How Physics Limits Intelligence?

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27 April 2016

Overview

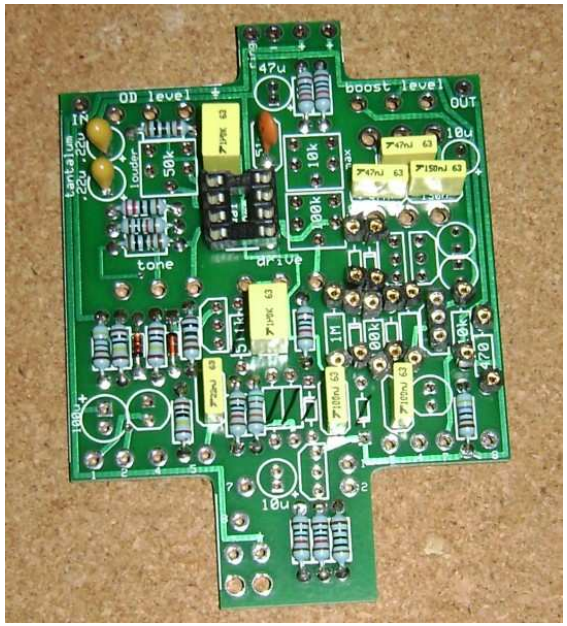
Computer vs. Brain

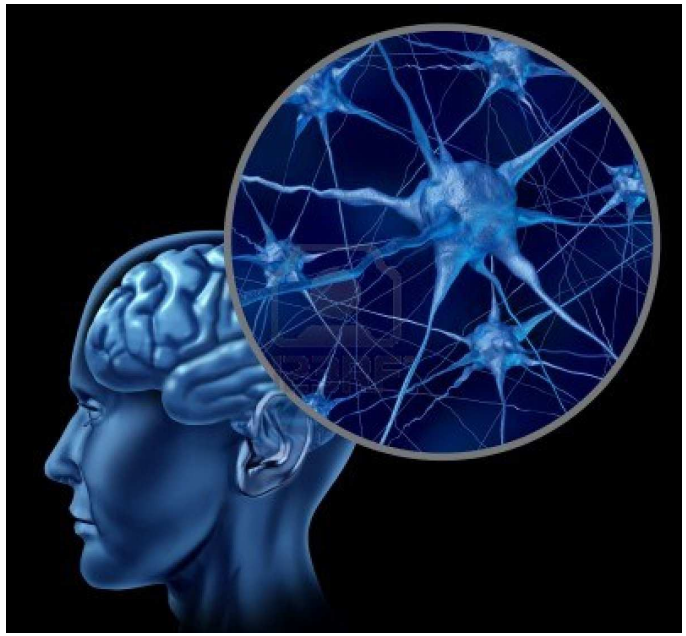
Core of the computer we have miniature "brain cells" called Transistors

Transistors are switches: made from silicon

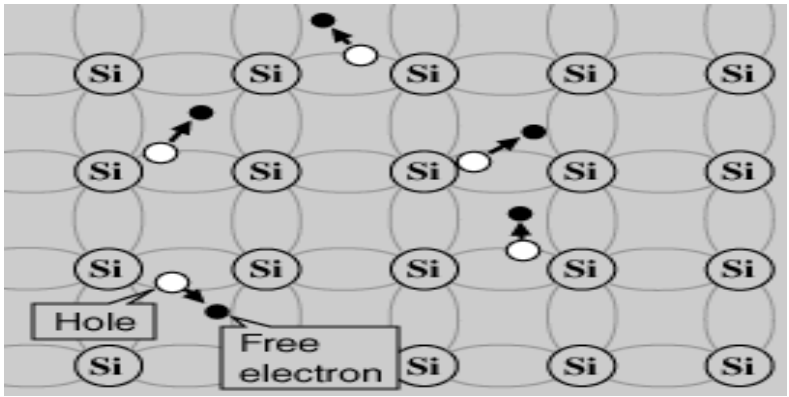
Core of the brain we have 100 billion cells called Neurons

the tiny switches: think and remember things





How is a transistor made?



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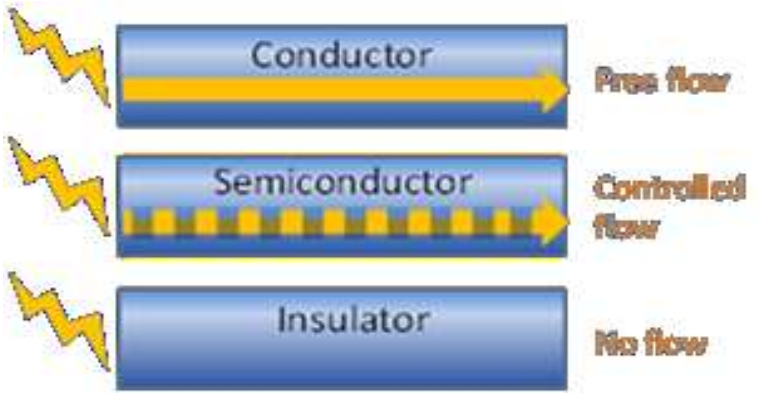
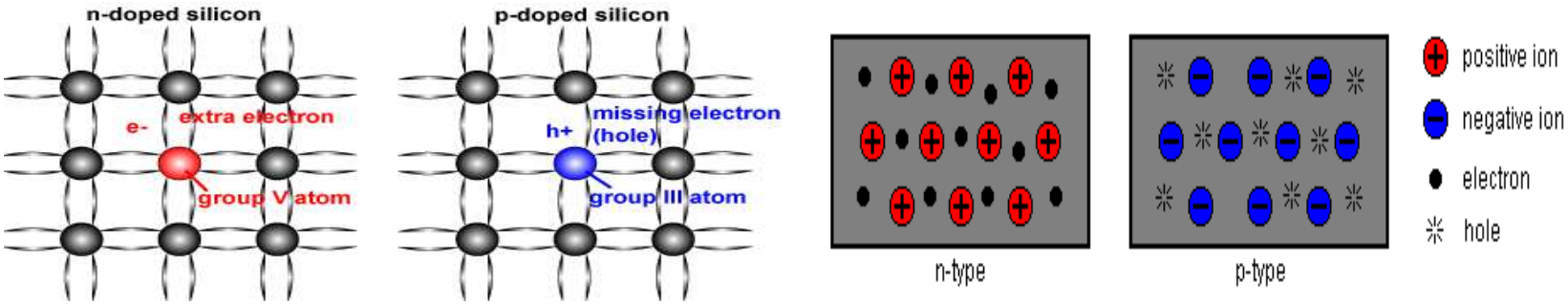


(d)

- Made from silicon: a chemical element found in sand
- Semiconductor: neither really a conductor nor an insulator

Changing the Behavior of Silicon with Impurities:

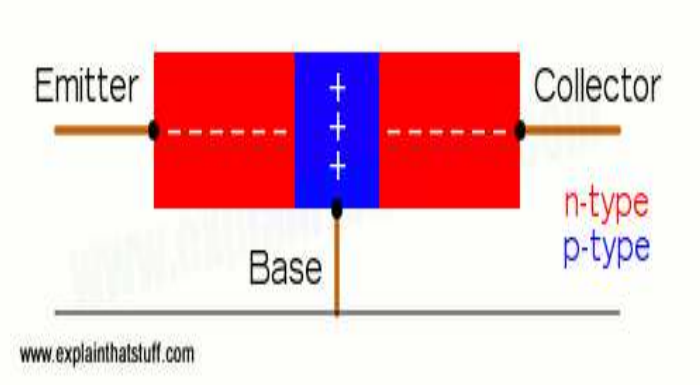


(e) (f)

Above process is known as doping:

- n-type: doped by Arsenic, Phosphorus or Antimony (silicon gain extra free electrons)
- p-type: doped by Boron, Gallium or Aluminum (silicon gain extra free holes)

Doped Silicon Sandwiches Works as a Transistor:



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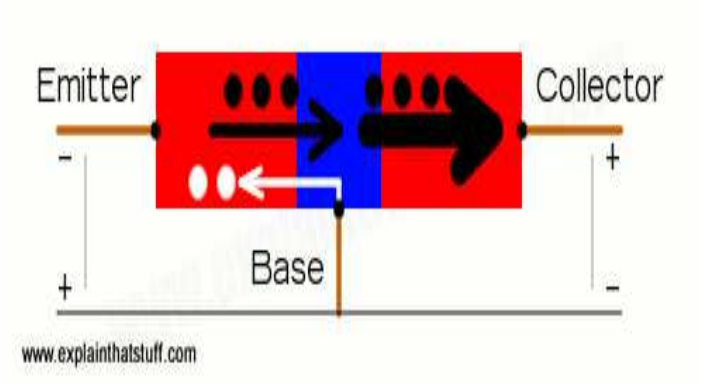
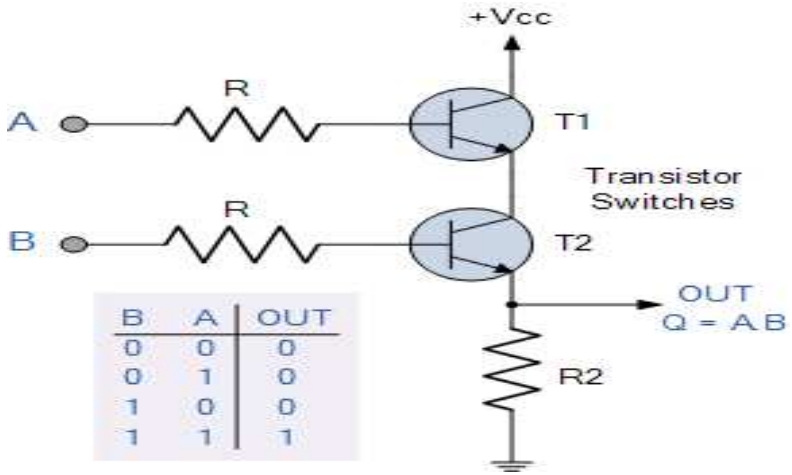


(h)

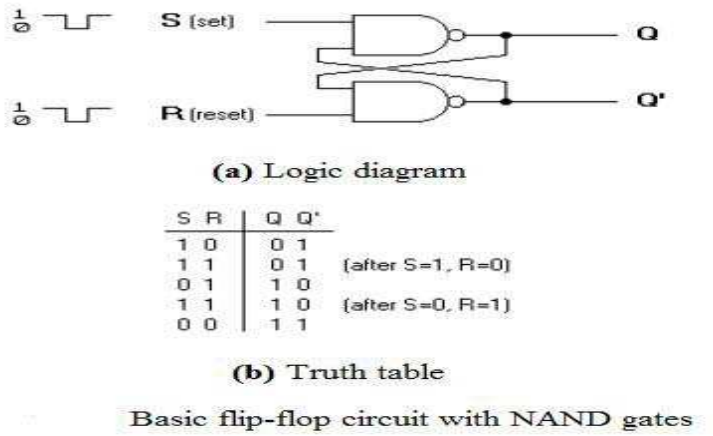
Attach a small positive voltage to the base

- Electrons are pulled from the emitter into the base and then from the base into the collector and the transistor switches to its ON state.
- So the base current switches the whole transistor ON and OFF.

How Do Transistors Work in Computers?



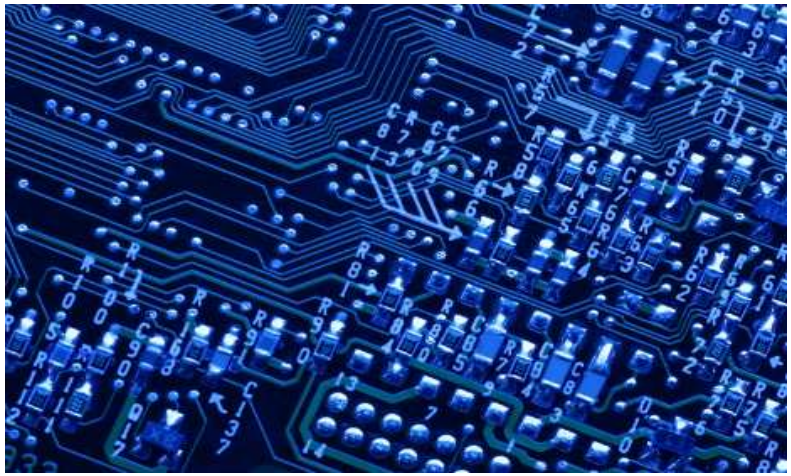
(i)



(j)

- Logic gates: few transistors switches together (make simple decisions based on Boolean algebra)
- Flip-flop: output connection feedback into their inputs (transistor stays ON or OFF even when the base current is removed)
- Flip-flop turns a transistors into a simple memory device that stores a zero (when it is off) or a one (when it is on).

Memory chips



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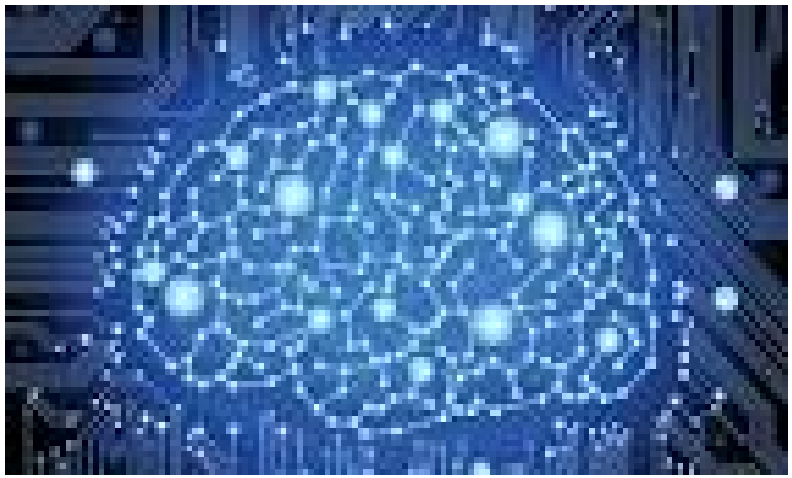
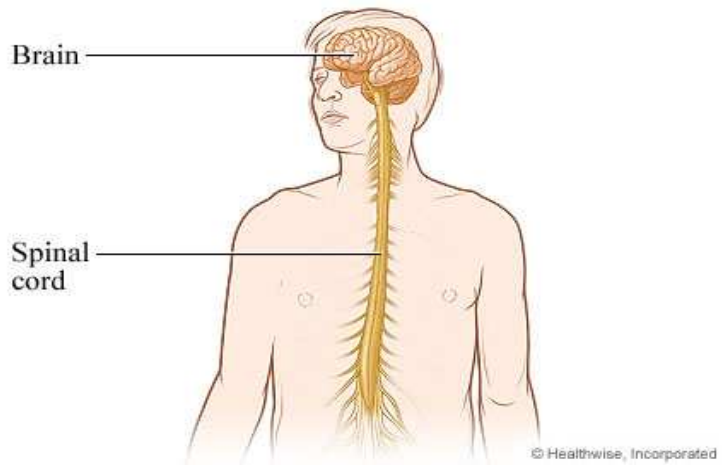


(l)

- A memory chips contains hundreds of million or even billions of transistors.
- Each transistors can be in two states (zero or one).
- With billions of transistors, a chip can store billions of zeros and ones.

Central Nervous System(CNS) and Neurons



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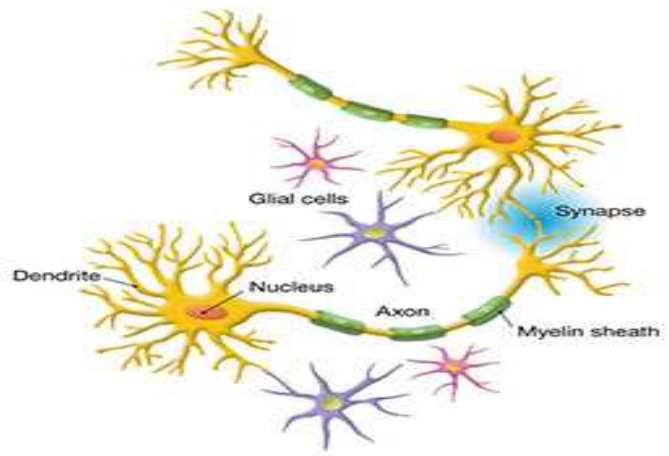
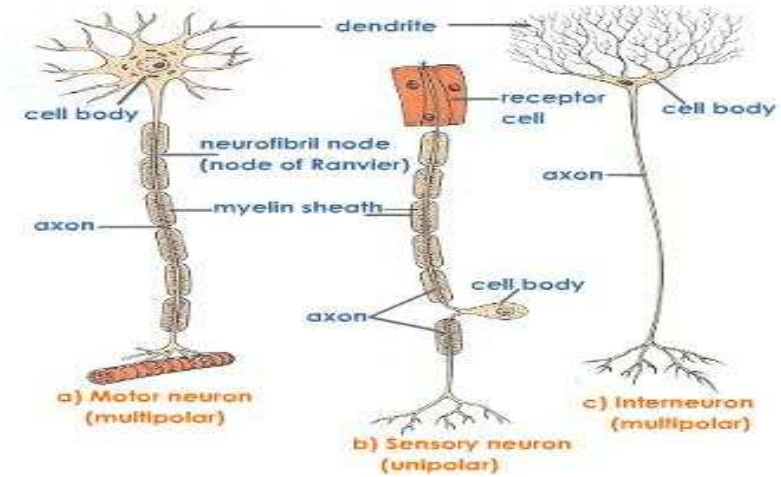


(n)

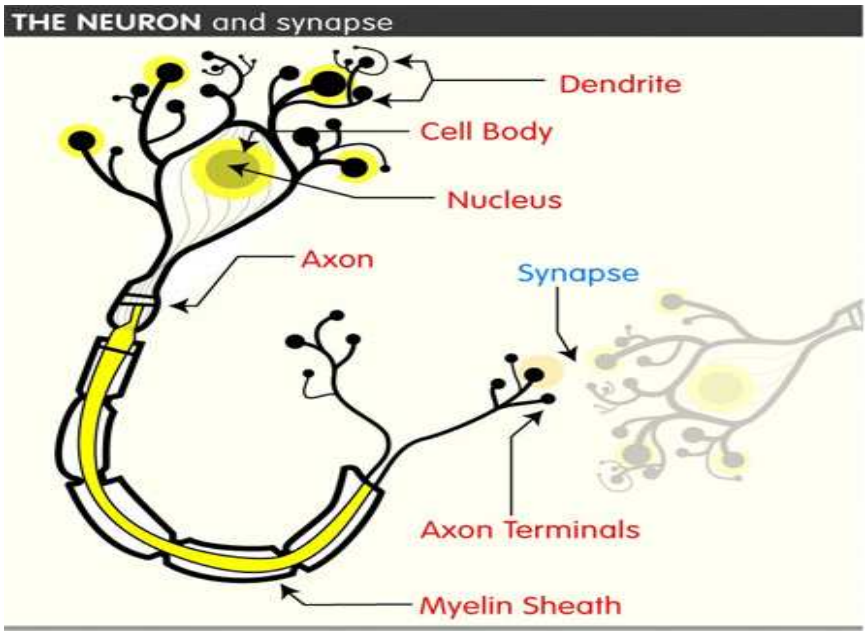
- CNS is composed of two kind of specialized cells: Neurons and Glia
- Function of neuron: to receive "INPUT" information from other neurons to process that information, then send information as "OUTPUT" to other neurons
- Neurons are the basic information processing structures in the CNS.

Three Kinds of Neuron



- Motor neurons: for conveying motor information (through which we are able to move)
- Sensory neurons: for conveying sensory information (to see, to hear, to smell, to taste and to touch)
- Inter neurons: which convey information between different types of neurons (cognitive information like think, dream, remember etc.)

Neuronal Signaling



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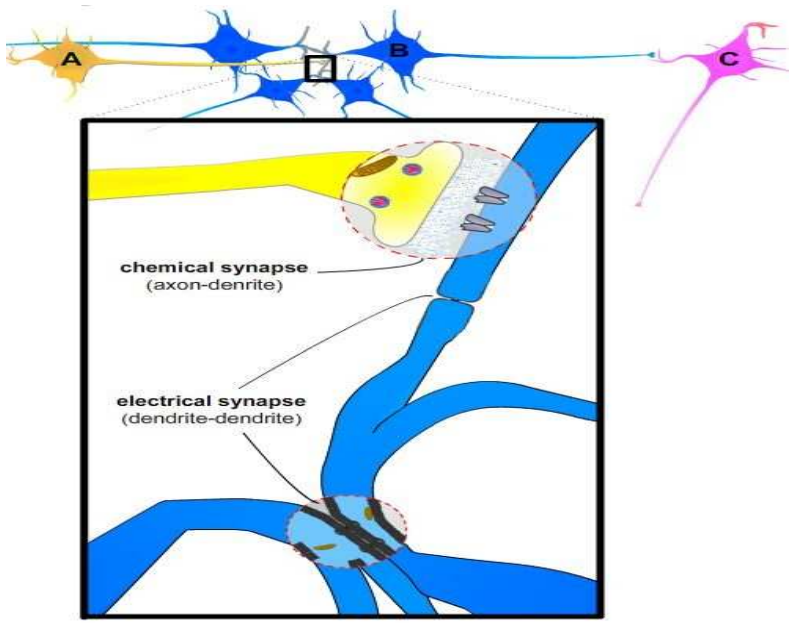
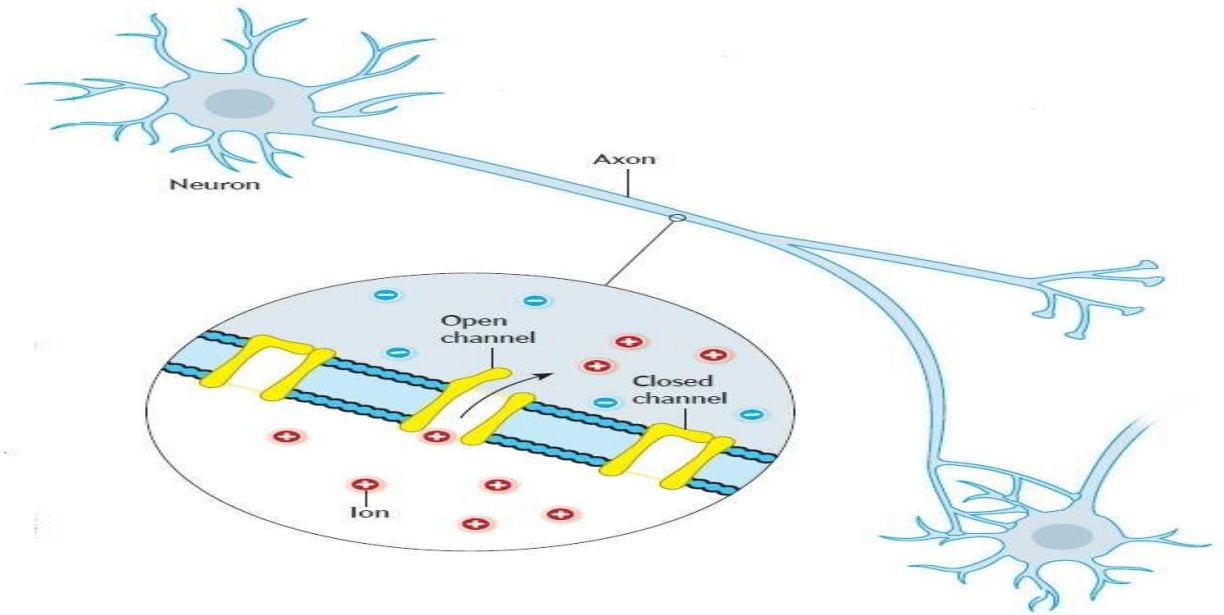


(p)

- Intracellular signaling: communication within the cell (conduction)
- Inter-cellular signaling: communication between the cell (neurotransmission)

Axons



- Axons enable neurons to form networks.
- When a neuron fires, it sends an electrical signal down its axon.
- The signal travels down the axon by opening ion channels embedded in the cellular membrane, which let ions through.
- When enough ions cross a channel, they change the voltage across the membrane, which it turn causes the channels nearby to open in a domino effect.

The Physics of Thought

- Just as shrinking transistors makes computer more powerful,
- brains with smaller component could, in principle pack in more power and become faster.
- Human neurons, however-and in particular, their long "tails," called axons may already be at (or close to) their physical limit.

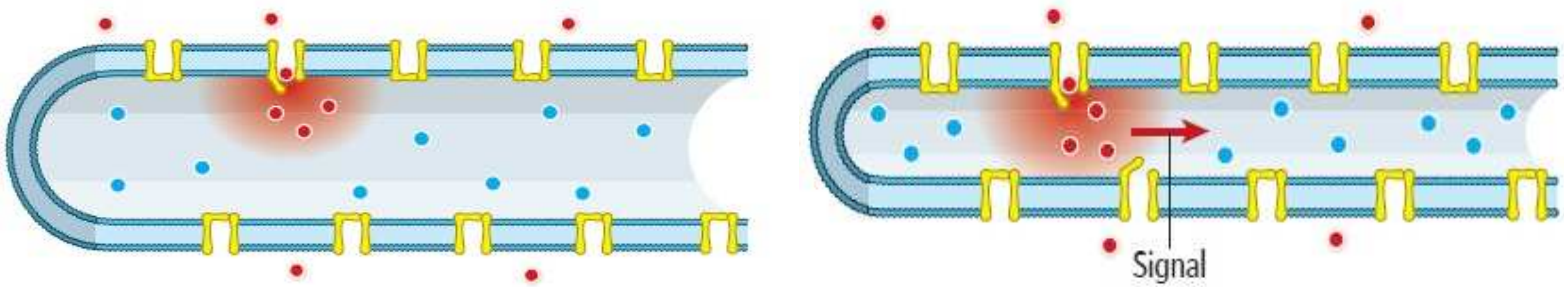
Hungary tapeworm in your head

Brain, our most energy-consuming organs: Representing only 2 percents of the weight of body, consumes 20 percents of the energy produced by the body.

Information, noise and energy are inextricably linked during communications

That connection exists at the thermodynamic level (mechanical+thermal+chemical equilibrium).

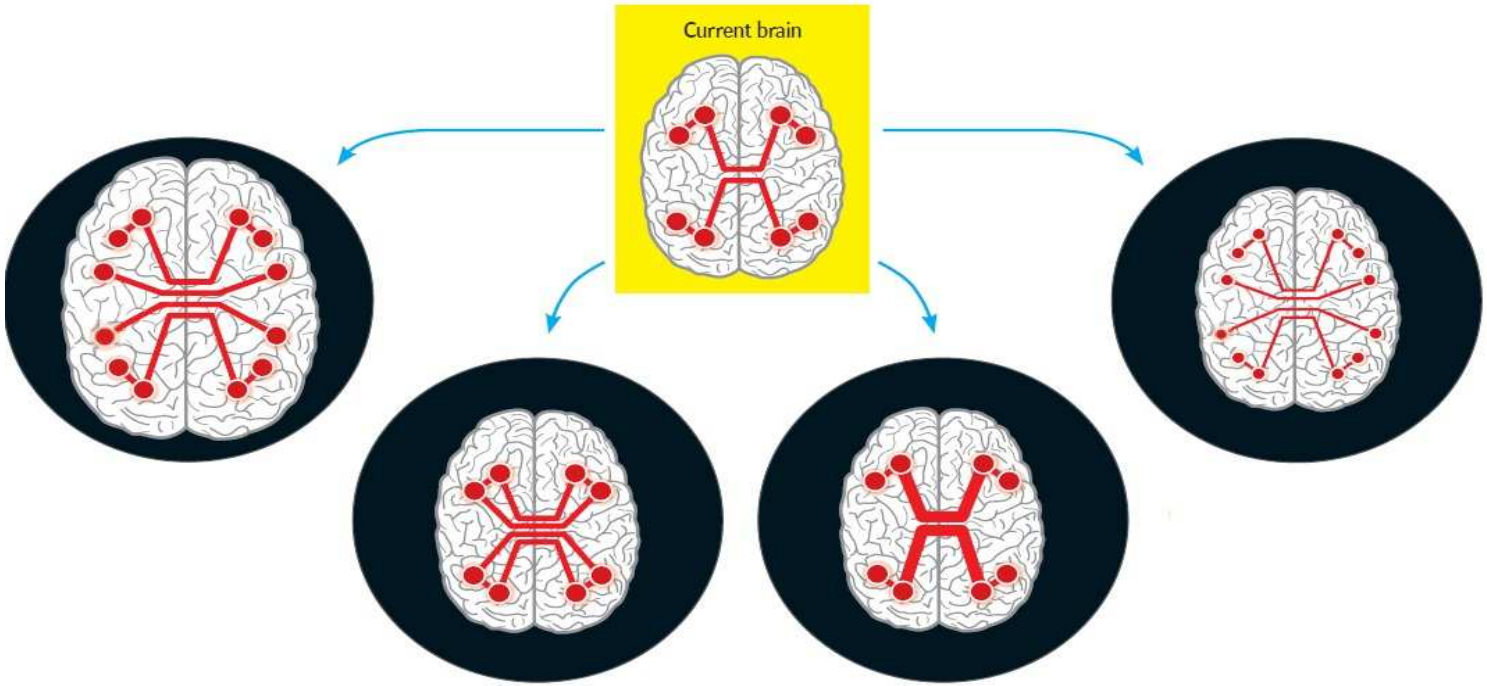
Inconsequential Blips and Unintended Cascade



(q) (r)

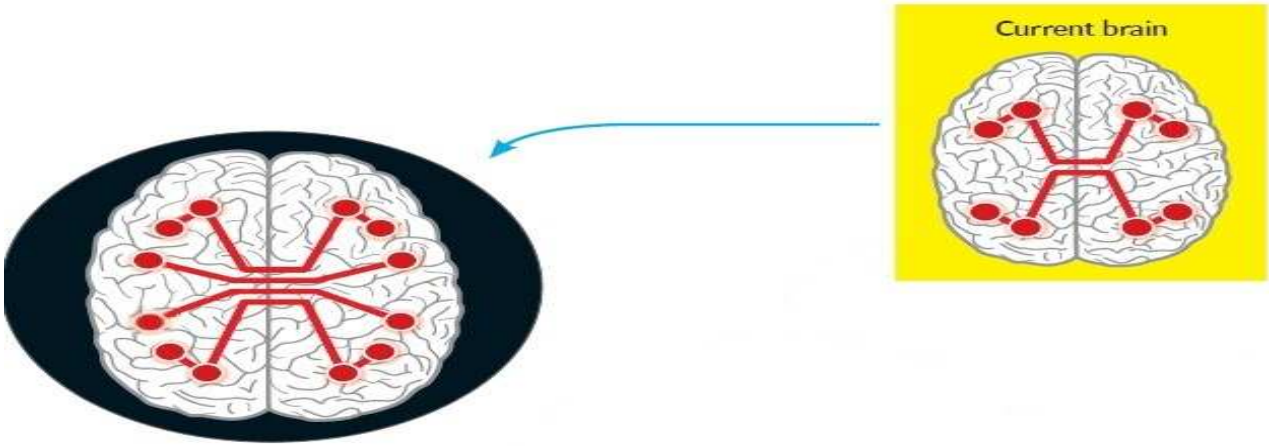
- Thinner axons would save space and consume less energy.
- Nature, however, seems to have made them already nearly as thin as they can be
- any thinner, and the random opening of the channels would make axons too noisy
- meaning that they would deliver too many signals when the neuron was not supposed to fire.

Why We Probably Cannot Get Much Smarter?



- Increase brain size,
- Increase interconnectedness,
- Increase signaling speed,
- Pack more neurons into the existing space.

Evolutionary Tweaks and Thermodynamic Hurdles



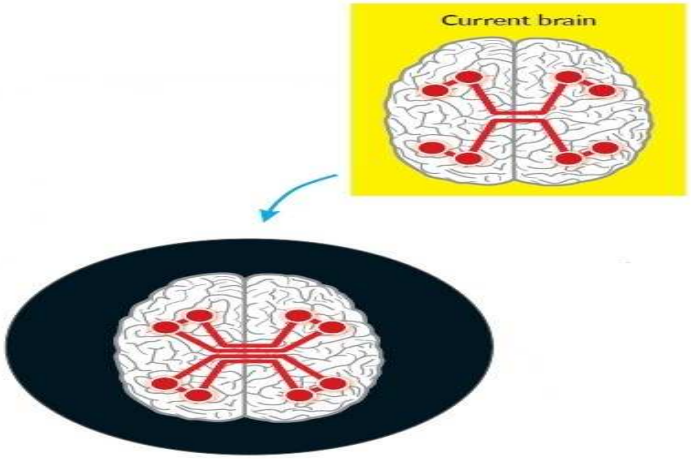
TWEAK: Increase brain size

Enlarge size by adding more neurons increases processing capacity

TRADE-OFFS

- Neurons consume a lot of energy
- And as brains get bigger, the axons, or "wires", that connect neurons have to become longer, which make the slower.
- Results: (1) Slows processing (2) Costs too much energy

Evolutionary Tweaks and Thermodynamic Hurdles Cont...



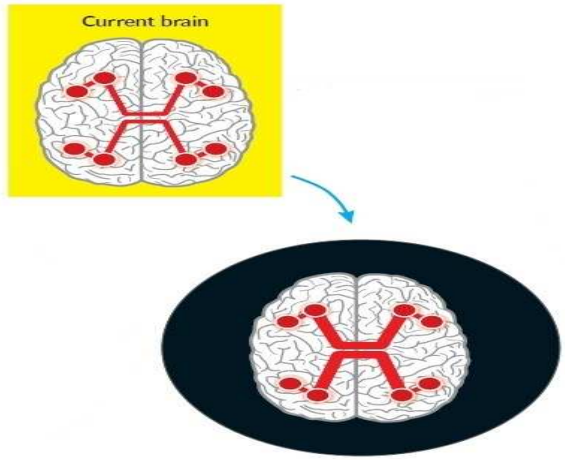
TWEAK: Increase interconnectedness

Adding more links between distant neurons enables brain parts to communicate faster

TRADE-OFFS

- The added wiring eats up energy (and takes up space)
- Result: Costs too much energy

Evolutionary Tweaks and Thermodynamic Hurdles Cont...



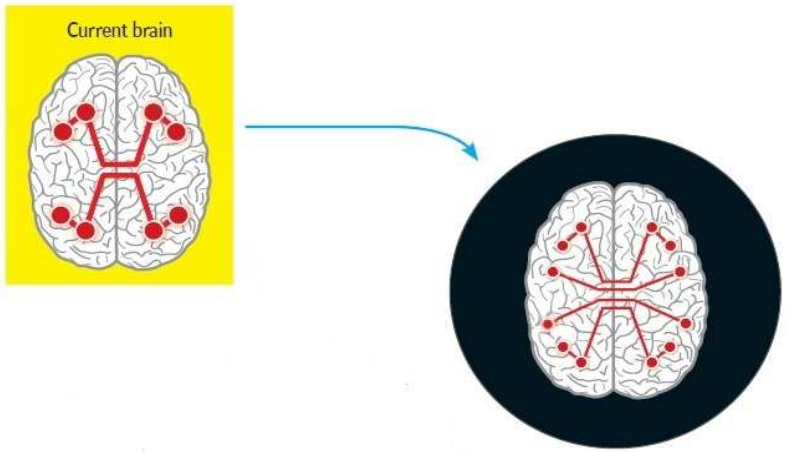
TWEAK: Increase signaling speed

Could be achieved by making axons thicker

TRADE-OFFS

- Thicker axons consume more energy (and take up more space) than thinner ones do
- Result: Costs too much energy

Evolutionary Tweaks and Thermodynamic Hurdles Cont...



TWEAK: Pack more neurons into the existing space

Achieved by shrinking neurons or axons, or both.

TRADE-OFFS

- If axons or neurons get too small, they tend to fire randomly
- Result: Signaling gets too noisy

Concluding Remarks

- Human Intelligence may be close to its evolutionary limit. Various lines of research suggest that most of the tweaks that could make us smarter would hit limit set by the laws of physics.
- Brain Size, for instance, helps up to a point but carries diminishing returns: brains become energy-hungry and slow. Better "wiring" across the brain brain also would consume energy and take up a disproportionate amount of space.
- Making wires thinner, would hit thermodynamic limitations similar to those that affect transistors in computer chips: communication would get noisy.

Perhaps we are already close to being as smart as a neuron-based intelligence can be.

The End