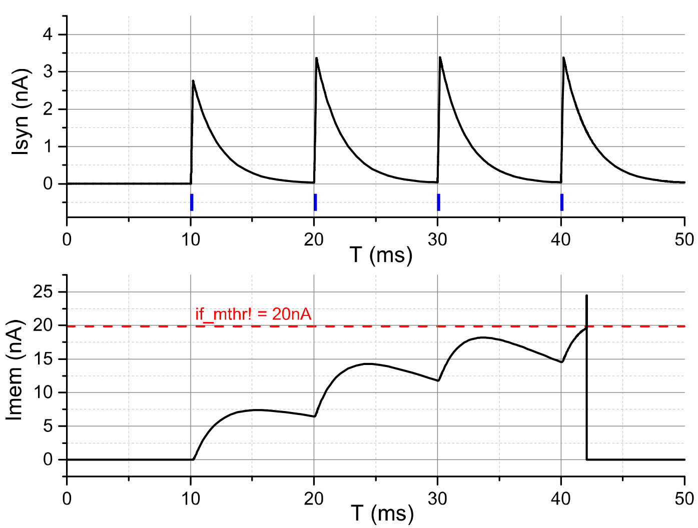
28nm FDSOI process. It occupies an area of 7.28mm², comprising 4 TCAM-based cores and 1 plastic core. Each TCAM core has 256 neurons and 16k TCAM-based programmable synapses, while the plastic core has 64 neurons with 4k plastic synapses and 4k programmable synapses.

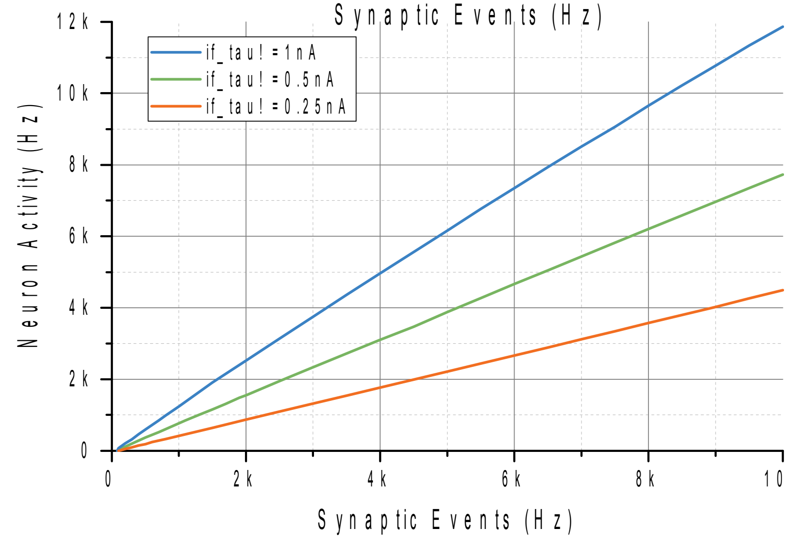
Chip Name	Dynap-sel
Process	ST 28nm FDSOI
Supply Voltage	1V
IO Number	176 + (internal 59)
Chip area	2.8mm x 2.6mm
Core Numbers	4 non-plastic cores 1 plastic core
Neuron Type	Analog AExp I&F
Neuron Area	20um²
Non-plastic Synapse Type	TCAM based 4-bit weight
Non-plastic Synapse Area	7.69um²
Plastic Synapse Type	Linear 4-bit weight
Plastic Synapse Area	72.5um²
Throughput of Router	1G Events/second
Scalability	16 x16 chips non-plastic core) 4 x4 chips (plastic cores)

Dynap-SEL neurons









Summary

- Brains as information processors
- What's special about the human brain?
- Key differences between brains and computers
- Artificial intelligence often modeled after nervous systems
- Today's largest computing systems exceed the capacity of brains, but need far more power
- Complexity of nervous systems is not matched in computer simulations
- Genetic information does not contain exact building plans
- Implicit vs. Explicit construction