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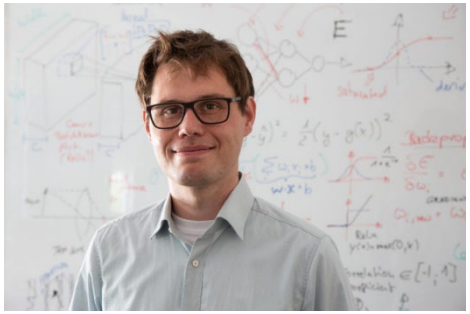
ERLANGEN-NÜRNBERG
FACULTY OF ENGINEERING

Cognitive Neuroscience for AI Developers (CNAID)

Welcome to CNAID !



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Time table

Week	Day	Date	Lecture type	Day	Date	Lecture type
1	Wed	19.04.2023	no lecture	Thu	20.04.2022	Lecture
2	Wed	26.04.2023	Exercise sheet (in present)	Thu	27.04.2022	Lecture
3	Wed	03.05.2023	Exercise sheet (in present)	Thu	04.05.2022	Lecture
4	Wed	10.05.2023	Exercise sheet (online)	Thu	11.05.2022	Lecture
5	Wed	17.05.2023	Exercise sheet (online)	Thu	18.05.2022	Vacation
6	Wed	24.05.2023	Online lecture	Thu	25.05.2022	Exercise sheet (in present)
7	Wed	31.05.2023	Test exam	Thu	01.06.2022	Lecture
8	Wed	07.06.2023	Exercise sheet (online)	Thu	08.06.2022	Vacation
9	Wed	14.06.2023	Lecture	Thu	15.06.2022	Lecture
10	Wed	21.06.2023	Exercise sheet (in present)	Thu	22.06.2022	Lecture
11	Wed	28.06.2023	Exercise sheet (online)	Thu	29.06.2023	Lecture
12	Wed	05.07.2023	Exercise sheet (online)	Thu	06.07.2023	Lecture
13	Wed	12.07.2023	Exercise sheet (in present)	Thu	13.07.2023	Lecture
14	Wed	19.07.2023	Exercise sheet (in present)	Thu	20.07.2023	Lecture
	H9	**08:15 - 09:45**		**HH**	**14:14 - 15:45**	

in present
online

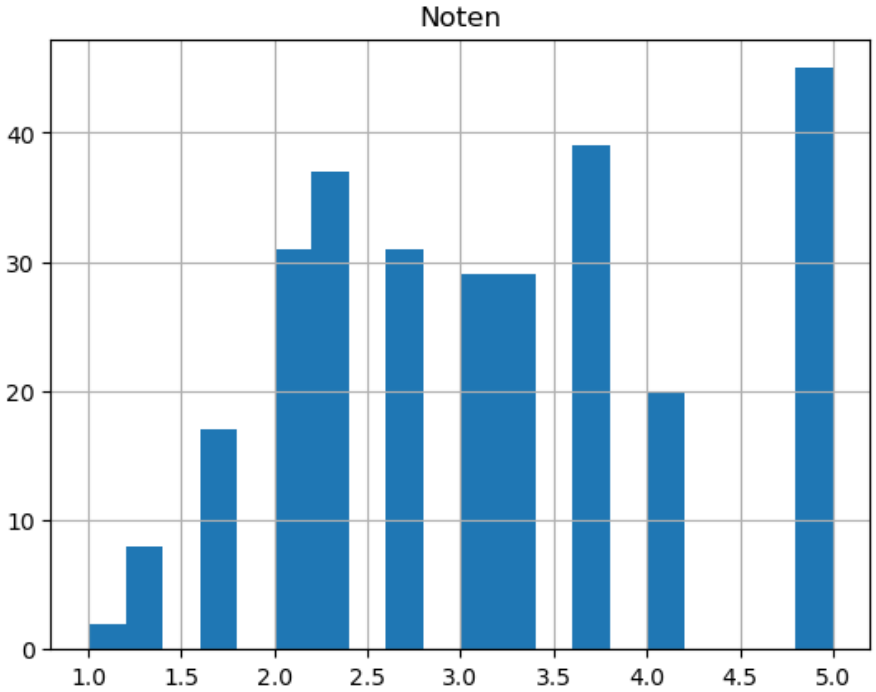
Video lectures on fau.tv (just add on)

https://www.fau.tv/course/id/3265

Studon course

https://www.studon.fau.de/crs4625843.html

Results of end-of-semester test in Winter 2022/23



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Topics of this lecture

- Cognitive Science, Philosophical Approach to cognitive science
- Psychological approach to cognitive science
- Neurons, Glia, Spiking, Neural Plasticity
- Development of the neural system, Electrophysiology
- Imaging techniques
- Methods for AI
- Brain structure
- Somatosensory System, Pain, Visual System
- Motor System
- Auditory System, Olfactory System, Gustatory System
- Language, Attention and Saliency
- Memory, Free Will an Consciousness

Literature

- **Cognitive Science**, Friedenberg, J., Silverman, G., & Spivey, M. J. (2021). **Cognitive science: an introduction to the study of mind.** Sage Publications. Fourth Edition
- **Cognitive Science**, Bermúdez, J. L. (2023). **Cognitive science: An introduction to the science of the mind.** Cambridge University Press. Fourth Edition
- **Cognitive Neuroscience**, Gazzaniga, M. S., Ivry, R. B., & Mangun, G. R. (2014). **Cognitive Neuroscience. The biology of the mind**,(2014). Fourth Edition
- **Cognitive Neuroscience**, Ward, J. (2015). **The student's guide to cognitive neuroscience.** psychology press. Third edition
- **Neurobiology**, Kandel, E. R., Schwartz, J. H., Jessell, T. M., Siegelbaum, S., Hudspeth, A. J., & Mack, S. (2013). **Principles of neural science.** New York: McGraw-hill. Fifth Edition

Cognitive Neuroscience for AI Developers

Introduction to Cognitive Science

The big picture -> What is Cognitive Science?

- **Cognitive Science:** scientific, interdisciplinary study of the mind.

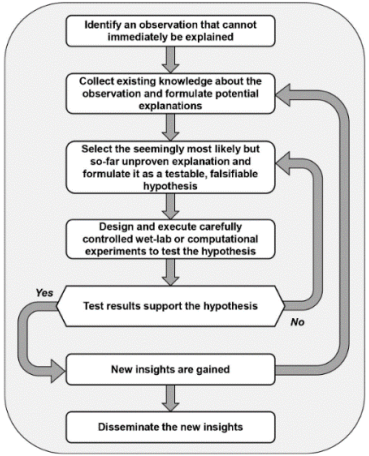
- **Mind**: „[…] *the complex of faculties involved in perceiving, remembering, considering, evaluating, and deciding. Mind is in some sense reflected in such occurrences as sensations, perceptions, emotions, memory, desires, various types of reasoning, motives, choices, traits of personality, and the unconscious.*" https://www.britannica.com/topic/mind

- **Cognition**: higher mental processes such as thinking, perceiving, imagining, speaking, acting, planning

Cognitive Science

- Highly **interdisciplinary** approach
- Main method: Scientific method (not philosophy and older disciplines)

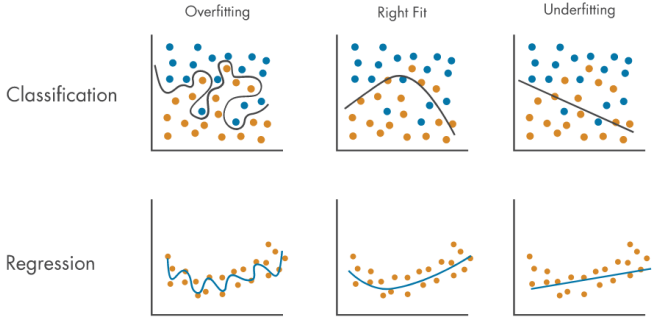
Scientific method: test hypothesis with experiment -> update hypothesis -> new Experiment (iterative process)



Voit, E. O. (2019). Perspective: Dimensions of the scientific method. *PLOS Computational Biology*, *15*(9), e1007279.

Cognitive Science

Scientific method



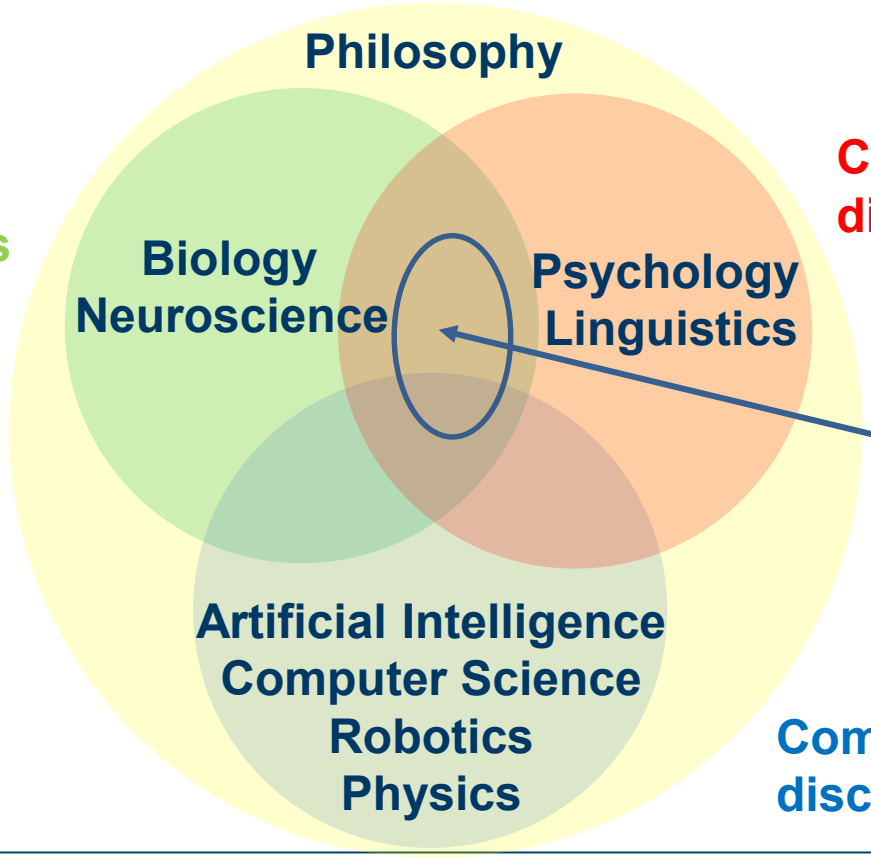
https://de.mathworks.com/discovery/overfitting.html

Occams razor: „*given two explanations of the data, all other things being equal, the simpler explanation is preferable.”*

“This principle is very much alive today in the emerging science of machine learning, whose expressed goal is often to discover the simplest hypothesis that is consistent with the sample data [1].”

Blumer, A., Ehrenfeucht, A., Haussler, D., & Warmuth, M. K. (1987). Occam's razor. *Information processing letters*, *24*(6), 377-380.
D. Angluin and C.H. Smith, Inductive inference: Theory and methods, Comput. Surv. 15 (3) (1983) 327-369.

Multi-disciplinary perspective



Biological disciplines

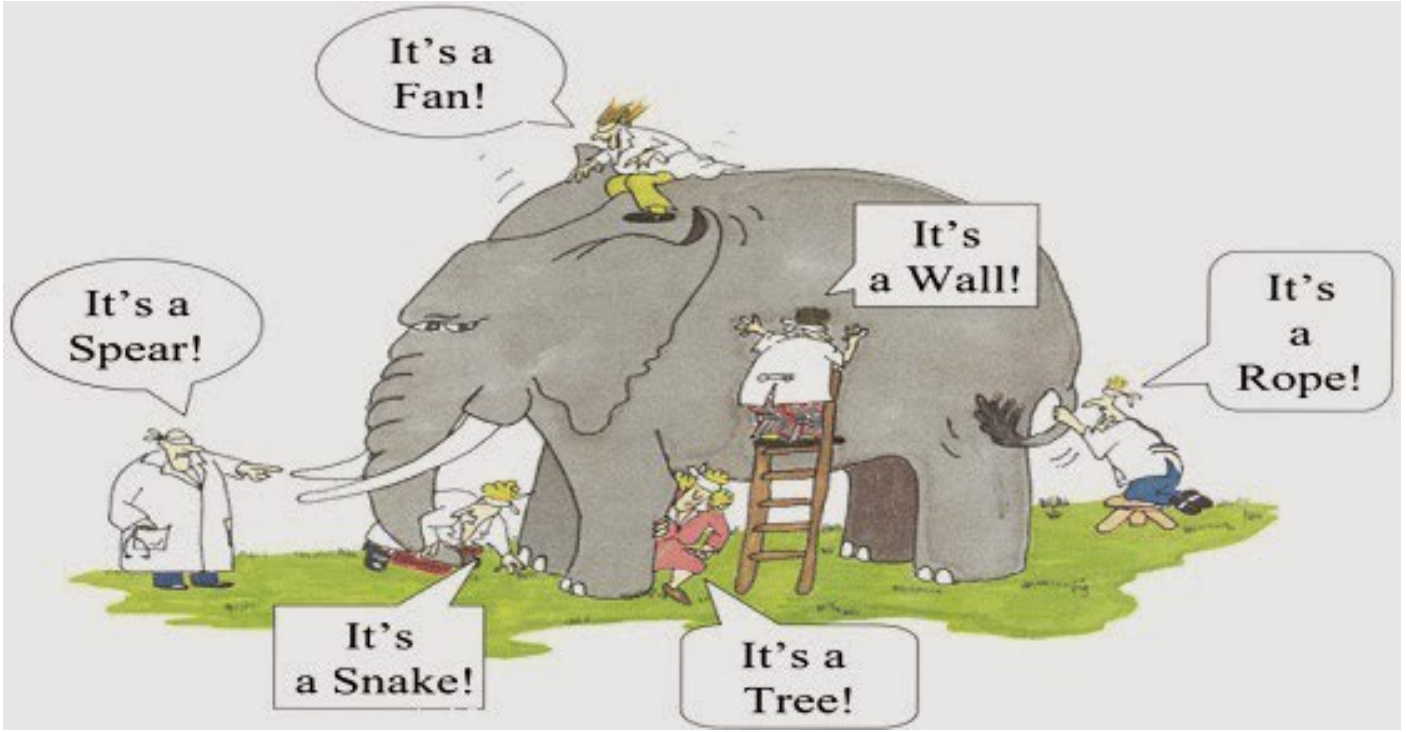
Cognitive disciplines

Computational disciplines

Cognitive Science is not the sum, but the intersection of all these disciplines -> goal is to understand the mind

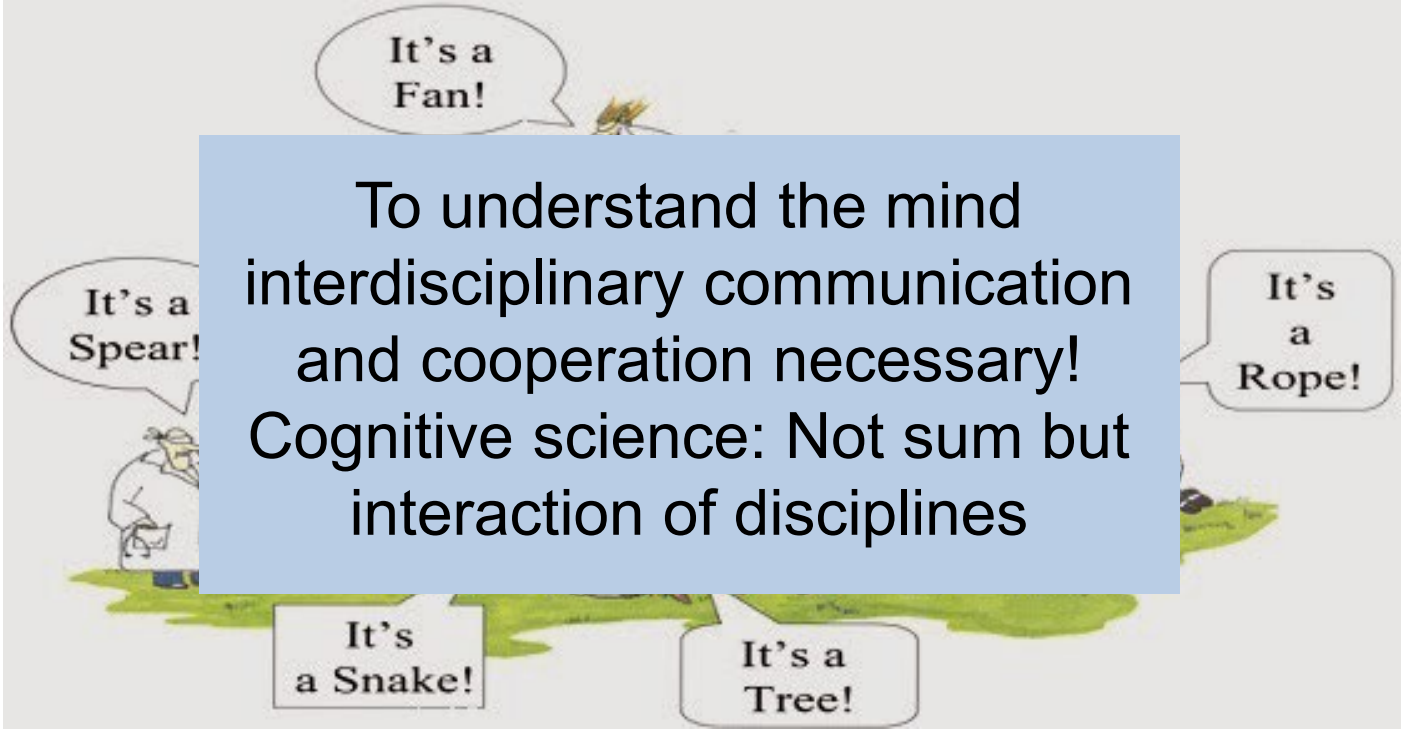
Cognitive Neuroscience (Neuropsychology)

The blind men and the elephant



Source: https://medium.com/betterism/the-blind-men-and-the-elephant-596ec8a72a7d

The blind men and the elephant



To understand the mind interdisciplinary communication and cooperation necessary! Cognitive science: Not sum but interaction of disciplines

Source: https://medium.com/betterism/the-blind-men-and-the-elephant-596ec8a72a7d

Questions to be answered:

How does the human mind work?

- How does cognition work?
- How is cognition implemented in the brain?
- How can cognition be implemented in machines?

Some of the hardest scientific problems

1. Brain is hard to observe, measure and manipulate
2. Brain is most complex entity in the known universe

The most complex entity in the known universe

- 100 billion (10^{11}) neurons
- 10,000 synapses per neuron
- 10^{15} synapses in total
- 10^{22} possible connections

Source: brainline.org

- only 1 of 10,000,000 possible connections is actually realized

The most complex entity in the known universe

- Number of possible brain states $> 2^{10^{11}}$
- Number of possible connectomes $> 2^{10^{22}} \sim 10^{10^{22}}$
- Number of protons in the observable universe $\sim 10^{80}$

How do we unravel how the brain processes information -> Problem of cognitive science and cognitive neuroscience

frontiers in NEUROSCIENCE

OPINION ARTICLE
published: 31 October 2014
doi: 10.3389/fnins.2014.00349

The tale of the neuroscientists and the computer: why mechanistic theory matters

Joshua W. Brown*

Psychological and Brain Sciences, Indiana University, Bloomington, IN, USA
**Correspondence: jwmbrown@indiana.edu*

Brown, J. W. (2014). The tale of the neuroscientists and the computer: why mechanistic theory matters. *Frontiers in neuroscience*, *8*, 349.

The tale of the neuroscientist and the computer

"Once upon a time, a group of neuroscientists happened upon a computer (Carandini, 2012). Not knowing how it worked, they each decided to find out how it sensed a variety of inputs and generated the sophisticated output seen on its display."

Brown, J. W. (2014). The tale of the neuroscientists and the computer: why mechanistic theory matters. *Frontiers in neuroscience*, *8*, 349.

The tale of the neuroscientist and the computer

"The EEG researcher quickly went to work, putting an EEG cap on the motherboard and measuring voltages at various points all over it, including on the outer case for a reference point. She found that when the hard disk was accessed, the disk controller showed higher voltages on average, and especially more power in the higher frequency bands. When there was a lot of computation, a lot of activity was seen around the CPU…."

Brown, J. W. (2014). The tale of the neuroscientists and the computer: why mechanistic theory matters. *Frontiers in neuroscience*, *8*, 349.

The tale of the neuroscientist and the computer

"Next, the enterprising physicist and cognitive neuroscientist came along. "We don't have enough spatial resolution to see inside the computer," they said. So they developed a new imaging technique by which activity can be measured, called the Metabolic Radiation Imaging (MRI) camera, which now measures the heat (infrared) given off by each part of the computer in the course of its operations.

At first, they found simply that lots of math operations lead to heat given off by certain parts of the CPU, and that memory storage involved the RAM, and that file operations engaged the hard disk…"

Brown, J. W. (2014). The tale of the neuroscientists and the computer: why mechanistic theory matters. *Frontiers in neuroscience*, *8*, 349.

The tale of the neuroscientist and the computer

"…Finally the neuropsychologist comes along. She argues (quite reasonably) that despite all of these findings of network interactions and voltage signals, we cannot infer that a given region is necessary without lesion studies. The neuropsychologist then gathers a hundred computers that have had hammer blows to various parts of the motherboard, extension cards, and disks. After testing their abilities extensively, she carefully selects just the few that have a specific problem with the video output. She finds that among computers that don't display video properly, there is an overlapping area of damage to the video card. This means of course that the video card is necessary for proper video monitor functioning. …"

Brown, J. W. (2014). The tale of the neuroscientists and the computer: why mechanistic theory matters. *Frontiers in neuroscience*, *8*, 349.

Moral of the story

- Cognitive neuroscience is still in an early stage phase
- We need a mechanistic theory to understand cognition in the brain
- We have to develop computer models that produce testable hypotheses
- We need a multi-disciplinary approach
- Neuroscience alone is not enough

Brown, J. W. (2014). The tale of the neuroscientists and the computer: why mechanistic theory matters. *Frontiers in neuroscience*, *8*, 349.

Schilling, A., Sedley, W., Gerum, R., Metzner, C., Tziridis, K., Maier, A., ... & Krauss, P. (2022). Predictive coding and stochastic resonance: Towards a unified theory of auditory (phantom) perception. *arXiv preprint arXiv:2204.03354*.

Main ideas of cognitive science
Boost by invention of computer

The cognitive revolution

- Started in 1950s
  - Psychology, linguistics were redefining themselves
  - Computer science and neuroscience came up
  - Personal computer novel brain imaging techniques boosted the development
- In 1960: start of the interdisciplinary field
  - Different names: information-processing psychology, cognitive studies, cognitive science

Miller, G. A. (2003). The cognitive revolution: a historical perspective. *Trends in cognitive sciences*, *7*(3), 141-144.

Central ideas of Cognitive Science

- Cognition is equivalent to computation / information processing

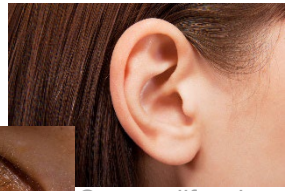
-> The mind/brain is an information processor

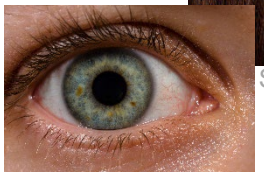
- Information processors represent and transform information
  - Mental representations of information
  - Mental processes that act on and manipulate these representations called computation

Mind – Computer – Analogy

Input

Source: adapterwelt.net





Source: lifescience.com

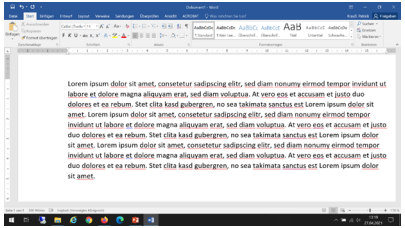
Source: wikipedia.org

Representation (binary)

Source: ifixit.com

Source: brainline.org

Processing / Computation

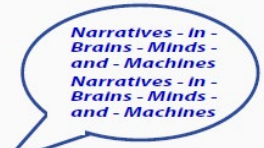


© P. Krauss

© P. Krauss

Output

Source: store.hp.com



© P. Krauss

Representations (something stands for something else)

Traditional cognitive science view !

4 types:

- Concepts (stands for entity) „apple“

- Propositions (statements about the world) „Mary has black hair.“
- Rules (relationship between propositions) „If it is raining, I will bring my umbrella.“
- Analogies (comparisons between situations) „Life is a roller coaster.“

Representations

Traditional cognitive science view !

Features of representations:

- Symbolic: a symbol is a surrogate and refers to its referent

The mind $

Representation (symbolic)

Intentionality: relationship between representation and what it is about

The world

Referent (non-symbolic)

Representations

Symbols can be assembled into physical symbol system (formal logical system)

Formal logical system: symbols are combined to expressions

Formal processes: manipulate expressions to create new expressions

-> Formal logical systems can allow for intelligence and intelligent behavior (Physical symbol system hypothesis (Newell & Simon, 1976))

-> hypotheses is often criticized, -> computers use symbols with no meaning as symbols are not connected to the environment (grounding problem)

Representations + Computation

Example: formal logic

Traditional cognitive science view !

Symbols: all, mammals, ….

Expression: all and only mammals nurse their young

Processes: rules of deduction
derive new, true expressions from known expressions

Expression 1: all and only mammals nurse their young

Expression 2: whales nurse their young

New expression: whales are mammals

-> Newell and Simon 1976 -> intelligence

Representations + Computation

Expert systems

- Solves problems were you normally need a human specialist (expert)
- Uses set of if-then rules
- Example: MYCIN (Shortliffe) -> regarded as first expert system
  - Diagnose of blood infections and meningitis
  - Helped to choose antibiotics
  - Simple inference machine with approx. 500 rules
  - Asks questions to the physician (yes/ no)

If (i) the infection is meningitis and (ii) organisms were not seen in the stain of the culture and (iii) the type of infection may be bacterial and (iv) the patient has been seriously burned, then there is suggestive evidence that *Pseudomonas aeruginosa* is one of the organisms that might be causing the infection.

Duda, R. O., & Shortliffe, E. H. (1983). Expert systems research. *Science*, *220*(4594), 261-268.

Lacave, C., & Diez, F. J. (2004). A review of explanation methods for heuristic expert systems. *The Knowledge Engineering Review*, *19*(2), 133-146.
Duda, R. O., & Shortliffe, E. H. (1983). Expert systems research. *Science*, *220*(4594), 261-268.
Qiu, S., Sallak, M., Schön, W., & Ming, H. X. (2018). A valuation-based system approach for risk assessment of belief rule-based expert systems. *Information Sciences*, *466*, 323-336.

Computation

Traditional cognitive science view !

The mind performs computations on representations.

e.g.

language: putting a verb into past tense

math: adding two numbers -> endless list

Define broad categories of mental operations according to:

- Type of operation
- Type of information that is processed

-> Any information processing can be described at different levels

Computation

Tri-level hypothesis (Marr, 1982)

- **Computational level (most abstract)**
  Which problem is the system trying to solve?
  e.g. to sort a set of numbers

Computation

Tri-level hypothesis (Marr, 1982)

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  Which problem is the system trying to solve?
  e.g. to sort a set of numbers
- **Algorithmic level**
  How does the system solve this problem? Algorithm? Procedure?
  e.g. bubble sort, binary tree sort, quicksort

Computation

Tri-level hypothesis (Marr, 1982)

- **Computational level (most abstract)**
  Which problem is the system trying to solve?
  e.g. to sort a set of numbers
- **Algorithmic level**
  How does the system solve this problem? Algorithm? Procedure?
  e.g. bubble sort, binary tree sort, quicksort
- **Implementational level**
  How is this algorithm implemented? Code? Physical?
  e.g. python code, assembler, logical gates, transistors, electron flow

Representations and Computation

Classical view

- Representations are symbolic
- Computation in sequential steps

Connectionist view (more modern)

- Representations are activation patterns spread over a neural network (Brain)
- Computations are parallel in the network

From symbolic AI -> Deep Learning

Computation

Tri-level hypothesis (Marr, 1982)

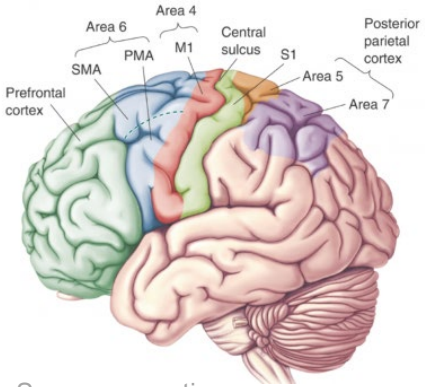
Tri-Level hypothesis can be applied to classical information processors as well as neural networks (Dawson 1998)

Structural levels of analysis in the nervous system

Brain

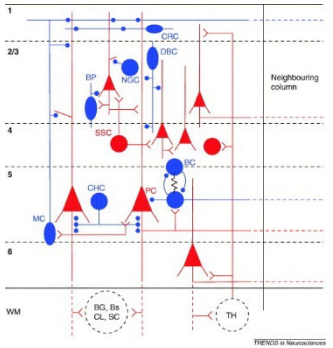
Source: brainline.org

Brain regions



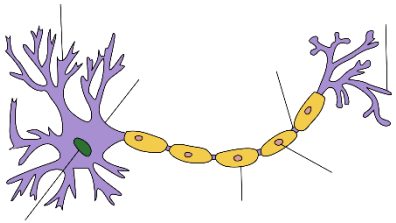
Source: operativeneurosurgery.com

Neural circuits



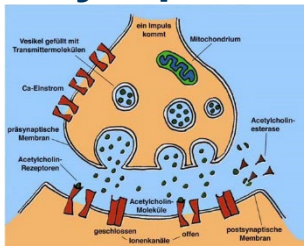
Source: Grillner et al., 2005

Neurons



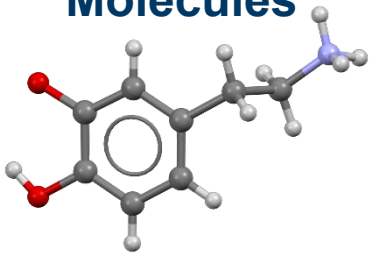
Source: wikipedia.org

Synapses



Source: www3.hhu.de

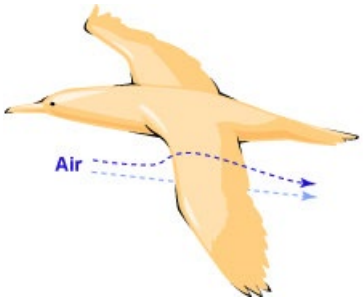
Molecules



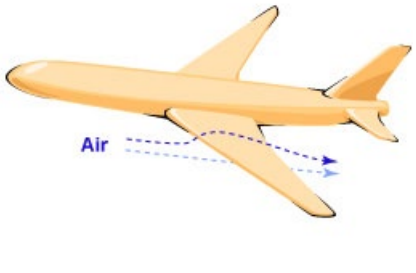
Source: wikipedia.org

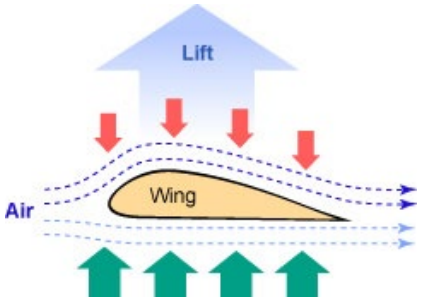
Metaphor

- Perhaps the algorithmic level is enough to build a general artificial intelligence
- It was enough to understand the physical principle behind bird flight
- -> not necessary to rebuild wings in all details to build planes



https://askabiologist.asu.edu/how-do-birds-fly





https://askabiologist.asu.edu/how-do-birds-fly

https://www.welt.de/regionales/berlin/article2107579/Kassen-gegen-zweiten-Rettungshelikopter.html

Cognitive Neuroscience for AI Developers

The Philosophical Approach

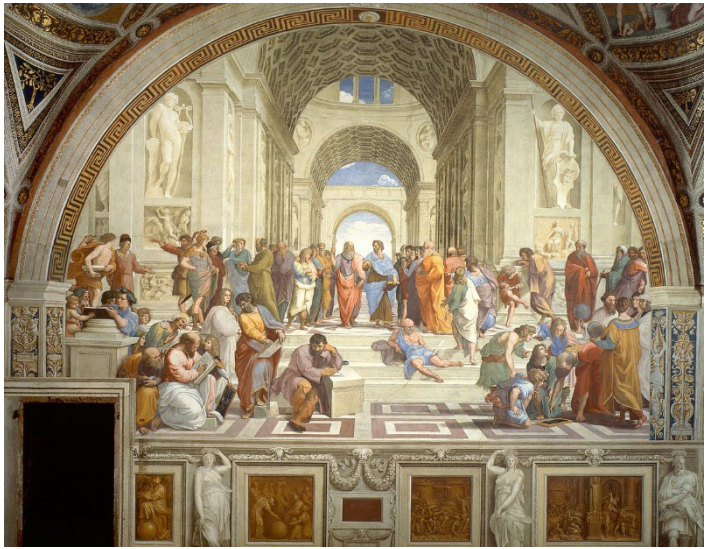
The way towards the cognitive revolution

-> back to the past

Philosophy….

The search for wisdom and knowledge
…is the oldest discipline (ancient Greeks)
…plays a critical role in
cognitive science

Not by producing results
(theoretical not experimental), but…

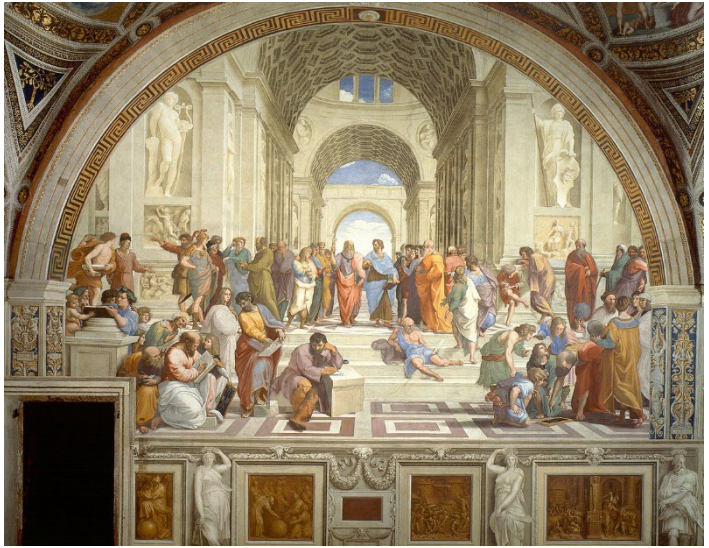


"The School of Athens"
by Raffaello Sanzio da Urbino

Source: wikipedia.org

Philosophy

- Defining problems
- Criticizing models
- Suggesting areas for future research
- Free to evaluate other disciplines
- *Find criteria for intelligence etc*



"The School of Athens"
by Raffaello Sanzio da Urbino

Source: wikipedia.org

Philosophy

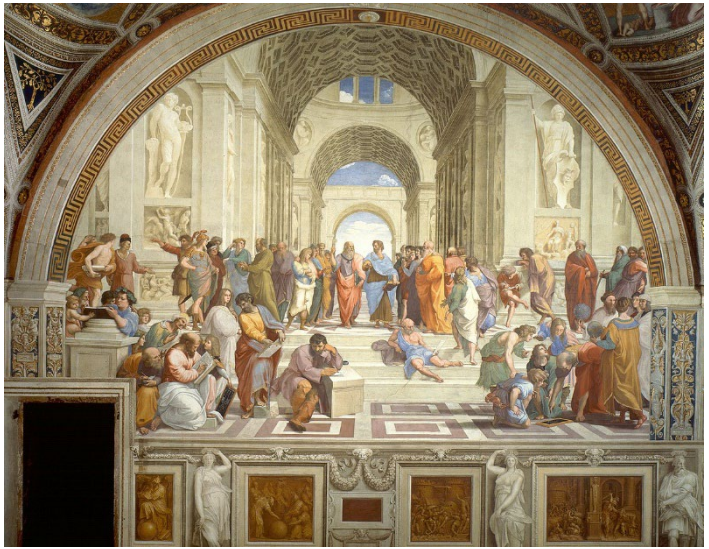
- **Primary method: reasoning**
- **Deductive reasoning:** applying rules of logic to statements, in order to derive new statements („College students learn three hours a night“. „Mary is a college student“. -> „Mary learns three hours a night“)
- **Inductive reasoning:** draw conclusions based on several observations of specific instances of the world („Whiskers the cat has four legs.“ „Scruffy the cat has four legs.“ ->“Cats have four legs“)
- But the do not use the scientific method (systematic form of induction)

Philosophy

2 (out of several) Branches of Philosophy

- **Metaphysics:** What is the nature of reality? (First causes of things and the nature of being) -> mind body problem

https://www.britannica.com/topic/metaphysics

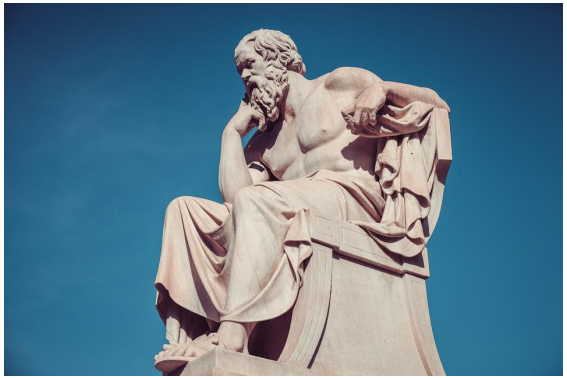


"The School of Athens" by Raffaello Sanzio da Urbino

Source: wikipedia.org

- **Epistemology** is the study of knowledge
  What is knowledge? How is knowledge represented in the mind?
  How do we come to acquire knowledge?

The philosophical approach of Cognitive Science



Source: forbes.com

Metaphysics

Mind-Body-Problem

What is mind? Is mind something physical?

Is body necessary to have a mind? (primarily metaphysical questions)

Epistemology

How do we come to know things? Are we born knowing certain things or is knowledge learned? How is mental knowledge organized?

The Mind-Body Problem: What is mind?

How are psychological and mental processes related to physical properties?

Brain: material and physical, measurable

Mind: subjective conscious experiences

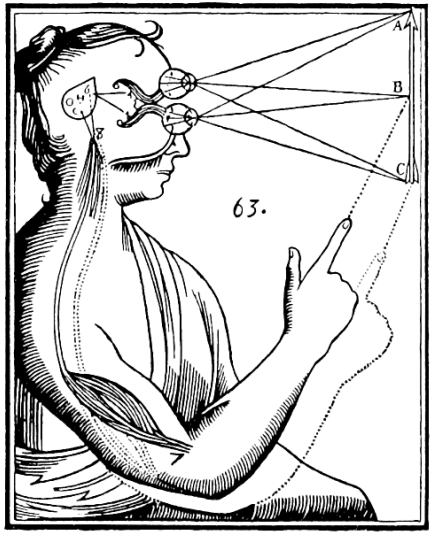
Mind as non-physical entity inhabiting the brain

„Ghost in the machine“

Two fundamental questions:

Is the mind physical or something else?

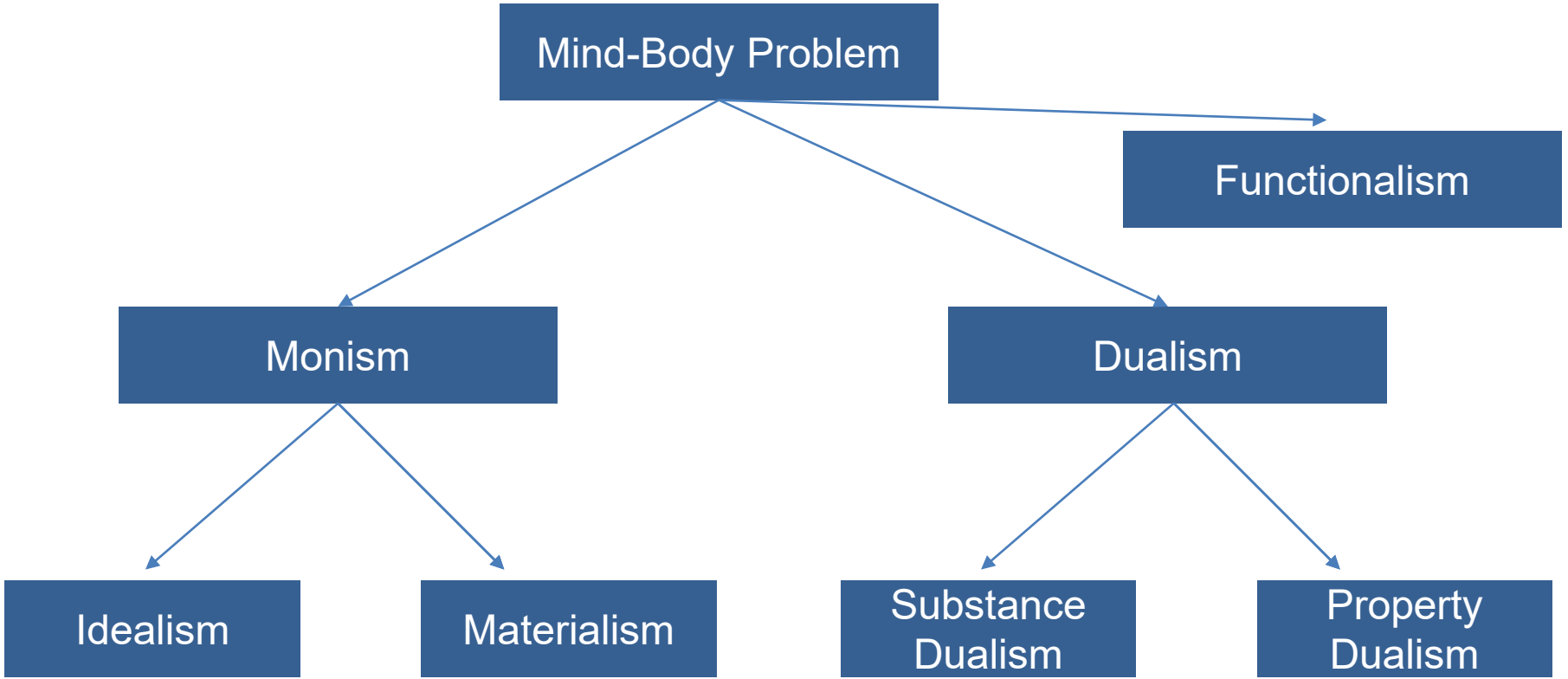
What is the causal relationship between mind and brain?



Source: wikipedia.org

René Descarte’s illustration of mind/body dualism.

Basic conceptions of the nature of mind



Basic conceptions of the nature of mind

Monism

- only one kind of state or substance in the universe
- Aristotle (384-322 BC): mind and body <-> form and matter
- Analogy: Different shapes of clay are different physical states of brain, no non-physical or spiritual substance

Basic conceptions of the nature of mind

Monism

- **Idealism:** The complete universe is mental
  - e.g. Simulation hypothesis

https://de.wikipedia.org/w/index.php?curid=6184755

- **Materialism** (physicalism): All things are made of atoms (Democritus ca. 460-370 BCE)
  - mind is the brain
  - mental states are physical states of the brain

Basic conceptions of the nature of mind

Dualism

- Mental and physical substances are possible
- Plato (427-347 BC): mind and body exist in two separate worlds
- Mind: ideal world of forms, immaterial, eternal e.g. idea of an ideal circle
- Body: material world, extended, perishable e.g. concrete, physical circles

Basic conceptions of the nature of mind

Substance Dualism (Descartes 1596-1650)

- There exist mental and physical substances
- Physical substances: world is made of atoms
- Mental substances: Unknown
- Theory: Minds can do e.g. pattern recognition. No physical substance can do pattern recognition. -> Minds are not physical.
- Criticism: 1) How do mental and physical substances interact? 2) Computers can do pattern recognition and much more!

Property Dualism

- Mind and body are of the same substance but have different properties
- Mental states are non-physical properties of the brain

Basic conceptions of the nature of mind

Critics on Dualism

- Dualism violates the principle of Occams razor: two different worlds that interact are needed. Not the simplest explanation
- Another problem: Brain damage changes mental states
- Computer can do a lot of tasks assumed to be impossible (e.g. ChatGPT can write novels)

Functionalism – Are minds limited to (human) brains?

Source: wikipedia.org

Source: swx.it

Source: wikipedia.org

https://plato.stanford.edu/entries/functionalism/

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Functionalism – Are minds limited to (human) brains?

Source: wikipedia.org

Source: swx.it

Source: wikipedia.org

"Functionalism is the doctrine that what makes something a thought, desire, pain (or any other type of mental state) depends not on its internal constitution, but solely on its function, or the role it plays, in the cognitive system of which it is a part."
https://plato.stanford.edu/entries/functionalism/

"For (an avowedly simplistic) example, a functionalist theory might characterize pain as the state that tends to be caused by bodily injury, to produce the belief that something is wrong with the body and the desire to be out of that state, to produce anxiety, and, in the absence of any stronger, conflicting desires, to cause wincing or moaning." https://plato.stanford.edu/entries/functionalism/

Functionalism – Are minds limited to (human) brains?

Source: wikipedia.org

Source: swx.it

Source: wikipedia.org

- Mind could be implemented in any physical system, artificial or natural, capable of supporting the appropriate computations

- The same mental state could be realized in quite different ways in two separate physical systems. **-> Concept of multiple realizability**

Functionalism – Are minds limited to (human) brains?

Source: wikipedia.org

Source: swx.it

Source: wikipedia.org

This could have some ethical implications: If mind can be realized in different systems at which point aliens or computers get human rights

Conclusion: Philosophy

- Allows to ask much broader questions than those of other disciplines
- Shows the „bigger picture“
- Gives key insights into the relationships between different areas
- Plays a very important role in the interdisciplinary endeavor of Cognitive Science
- Non-empirical approach, in contrast to the scientific method
- Concepts validated based on logical reasoning and argument
- Philosophy is better suited to ask questions than to provide answers
- Close 2-way collaboration between philosophy and science is required

Thank you for your attention !