High Level Brain Functions and Structure Can Inspire Autonomous Systems with More General Intelligence

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IARIA

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Outline

Aims

- explore high level structure and functions provided by our brain
- use engineering intuition to inspire design of (more) general AI systems

Engineering intuition

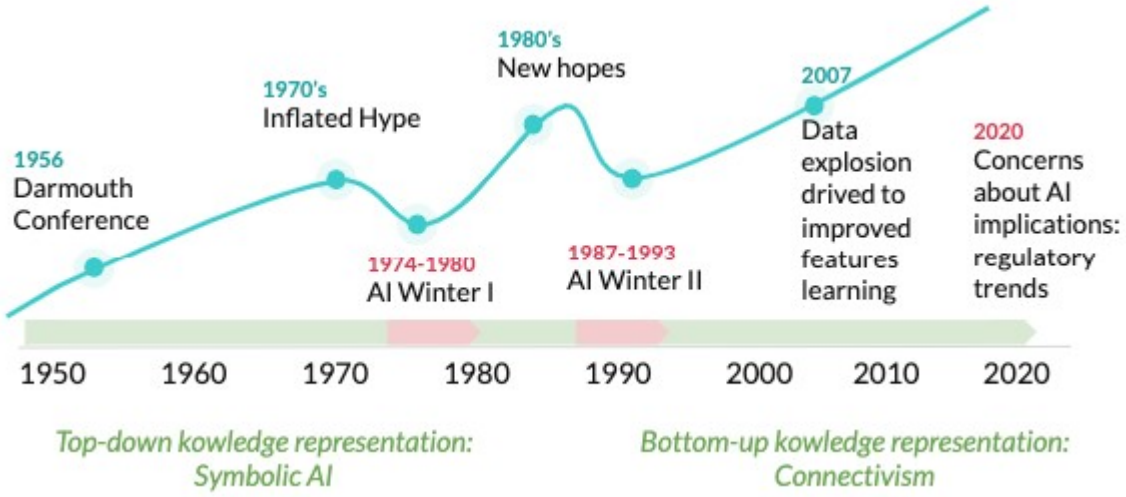
AI expectations

Current thinking

- plenty of research funding
- good servant but bad master
- regulations? safety?

Techniques

- deep and reinforcement learning
  → apparent limits
  → data and energy hungry
- causal inference
  → going beyond curve fitting
- need new breakthrough



finextra.com/the-long-read/62/what-should-be-taken-into-account-if-artificial-intelligence-is-to-be-regulated

General AI

My thinking

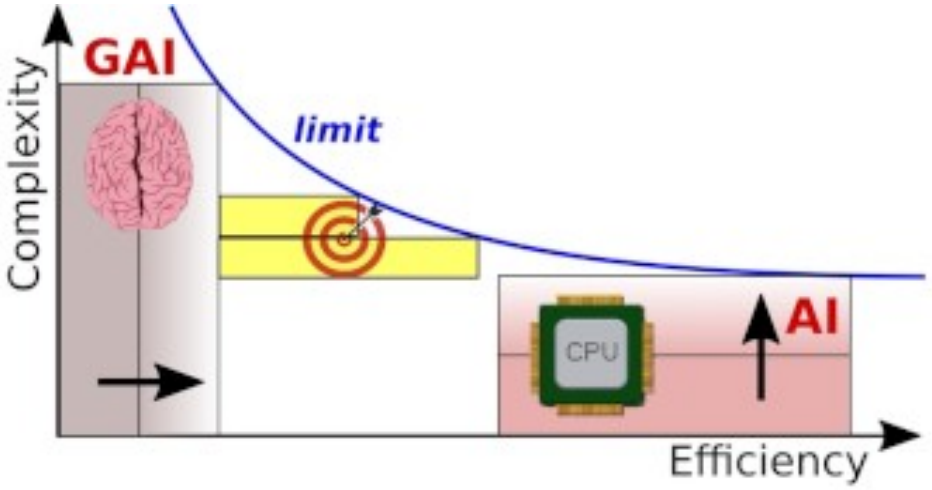
- statistical learning alone cannot lead to general AI
  → no matter of scale, there are limits what can be learned

- no widespread understanding of what general AI should be
  → what are we ultimately trying to build?

- the only system offering general AI is our brain
  → our brain is the most complex structure in the Universe
  → with certainty, no technology can ever create a structure with such complexity

- owing to 25 years of my engineering experience
  → processing data from brain scans useful, but it obscures the ultimate aims
  → let’s first explore high level organization and functions provided by brain
  → choose functions to be provided by the AI system, then think their implementation
  → even our brain cannot solve every possible problem

Problem solving: complexity versus efficiency



general
probabilistic
learning-based
abstract
algebraic
symbolic

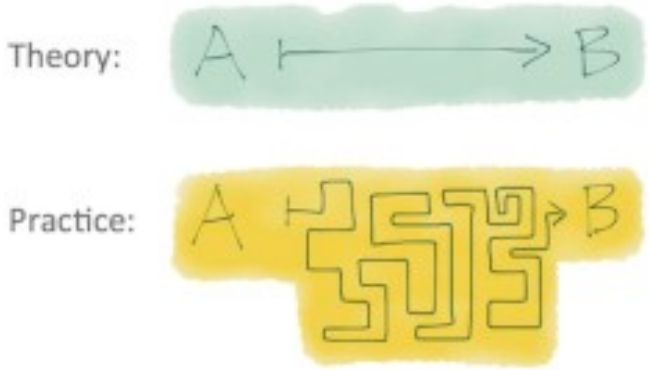
Methods

specific
deterministic
rule-based
quantitative
computational
numerical

Engineering complex systems

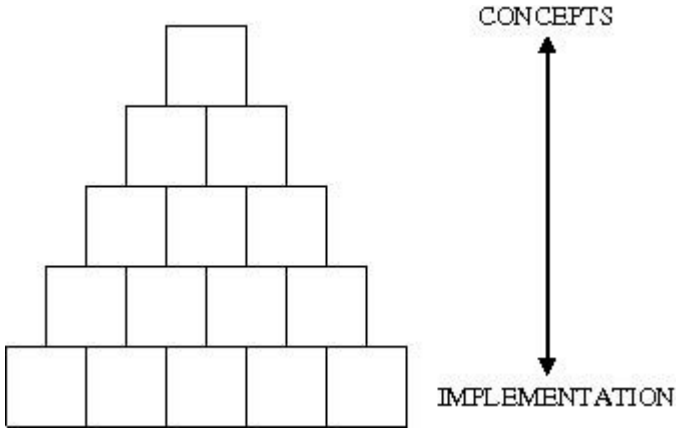
Enable evolution

- start from simple, good enough solutions
- add complexity to solve emerging problems
- example: building the Internet



Top-down evolution

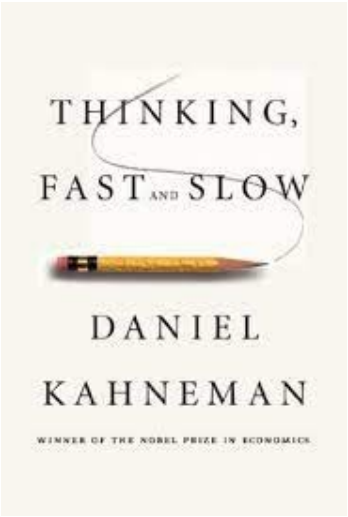
- start from theoretical limits (best possible)
- translate high level concepts to more detailed low level implementation
- break down complexity into smaller tasks



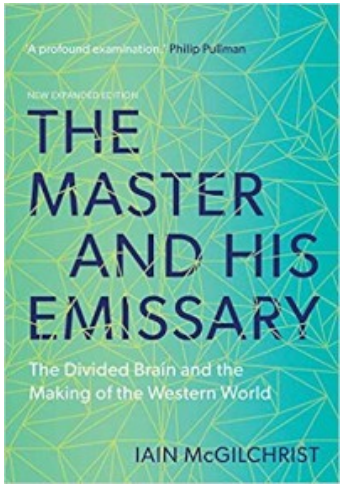
Bottom-up evolution

- heuristically improve existing solutions until reaching the ultimate limits
- integrate tasks into a complete system

References



Daniel Kahneman,
Israel



Ian Mcgilchrist,
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Control of Human Brain
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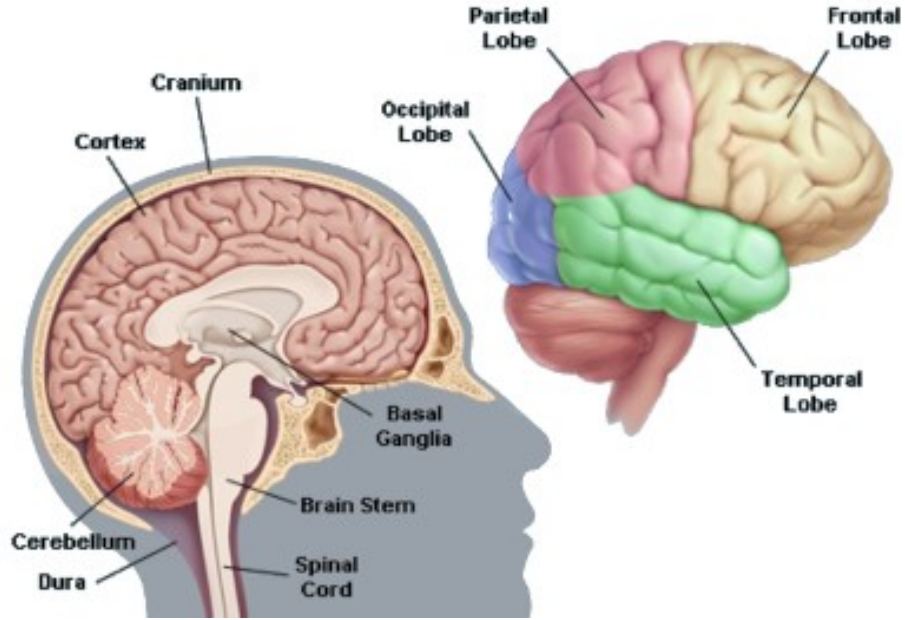
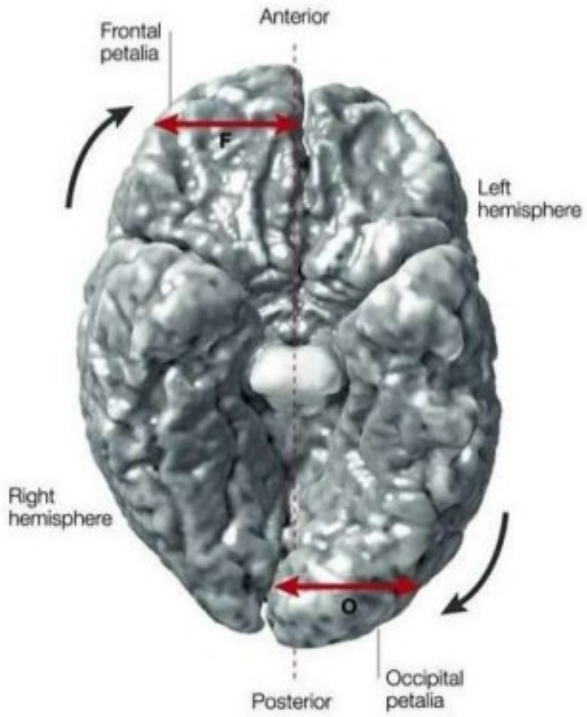
Human brain

Structure vs. function

- in biology, they are nearly the same thing
- high level organization of brain is simple and straightforward
- low level organization progressively more complex



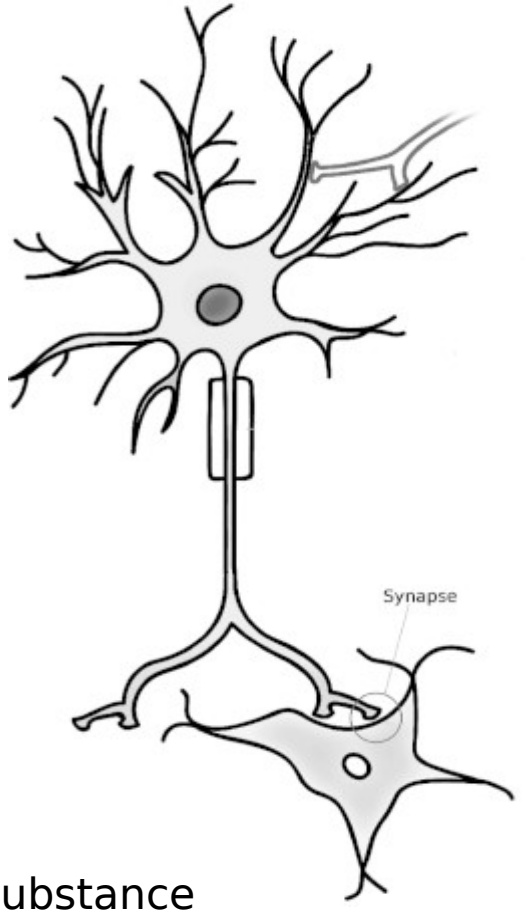


view from bottom

Human brain

Facts

- 100 billion neurons with 100 trillion synaptic connections
  → 1 neuron process signals from about 3,000 other neurons
  → signal-to-noise ratio close to theoretical minimum
- extreme plasticity (rewiring, pruning, self-repair)
- immune system recognizes brain as a foreign object
- interactions in multiple domains
  (chemical, mechanical, electromagnetic, quantum)
- data processing of 18+ sensory signal types
  (visual, acceleration, gravity, chemical, …)
- hardware and software is the same thing
- every single neuron is a supercomputer on its own



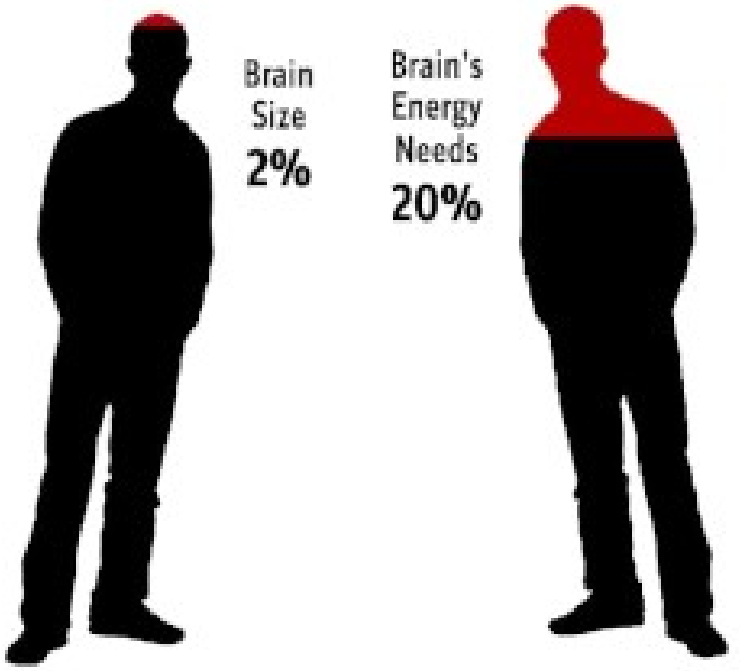
Engineering intuition

- implementation of general AI needs a great deal of biological substance
- purely technological solutions can only attempt to mimic some brain functions

Human brain energy demands

Facts

- least energy efficient organ in our body
- consumes between 9% to 20% of overall energy
  → waste from metabolism must be removed
  → store energy (food) whenever possible
  → varies substantially during day
- 30% of oxygen consumption at rest
- strive to keep consumption close to 9%
  → avoid thinking and reward it
  → prefer ready-made solutions
  → most of the time animal-level info processing



Engineering intuition

- energy efficiency must be resolved before attempting to implement general AI
- general AI must have sleep and idle modes
  → more problematic for biological systems
  → sparse AI systems?

Human brain capabilities

Facts

- total throughput of neocortex is 1 Terabite/sec
- memory unlimited?
- 99% of processes are in unconscious mind
  → most activities are automated
  → largely emotional decisions, rational thinking much less

Intelligence (IQ)

- 1 dimension among the brain capabilities
- increase in thinking efficiency (memory, speed) up to about IQ160
  → these skills can be trained
- above IQ160, emergence of complex thinking patterns
- emotions can drop IQ by 30 or more points

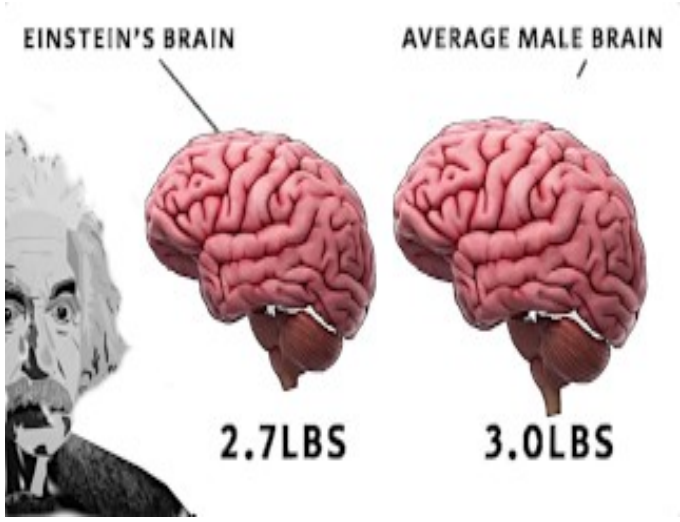
Daniel Tammet

Tammet set a record on March 14th 2004 when he recited the famous mathematical constant Pi (3.141...) to 22,514 decimal places from memory in a time of 5 hours, 9 minutes.

Engineering intuition

- development of general AI needs strong drivers
- general AI needs to implement complex data processing patterns

Human brain evolution



Facts

- unstable, chaotic but extremely fast via artificial selection
  → only 4.5 mil. years (birds needed 80 mil. years to fly)
  → goals of artificial selection change over time
- weight peaked 150,000 years ago at 1650g
  → slow decline till 200 years ago (Industrial Revolution)
  → then faster decline, now 1350g
  → milestones: speech, writing, book printing, IT revolution
- decoupled from body evolution
  → all humans identical bodies (phenotype)
  → massive differences in brain structures (even within close relatives)
  → some areas (non-) existent or different 10-40x in size

Engineering intuition

- there cannot be a unique implementation of general AI
- evolution by combining different AI systems?
- scaling up may not always be the best approach

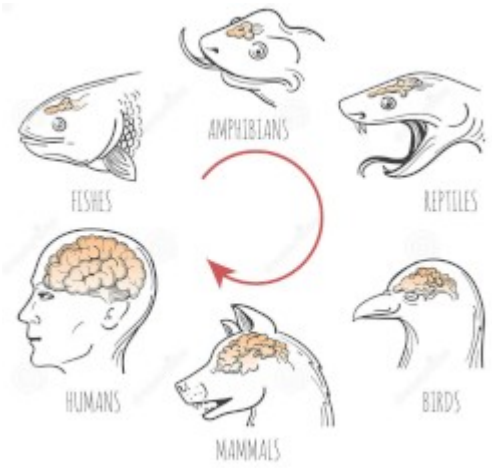
Human brain design

Fundamental questions

- Why primates have larger brains if they process the same environmental information?
- Why brains are allowed to be large if they consume incredible amount of energy?
- Why are brains divided? Why are hemispheres asymmetrical?

Main drivers of brain evolution

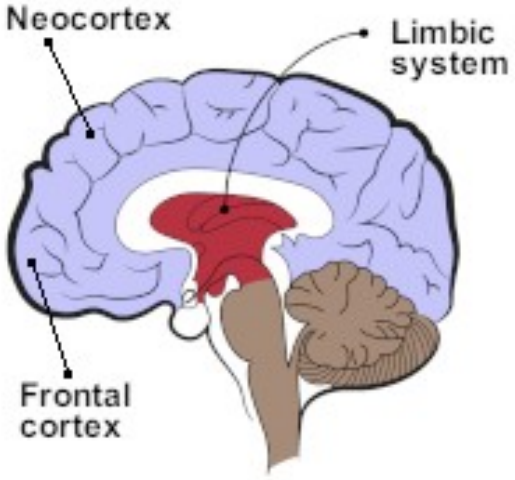
- processing repetitive events (food, reproduction, safety)
  → spatial orientation, from night to day living
- social interactions (capacity about 150 acquaintances)
  → cooperation, cheating, decoding feelings of others
- support from other biological systems
  → many opportunities for indirect brain control



Engineering intuition

- development of general AI needs strong drivers i.e. what functionality to provide?
- design and implementation of general AI is strongly tasks dependent
- major difference if goal is to exist in environment or to communicate with others

Old and new brain



Limbic system

- 10% of total brain weight
- emotional behavior, basic living tasks
- hormonal control, main source of living will
- little energy demands

Cortext and neocortex

- 80% of brain weight
- reasoning, performing complex tasks
- hormonal and other type of control
  → dominate the behavior in modern societies
  → can be controlled externally
- high energy demands
  → irreversible changes after 6min w/o energy

Duality of consciousness

- constant negotiations between neo/cortex and limbic system

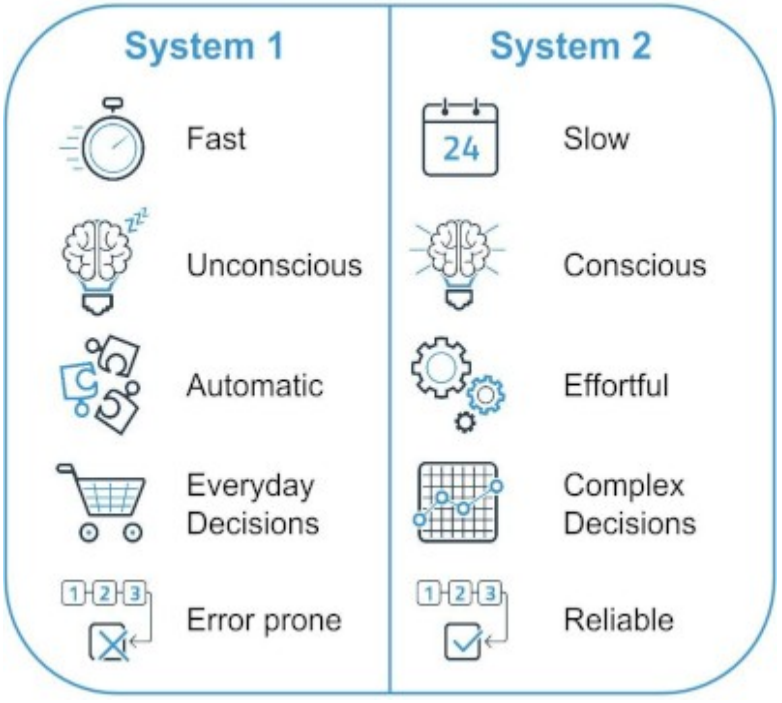
Frontal cortex

- females: caring for children
- males: innovation and creativity

Engineering intuition

- general AI requires specialized sub-systems that constantly negotiate

Brain as 2 systems



System 1 aka Intuition

- generates impressions, intentions, feelings
- gut feeling, react to environment, difficult to control
  - fast accurate short term predictions, parallel, integral
  - routine decisions but occasional mistakes
  - automated, low energy, always on, familiar situations

System 2 aka Reasoning

- conscious reasoning, choice what to do and think
- highly focused, slow, allow conflicting ideas, analytic
- considers evidence and question assumptions
- activated when mistakes may be costly
- energy hungry, serial, add-on, from 3 years of age

Engineering intuition

- accurate perception of reality requires proper configuration and cooperation of these 2 systems, easy to manipulate

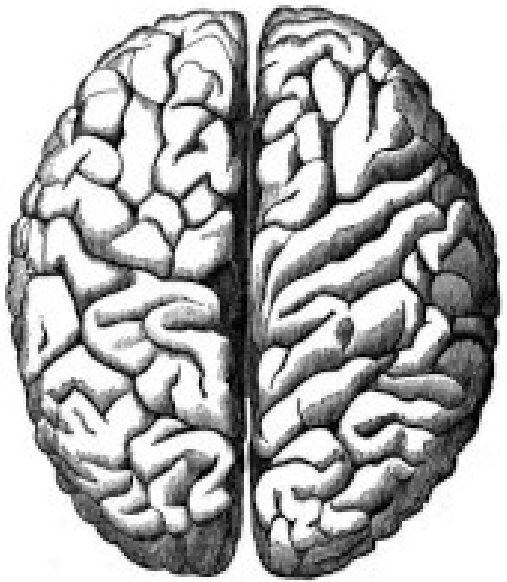
Divided brain

Simplified (popular) views

- right hemisphere: feelings, imagination, creativity, fantasy, art, holistic view
- left hemisphere: logic, reasoning, facts, practical, math, science, details oriented

Facts

- hemispheres are asymmetrical
- they are connected by only 2% of all neurons
  → inhibit the other side
  → split and re-create the perceived reality
- control our attention
  → 2 kinds of attentions to be synthesized
- hemispheres are interdependent
  → both involved in logic, speech, emotions etc.
  → but different attitudes to reality and tasks



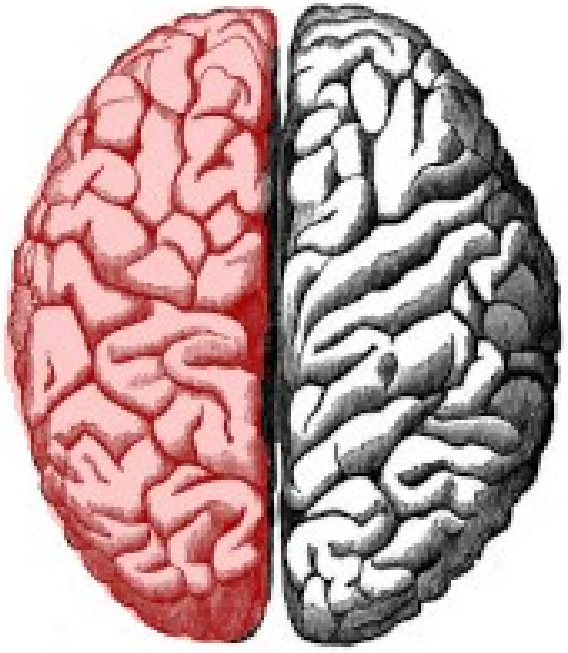
Engineering intuition

- general AI requires combining multiple views of reality

Left hemisphere (LH)

Facts

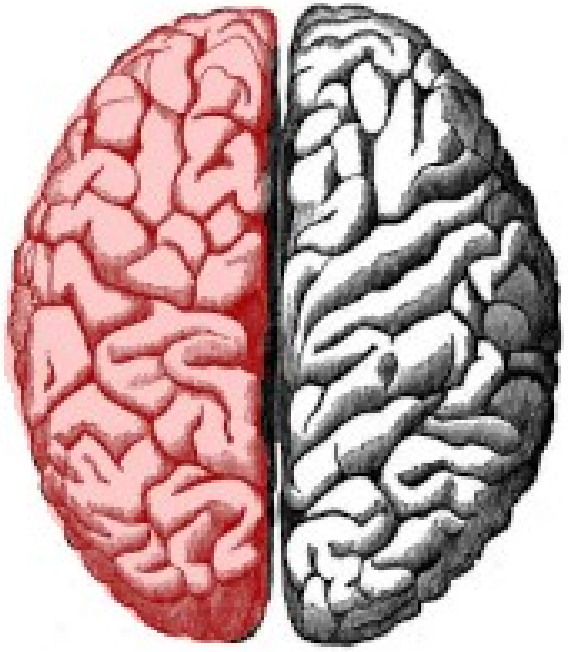
- work with memory and experience
  → things we already know and understand
  → focus on non-living things
  → strongly relies on what it already knows
- fast decisions, jumps to conclusions
  → does not know what it does not know
- reality narrowed down to certainties
- the world is seen as fixed, narrow, fragmented
- things need to be explicit and clear
  → does not understand implicit
  → language is the most explicit way of communicating
- does not care about context
  → enforces abstractions



Left hemisphere (LH)

Facts (cont.)

- tend to generalize and abstract
  → categorize things into small number of categories
- optimistic, ignore problems, denies reality
- fast algorithms
  → generates reality representation for RH
  → believes more data can solve the problem
- functions in LH are easier to understand and explain
  → much more resembles a computer than RH



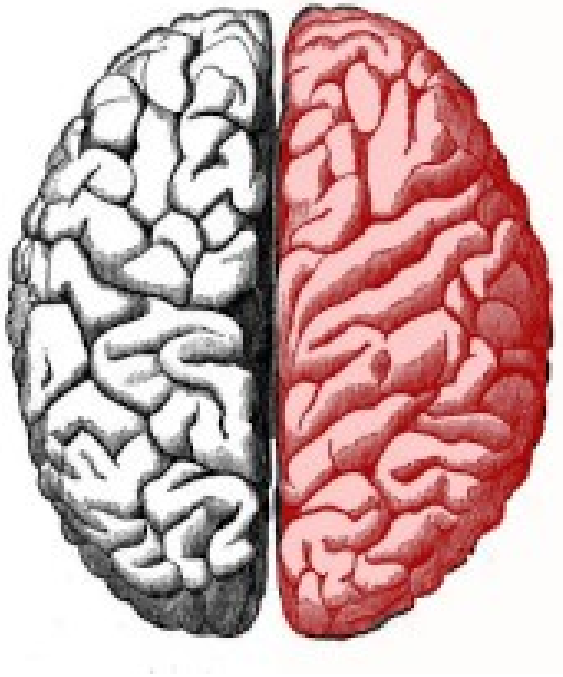
Engineering intuition

- functions of LH should be much easier to implement
- deep learning is useful to model or implement some functions in LH

Right hemisphere (RH)

Facts

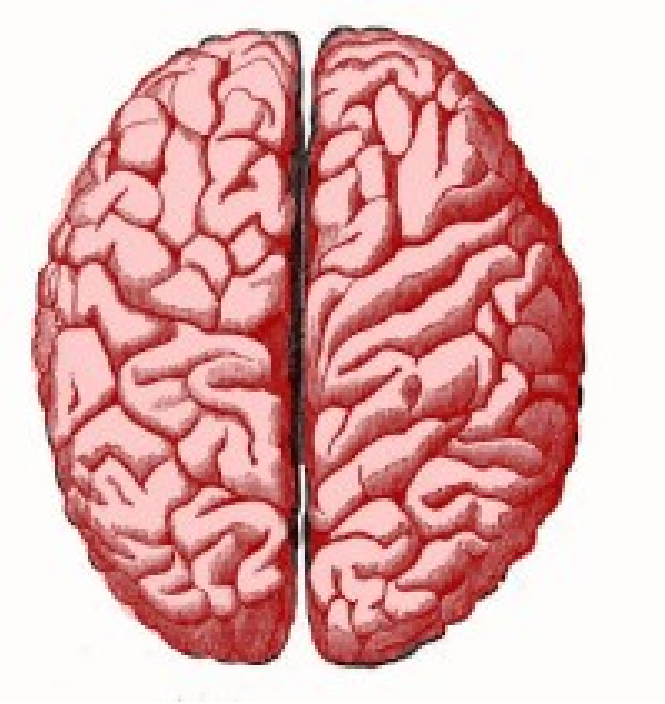
- broad views, complete picture
- world is flow of interdependent parts
  → RH remembers animated views
  → specialized for music and playing instruments
- good representation of reality
  → work with what it sees, less what it knows
  → depths of space, time and emotions
- vigilant, open to new, look for opportunities
- careful about conclusions, questions LH's conclusions
- decodes implicit (hidden) meanings in speech
  → how it is said, what is not said
  → understand the context
- fine categorizations, preserve uniqueness



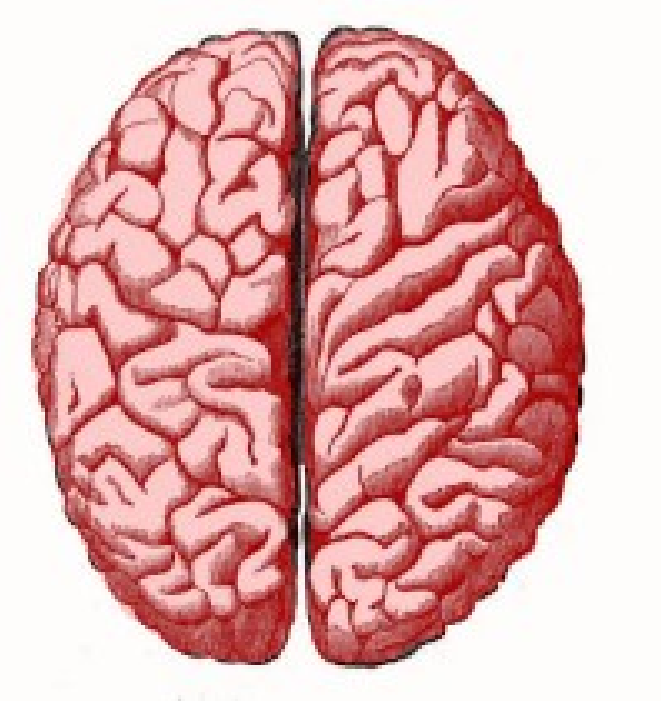
Left and right hemisphere

Facts

- RH supervises LH (master-emissary)
- our semi-automated perception of reality:
  1. RH gets whole picture
  2. LH breaks it down to pieces
  3. RH assembles back whole picture in proper context
  4. new things interpreted by RH are stored in LH memory
- RH is more universal, it can replace LH functions
  → other way around is much harder
  → stroke in RH has more severe consequences
- networks in LH more locally and tightly coupled, networks in RH more global
- LH started to (again) dominate our culture
  → mechanistic world, everything measured and analyzed
  → but optimistic attitudes, ignoring problems



Creativity



Facts

- autism affects much more RH
- the “Aha” moment appears in RH
- both hemispheres
  → IQ and creativity
  → complex task solving in Frontal lobes
- genuinely original creativity
  → RH clearly superior

Engineering intuition

- challenge for general AI is to mimic functions in RH
- first step is to describe functions and tasks in RH
- complementary strategies for reality perception provided in LH and RH are required to design general AI

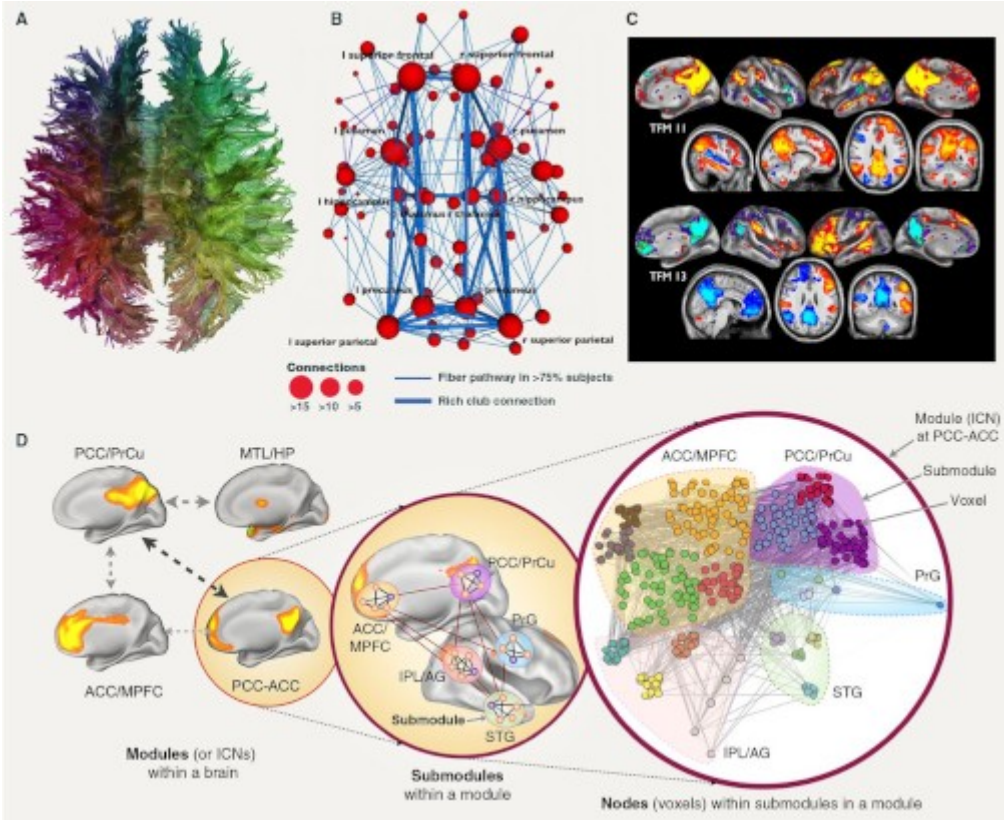
Universality of brain

Myths

- at birth, brain is unstructured dense network of neurons
- it forms networks and create structure by learning

Reality

- many existing modules at birth
  → specialized for different tasks
  → often overlap in space-time
- modules require different levels of finishing by learning



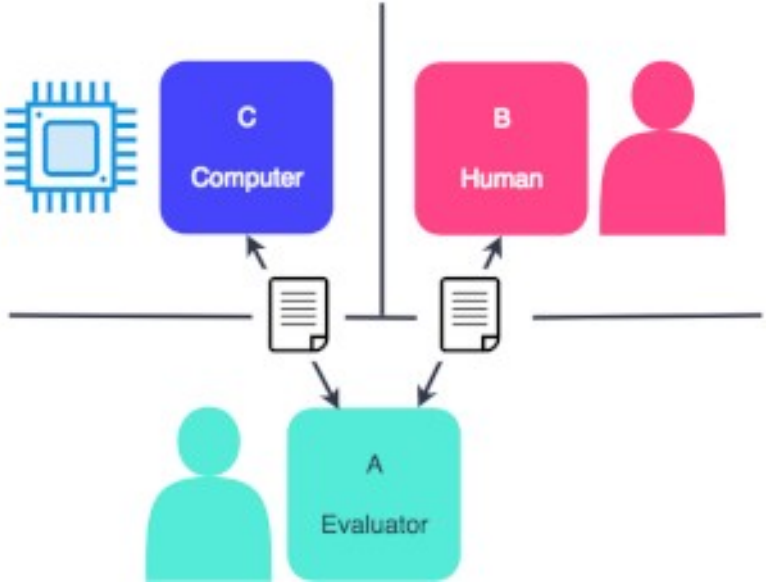
Engineering intuition

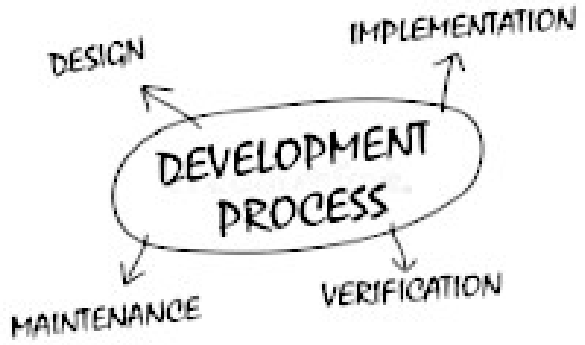
- implementation of general AI requires partially specialized circuits
- overlapping these circuits may improve efficiency

Can we build general AI?

What are the aims?

- more general problem solving system?
- imitate human brain or pass the Turing test?
- replace humans in more kinds of jobs?





What would be required?

1. Design

- general procedure to decompose complex tasks into smaller simpler sub-tasks
- modular hierarchical design inevitable
- improved mathematical tools

2. Implementation

- biological circuits difficult to control, but better energy and storage efficiency
- energy efficiency critical
- circuits with different levels of specialization and adaptivity

Claims

a) Knowledge of high level brain structure and functions can be used to design intelligent systems as well as to devise systems for the brain control and manipulation.

b) In complex systems, the structure and function are interrelated. This can be exploited by deep learning.

c) The human brain represents a very loose upper-bound on the achievable complexity of any technology.

d) The human brain level of general intelligence is not achievable by any existing or future technology.

e) The energy efficiency of information processing is one of the most fundamental limits in physics of computations.

f) Biological circuits are difficult to control, but they are inevitable in constructing systems with general intelligence due to their energy and information storage efficiency.

g) Building general intelligence systems is constrained by the availability of appropriate mathematical tools.

Claims (cont.)

h) General intelligence is not the same as passing the Turing test.

i) In many scenarios, more general problem solving rather than general intelligence may be sufficient.

j) General intelligence can be decomposed into a finite set of tasks and functions of varying specificity.

k) General intelligence can be approximated by combining many narrow-sense intelligence systems.

l) General intelligence must be implemented as interacting hierarchical heterogeneous circuits.

m) The reality should be projected into multiple views to aid the perception and decision making.

Thank you!

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