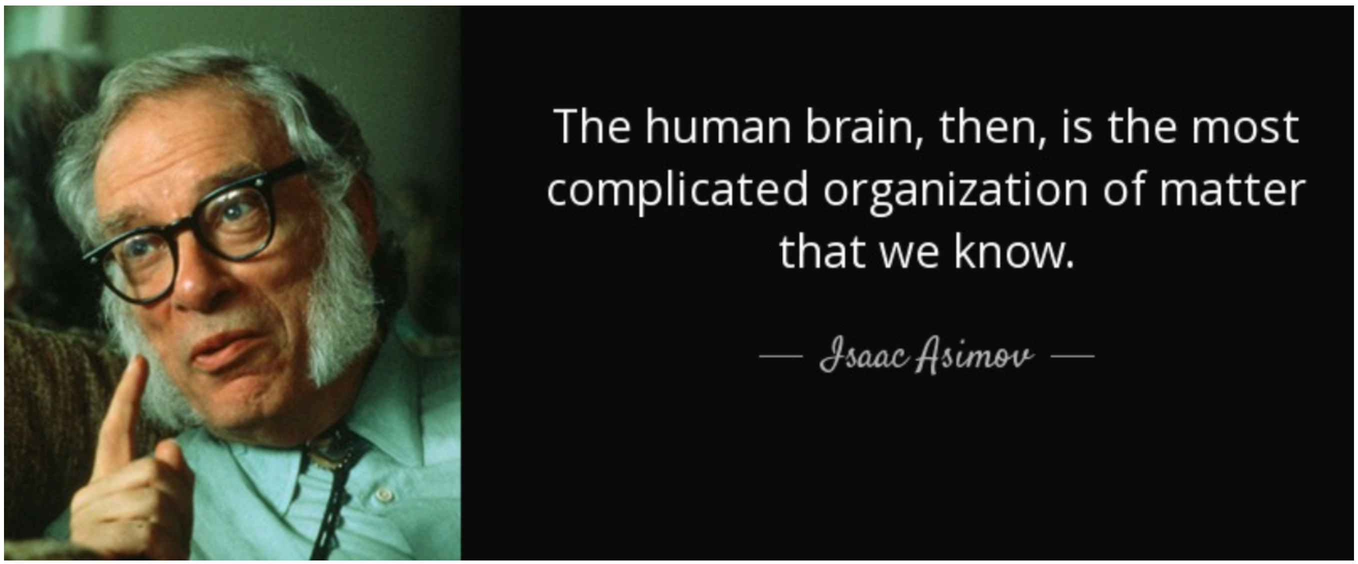
Principles of Cognition



Constantin Rezlescu
2 October 2017
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Objectives

- Give you a broad overview of the field & understanding of big theoretical questions and challenges
- Focus on basic principles and selected examples
- ‘Zoom’ lens—form abstract to highly specific
- Introduce you to (some of) the active research areas, experimental methods available and computational approaches
- Orient you towards the subject(s) more suited to your interests
- Get you thinking about your final project

Range of skills and knowledge

- Abstract perspective on cognition
- Understand relevance of formal models
- Ability to design experiments
- Analyze data
- Carry out original research
- Apply fundamental research to practical problems

Course summary

- **02/10/2017** – Constantin Rezlescu: Foundations
- **09/10/2017** – Sam Schwartzkopf: Scientific reasoning
- **16/10/2017** – Zita Eva Patai: Memory and navigation
- **23/10/2017** – David Shanks: Mental construction
- **30/10/2017** – Constantin Rezlescu: Object and face recognition

READING WEEK

- **13/11/2017** – Lasana Harris: Social cognition
- **20/11/2017** – Jeremy Skipper: Language cognition
- **27/11/2017** – David Vinson: Embodied cognition
- **04/12/2017** – Karl Friston: The free-energy principle
- **11/12/2017** – Constantin Rezlescu: Big ideas and big debates in cognition

Logistics

- **Readings** for all lectures will be uploaded on Moodle.
  - Read them before the lecture! (quizzes)
- **Lecture slides** will be on Moodle before or slightly after each lecture
  - Lectures are recorded – recordings will be appearing on Moodle 2-3 days after each lecture
- **Assessment**:
  - 100% coursework
  - Essay topics will be announced soon on Moodle
  - Deadline: 30/01/2018 (?)
- **Contact**:
  - For any lecture related question email the lecturer
- For any general issue about the module email me (c.rezlescu@ucl.ac.uk)
- Slack!

Lecture 1: Foundations

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2 October 2017
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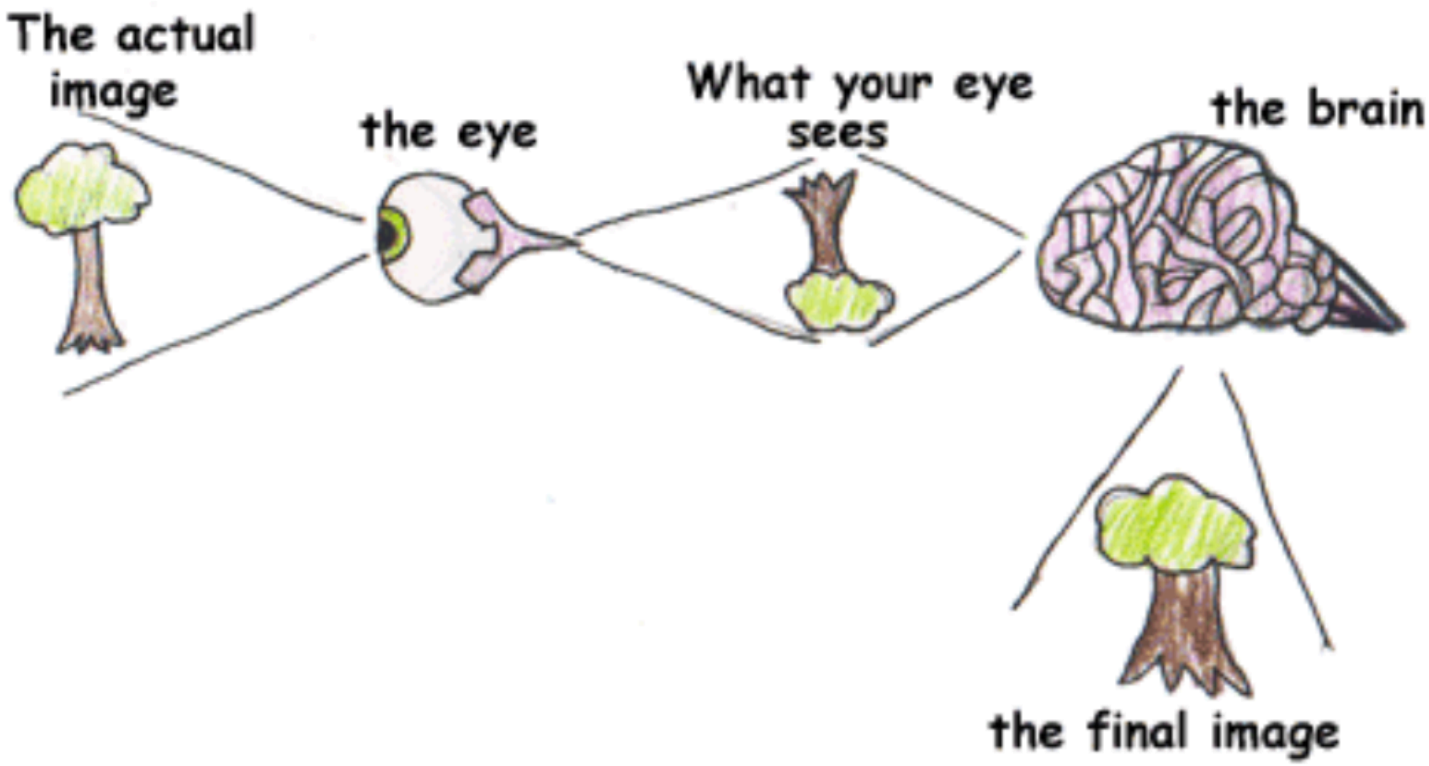
Outline

1. What is cognitive science?
2. A (very) brief history
3. Methods in cognitive science
4. Levels of analysis

Puzzle no. 1

The retinal image is upside down; but subjective experience isn't. Why not?



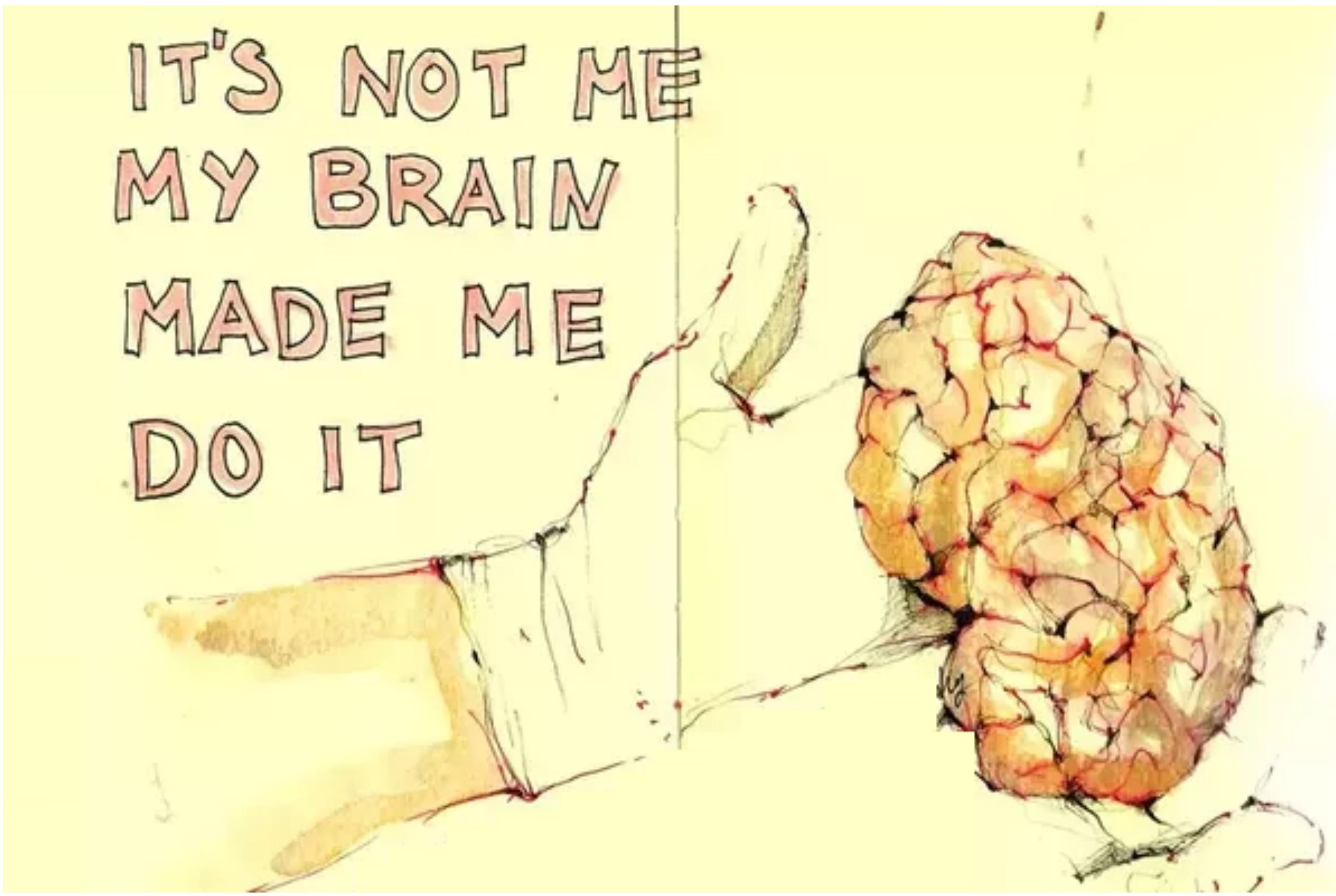
https://www.youtube.com/watch?v=-kohUpQwZt8

Puzzle no. 2

When does it pay off to think for yourself; when can you ‘free-load’? (e.g. ‘bubbles,’ fashion) (and implications from cognitive/brain evolution?)

Puzzle no. 3

If we understood the brain processes underlying volition, would we believe in free will?



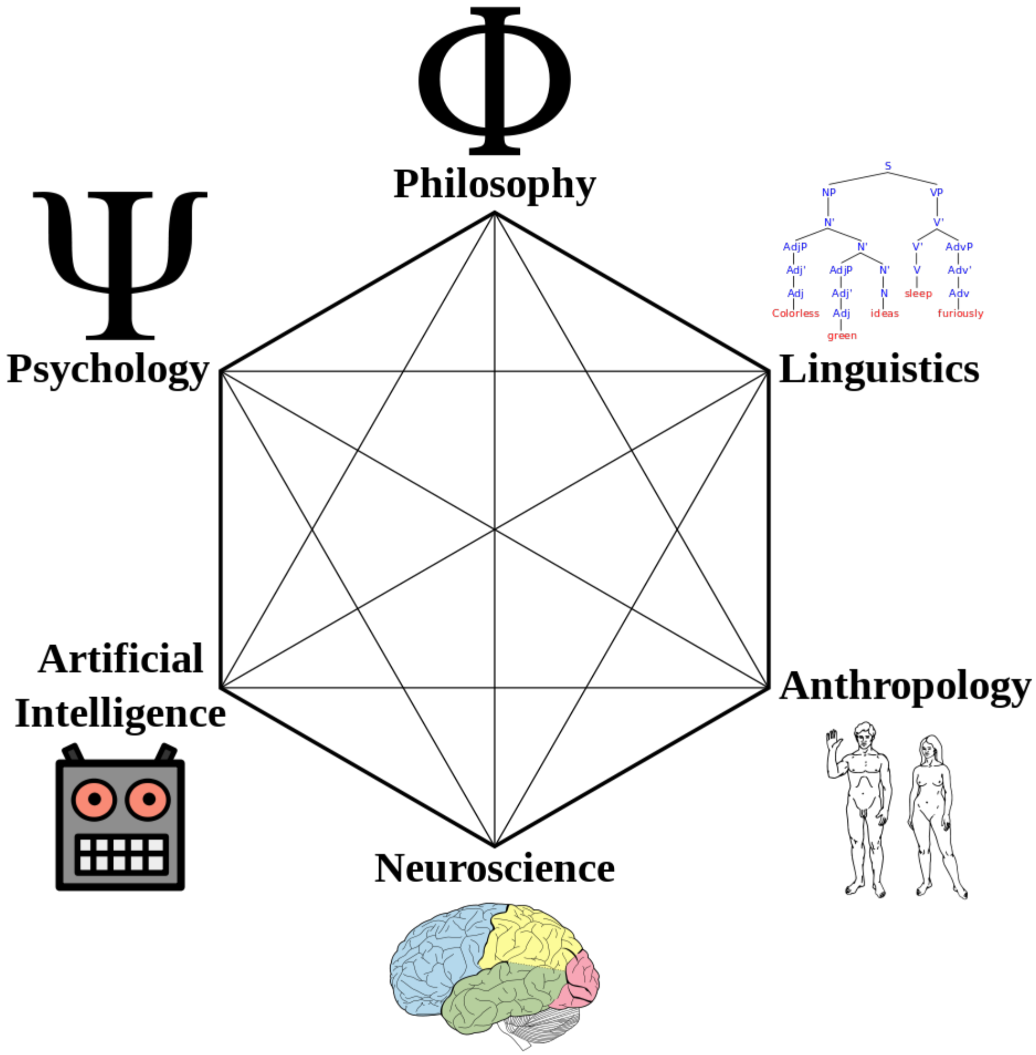
1. What is cognitive science?

According to MIT Press' exhaustive A Companion to Cognitive Science: "Cognitive science is the multidisciplinary scientific study of cognition and its role in intelligent agency. It examines what cognition is, what it does, and how it works."

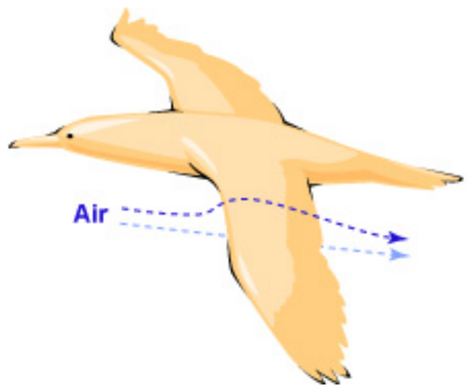
-William Bechtel and George Graham

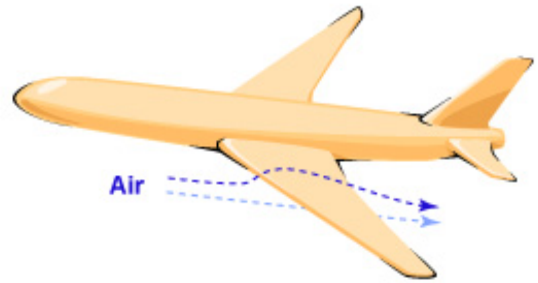
Multidisciplinary!
- crossing traditional disciplinary boundaries or using the methods of more than one area of study.

Problems matter, not disciplines...



Cognitive science as reverse engineering





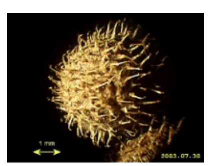
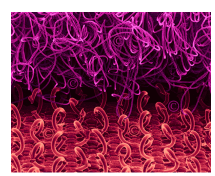
Cognitive science vs. artificial intelligence

- Cognitive science: towards computational models of human intelligence

- Artificial intelligence: aims to build computer systems to do things normally requiring intelligence in humans

But the two are closely related

- The biggest single empirical constraint on any model of a cognitive process is that it solves the task successfully
- And without powerful computational tools, it is impossible even to understand the problems the brain solves
  - Cognitive science needs engineering (Artificial intelligence)
- The *only* working example of an intelligent learning system is the brain
- And many engineering problems are defined in terms of human cognition (from object recognition, to machine translation)
  - Engineering needs cognitive science (cf Biomimetics)

burrs   velcro

Opportunities!

- Field is at early stages
- Only few established “Principles of Cognition”
- Lack of agreement on a number of central issues – active debates
- Multidisciplinary nature of the field
- You all have different backgrounds!

2. A (very) brief history

- Introspection
- Behaviorism
- Cognitive revolution

The beginning of experimental psychology

Wilhelm Wundt (1832-1920)

- Founded first experimental psychology laboratory Leipzig (1879)
- **Structuralism**: “Human mental experience, no matter how complex, can be viewed as blends or combinations of simple processes or elements.”
- But rather than **computational components**, building blocks are **subjective experience** (qualia)

The introspective mind

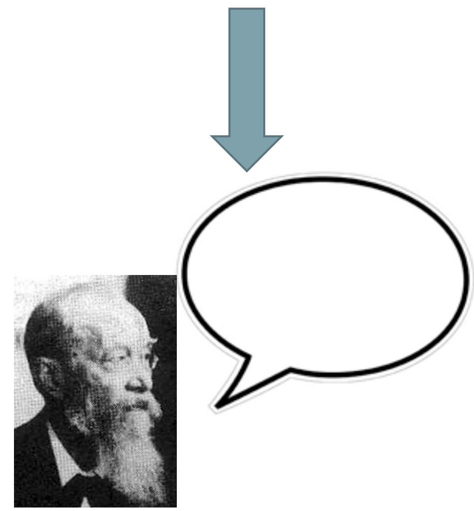
- **Experimental Psychology** "…the investigation of conscious processes in the modes of connection peculiar to them"

- **Method** – Systematic introspection, under experimental control, replicability

The method in action

- very simple stimuli -> verbal report

O listens to a metronome. After a time the beats form rhythmic groupings and various conscious experiences may be reported, such as, at the end of a group there is an impression of an “agreeable whole”. He then tries to describe the qualities of this experience, such as feelings of pleasure or displeasure, tension or excitement



- **Attempt** to isolate the “elements of consciousness” out of which more complex mental events are made.

- **Metronome**: single beat = a sensation
  Combination into rhythms = an idea.

Problems for introspection

- Non-sensorial conscious mental contents: imageless thoughts (Külpe)
- Introspection yielded different results depending on who was using it and what they were seeking
  - Different labs produced very different results (e.g., Leipzig vs. Cornell)
- Introspection can change the phenomenon observed
- Self-analysis was not feasible because introspective students cannot appreciate the processes or mechanisms of their own mental processes
- Introspective techniques actually resulted in retrospection – the memory of a sensation rather than the sensation itself

The introspection illusion

Taylor Swift
(@taylorswift13)

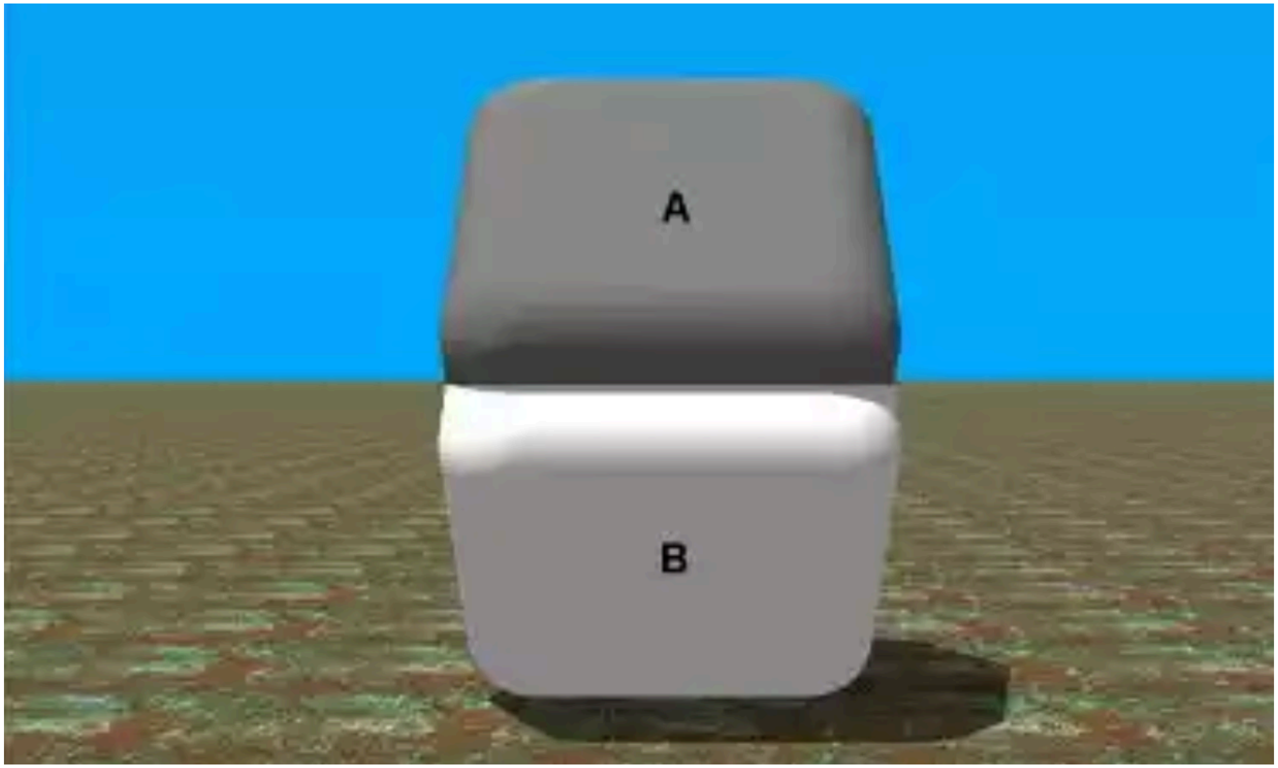
I don't understand this odd dress debate and I feel like it's a trick somehow. I'm confused and scared. PS it's OBVIOUSLY BLUE AND BLACK

February 27, 2015

The unreliability of introspection in perception

- How much can we introspect about the retinal image?

- Endless visual illusions



The unreliability of introspection in perception

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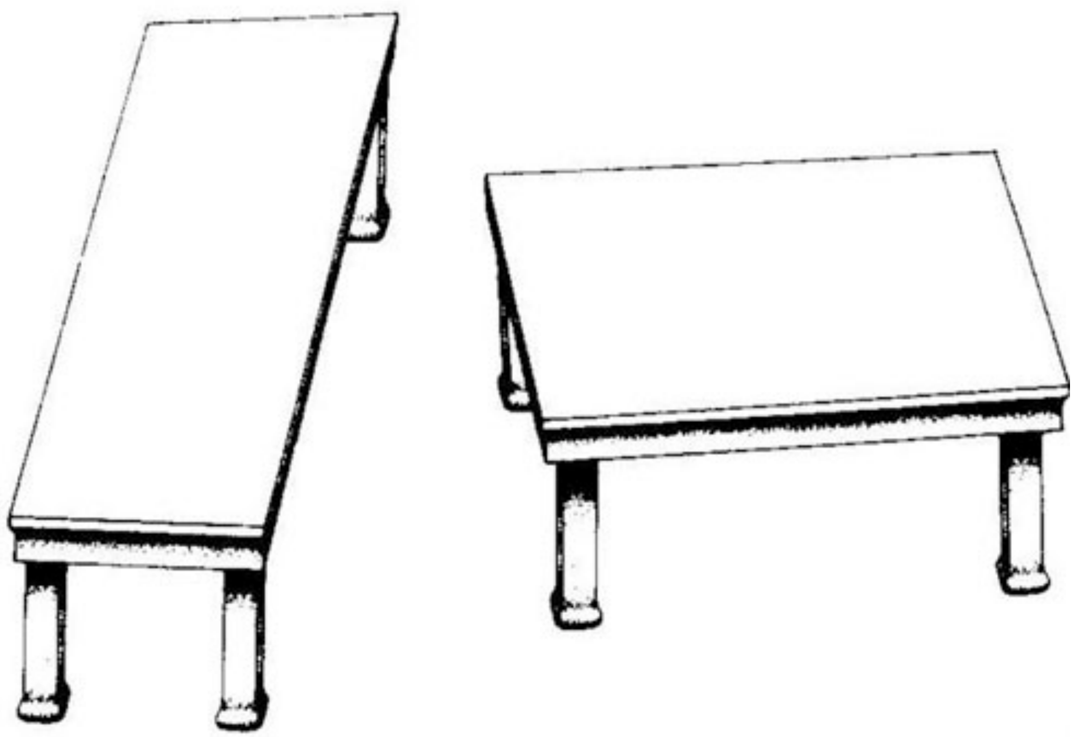


Little better for knowledge or decision

- People often can't explain their behaviour

(Johansson & Hall's choice blindness, Science 2005)

Behaviorism

- Perhaps psychology is not about subjective experience but objective behaviour?

- Emergence of behaviorism: very strong claim that psychological laws should be framed over direct relationships between physically characterised stimuli **(S)** and/or responses **(R)**

- Main method: looking at animal learning: where stimuli and learning can be carefully **controlled** and **measured**

Setting the stage: Pavlov (1849-1936)

Physiologist studying dog digestion, found, by chance, that dog salivation was triggered by a bell that usually preceded food

Thus, the dog had learned an CS-US (bell-food) association

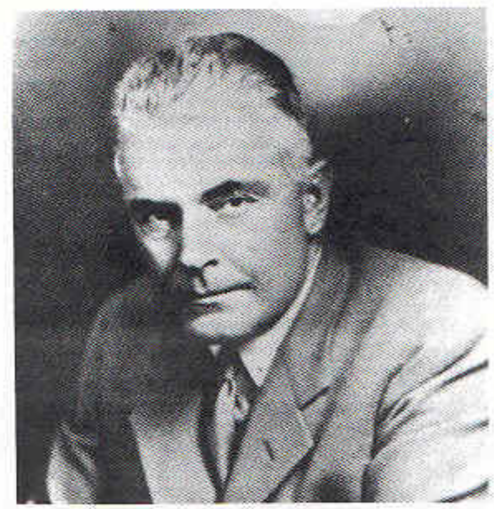
Classical or Pavlovian conditioning

CS = conditioned stimulus (bell) -> CR = conditioned response (salivating)
US = unconditioned stimulus (food)

Founder of behaviorism: Watson (1878–1959)

- **Watson** dismissed introspection as hopelessly unscientific. To be replaced with:
  - Study of **observable behaviour** and observable behavioural responses.
  - **Explained** via Stimulus-Stimulus and Stimulus-Response links
  - **Thought** is movement of the larynx (hidden behaviour)
  - **Using** careful 'operational' definitions of all psychological terms (or tried to)

Psychology as the Science of Behavior

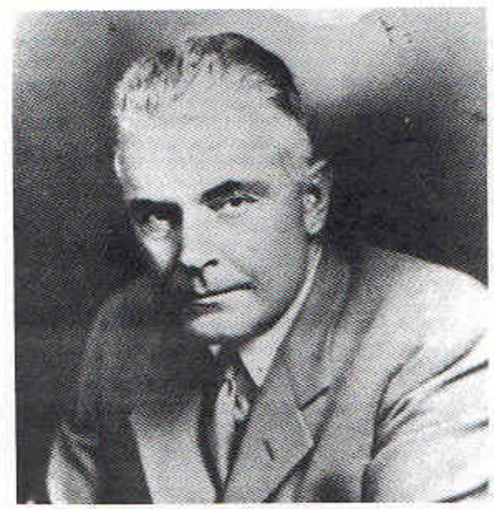


John Broadus Watson (1878–1958). (Archives of the History of American Psychology, University of Akron).

Founder of behaviorism: Watson (1878–1959)

- Psychology is the science of behaviour.
- Psychology is not the science of mind.
- Behaviour can be described and explained without making ultimate reference to mental events or to internal psychological processes.

Psychology as the Science of Behavior



John Broadus Watson (1878–1958). *(Archives of the History of American Psychology, University of Akron).*

Radical behaviorism: Skinner (1904 – 1990)

Further developed behaviorist research, working on **operant or Skinnerian conditioning** (building relationships between Responses and Rewards/ Punishments)

Produced a vast research programme on learning in pigeons in the “Skinner box”

Schedules of food reward determined by, e.g., lever pressing

Starting point for ideas of reinforcement learning in neuroscience and machine learning

PIONEERS OF PSYCHOLOGY

B. F. Skinner with one of his subjects. *[Ken Heyman]*.

And it was radical

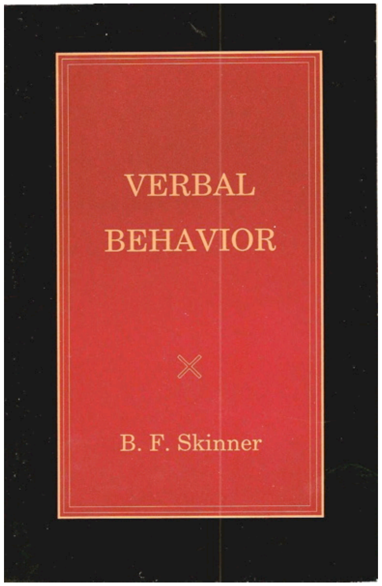
Aimed to explain *all* human behaviour, including language

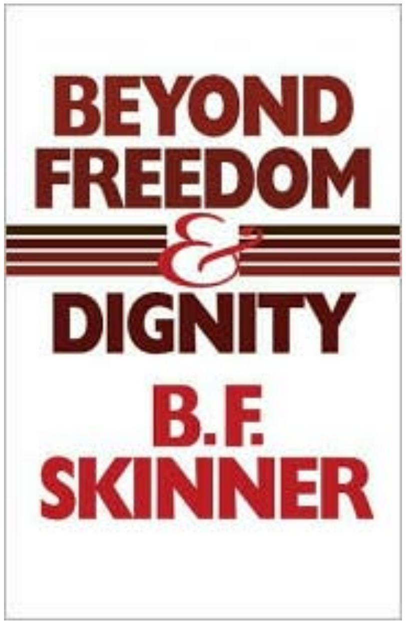
No real theory of perception or motor control

Typically no attempt to link with the brain

Reinforcement history explicitly viewed as the correct alternative to our view of ourselves as reasoning beings.

Only innate structure is principles of association

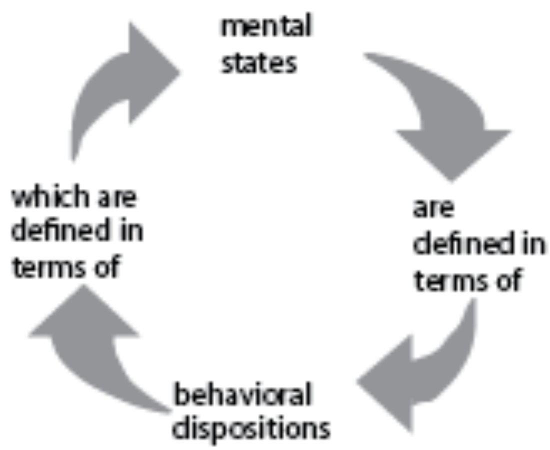




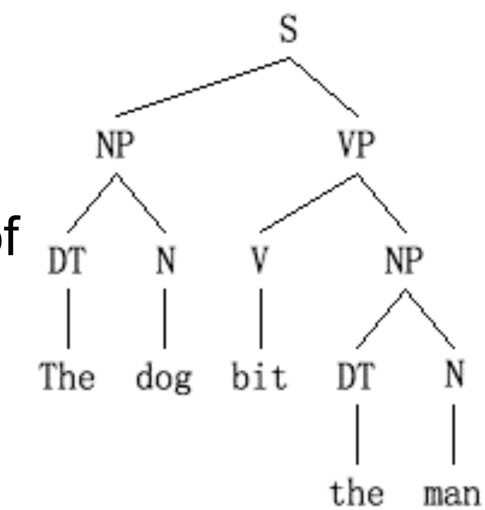
Problems for behaviorism

- Perception and motor control: Associations between categories "lever," "press," - but this is circular – these categories must be explained.

So: circularity



- Language : Chomsky showed that the infinite creativity of language cannot be explained in S-R terms (we learn rules for language, not S-R associations)



Problems for behaviorism

- Chomsky: Language comprehension with mental grammars consisting of rules.

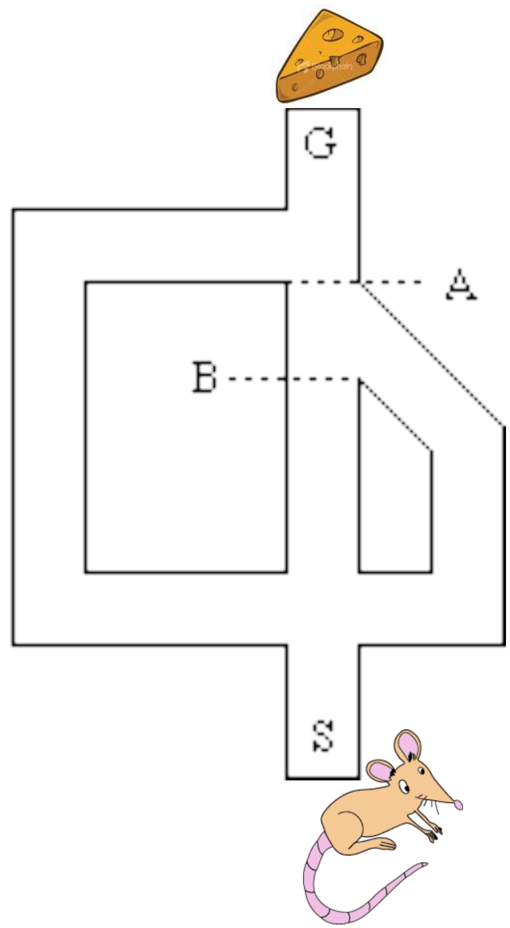
- Behaviorist models cannot explain the rapid acquisition of language by young children, i.e., the phenomenon of “lexical explosion.”

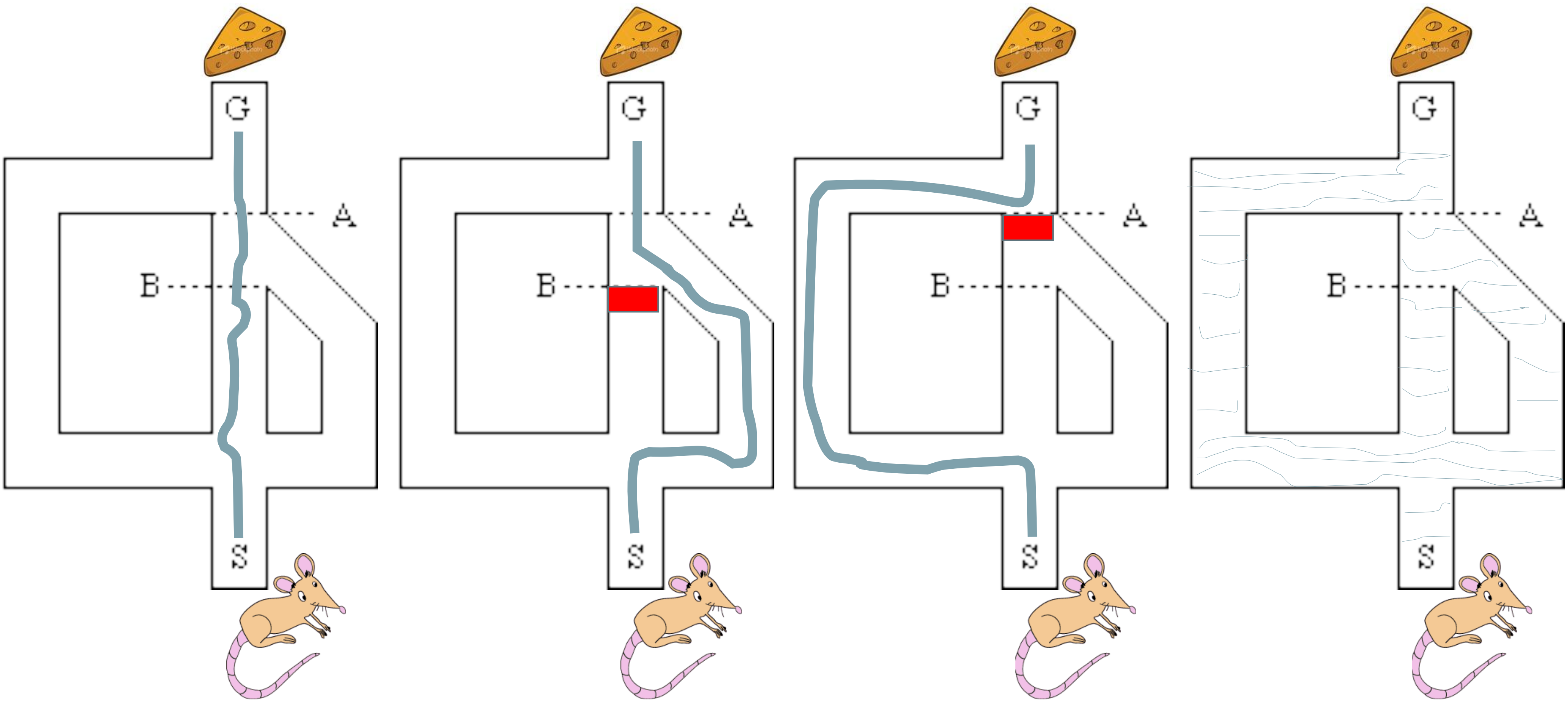
- When put to the test of uttering a grammatical sentence, a person has a virtually infinite number of possible responses available, and the only way in which to understand this virtually infinite generative capacity is to suppose that a person possesses a powerful and abstract innate grammar.

- It appears to be a fundamental fact about human beings that our behavioral capacities often surpass the limitations of individual reinforcement histories.

- **Flexibility of behaviour** i.e., behaviour guided by reasoning to the solution of a novel problem
- **Example** Rats tend to take the shortest route through a maze rather than the one that has been most reinforced

  (Hull and Tolman)

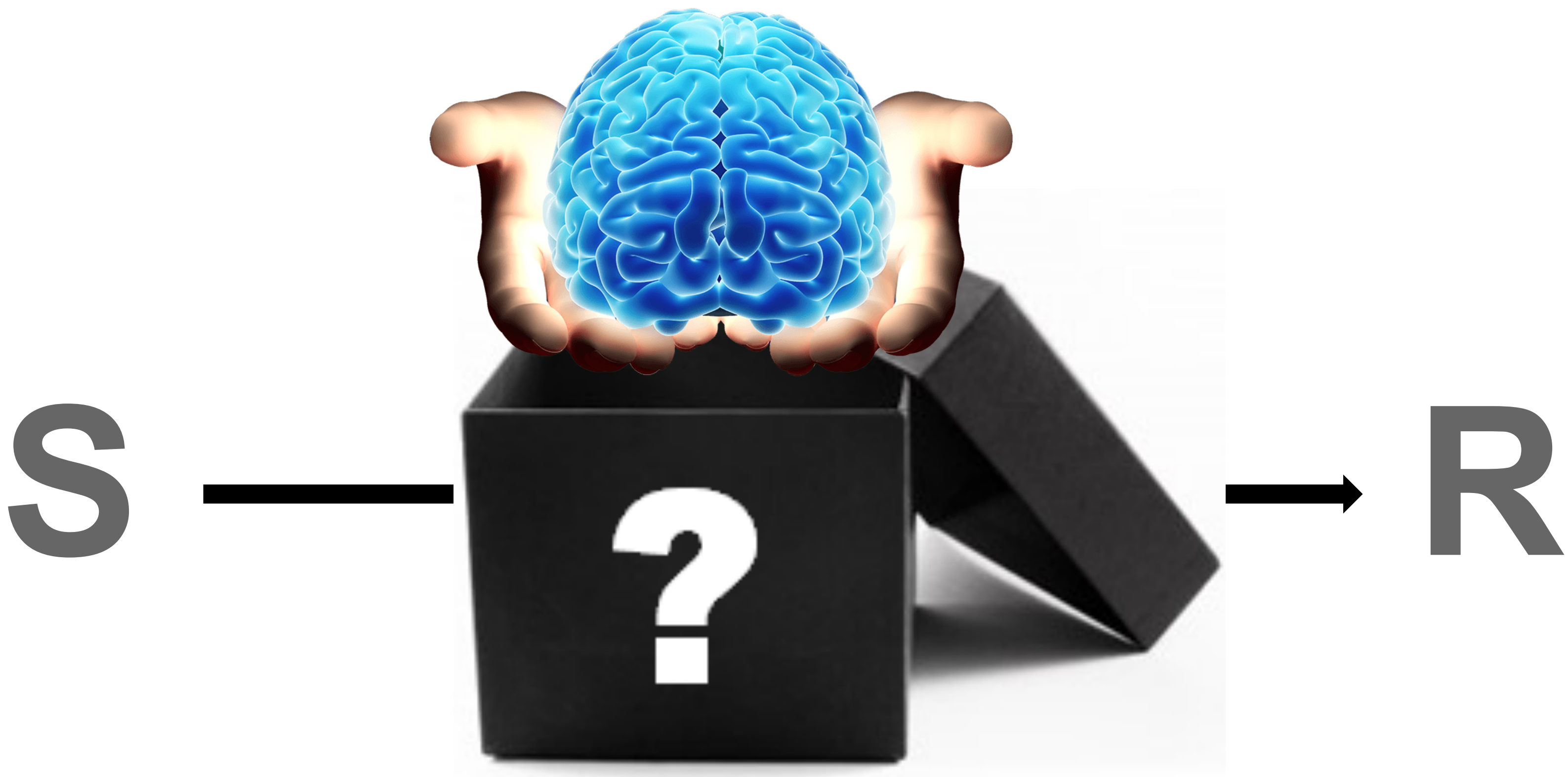




S-R links are radically different!

"Stimulus, response! Stimulus, response! Don't you ever *think*?"

Suggests the need to peer inside the "black box"



Suggests the need to peer inside the “black box”

- Rats with maps
- Abstract goals
- Human Language
- Beliefs about causality
- Other minds
- Memory

Computation as a framework

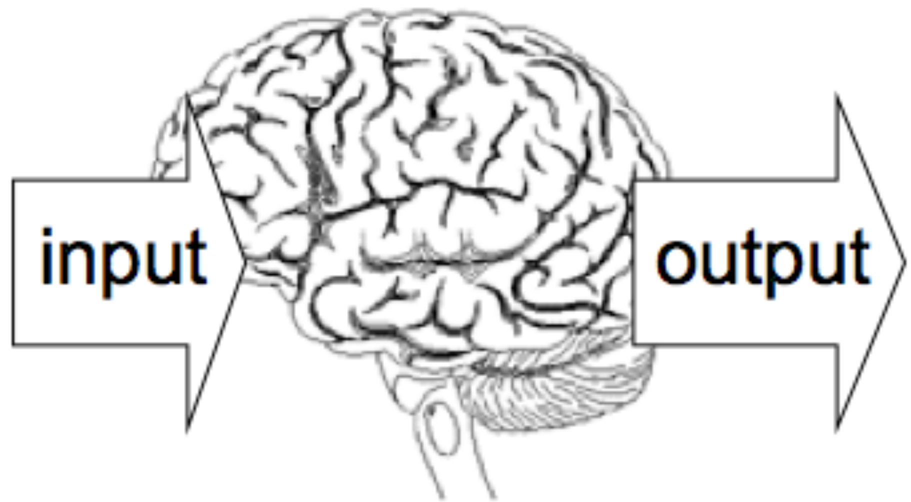
The cognitive revolution

- **Cognitive science** gradually emerged through the late 40s, 50s, and 60s in the work of Kenneth Craik, George Miller, Jerome Bruner, Herbert Simon, Alan Newell, Noam Chomsky…
- Allowed the mind back in to mediate between S and R, in causing intelligent behaviour
- Cognition as **computation**
- At this time, primitive computers had been around for only a few years, but pioneers such as John McCarthy, Marvin Minsky, Allen Newell, and Herbert Simon were founding the field of **artificial intelligence**

Information Processing Assumption

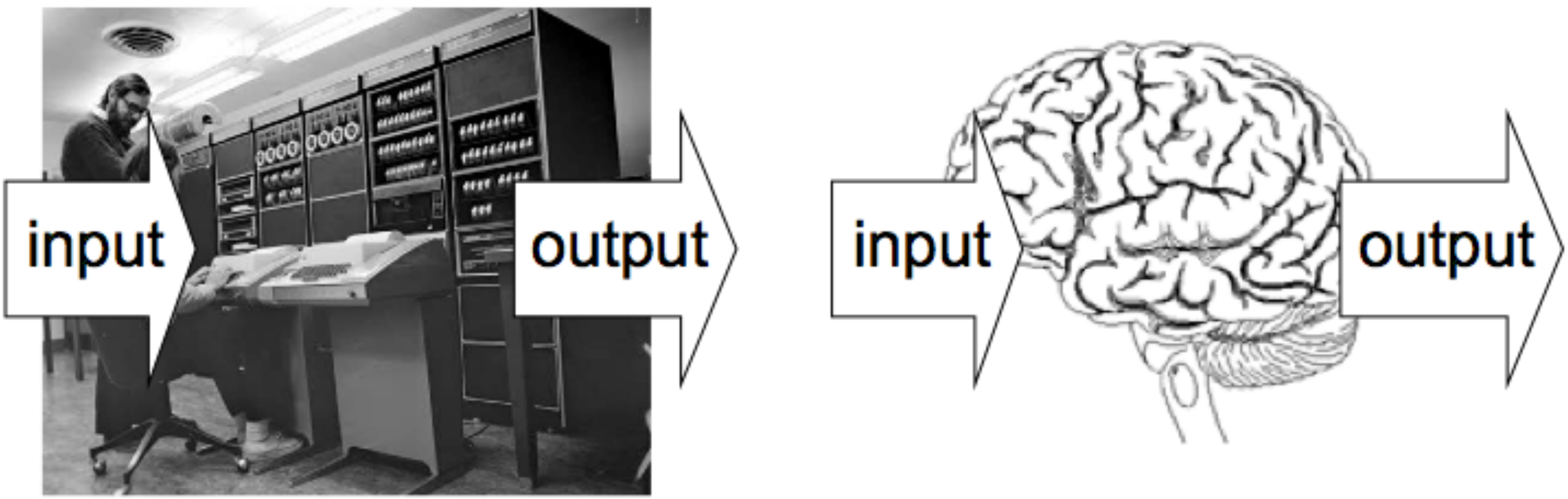
"The mind is a complex system that receives, stores, retrieves, transforms and transmits information. These operations are called computations or information processes."

Brain as Computer



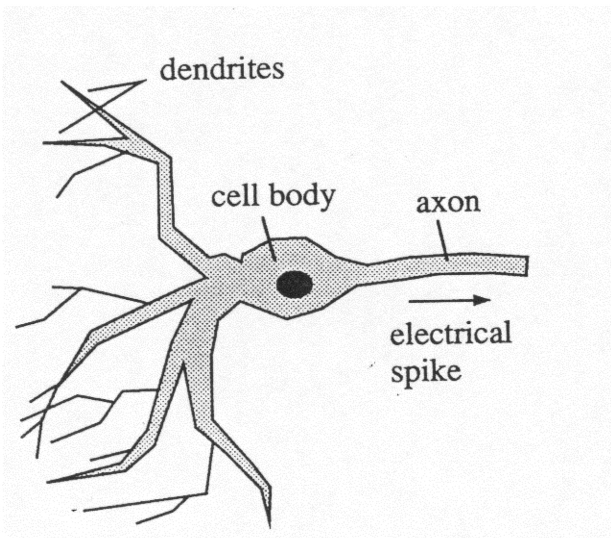
Brains vs. Computers

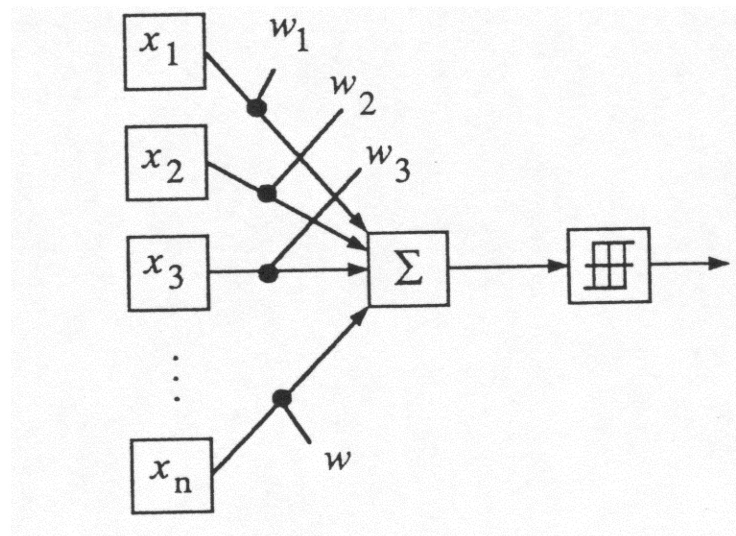
Brain as Computer



Natural versus Artificial Neuron

McCullough Pitts Neuron (1943)





AI beginnings

- The first AI conference (1956): Dartmouth College
- Newell & Simon: The first computer programme:
  The Logic Theorist
- “Logic Theory Machine” (1956): "In this paper we describe a complex information processing system, which we call the logic theory machine, that is capable of discovering proofs for theorems in symbolic logic. “
- 1st draft of Marvin Minsky's "Steps toward AI"

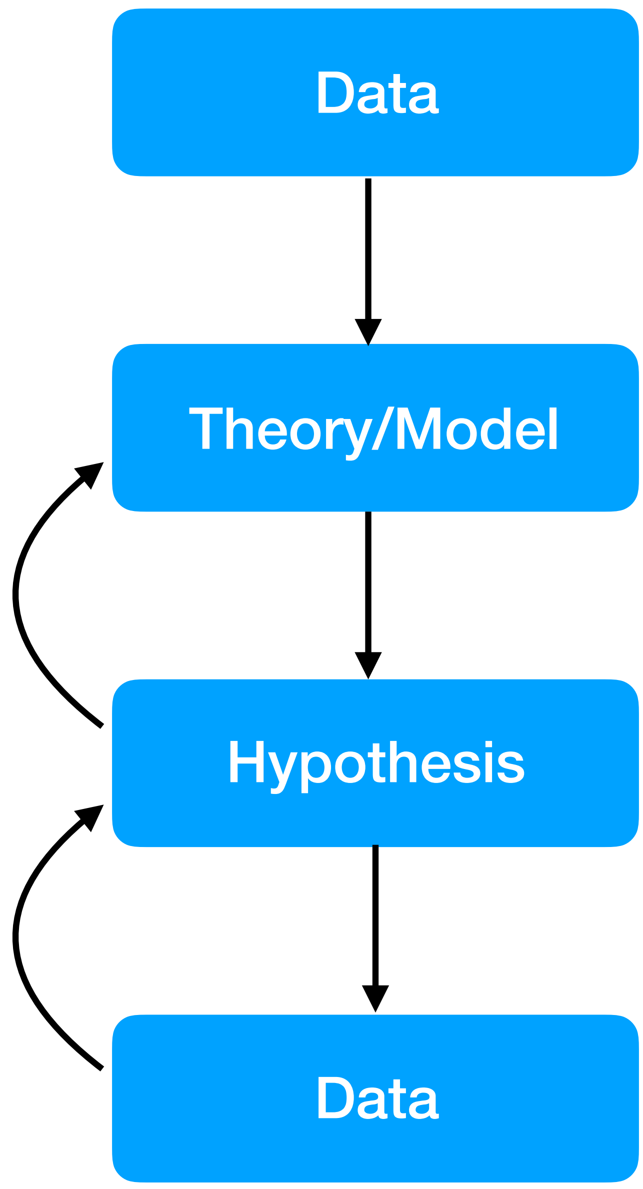
The birth of cognitive science

11 September 1956: Symposium on Information Theory at MIT
(Revolution against behaviorism)

<u>THEME</u>: *Is cognition ‘information processing’ (data+ algorithms)?*

Allen Newell & Herbert Simon (AI)
The first computer program
McCarthy, Minsky (AI)
Modelling intelligence
George Miller (Experimental psychology)
"*Human Memory and the Storage o Information”: magic number 7*
Noam Chomsky (Linguistics)
Transformational grammar

3. Methods in cognitive science


Data
Theory/Model
Hypothesis
Data

What is a model?

Loosely speaking, a model of brain function is simply a description of how a particular process (for example, goal-directed movement) works in the brain

Many different forms:

- Box diagram
- Verbal description
- Simple mathematical model of a psychophysical relation
- Complex neural network involving several mathematical equations

What is a hypothesis?

Loosely speaking, a model of brain function is simply a description of how a particular process (for example, goal-directed movement) works in the brain

Many different forms:

- Box diagram
- Verbal description
- Simple mathematical model of a psychophysical relation
- Complex neural network involving several mathematical equations

Observation

E.g. Piaget’s (1936) theory of cognitive development

- how a child constructs a mental model of the world
- observe how fundamental concepts (e.g. number, time, quantity, causality) emerge
- schemas: the basic building blocks of cognitive models, that enable us to form a mental representation of the world
- “units” of knowledge

Controlled experiments

- An investigation in which a **hypothesis** is scientifically tested
- Aim: Establish cause and effect
- Designing, building, and experimenting with computational models is the central method of artificial intelligence (AI)
- Ideally in cognitive science, computational models and psychological experimentation go hand in hand…

Behavioural studies

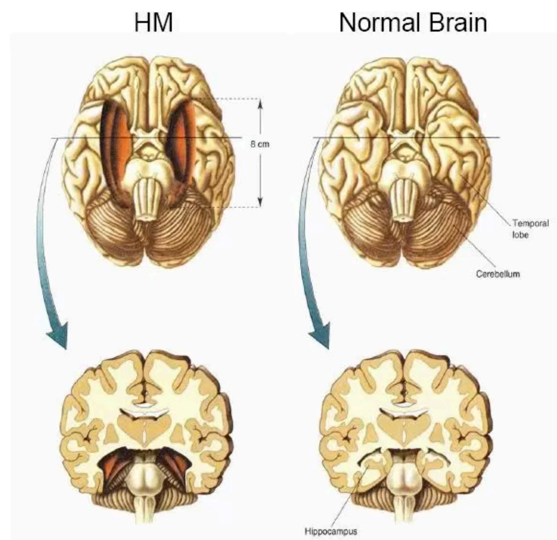
people, often undergraduates satisfying course requirements, are brought into the laboratory so that different kinds of thinking can be studied under controlled conditions.

→ **Amazon Mechanical Turk**

Patient (lesion) studies

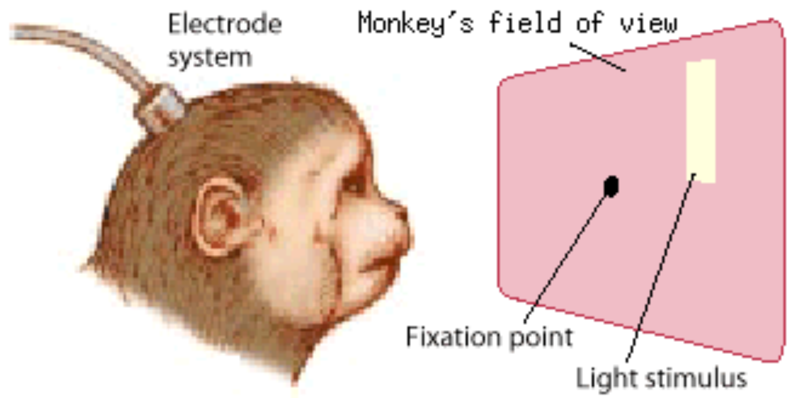
- language: Broca’s and Wernicke’s patients
- memory: HM (Henry Molaison)
- perception, consciousness: split-brain patients

HM

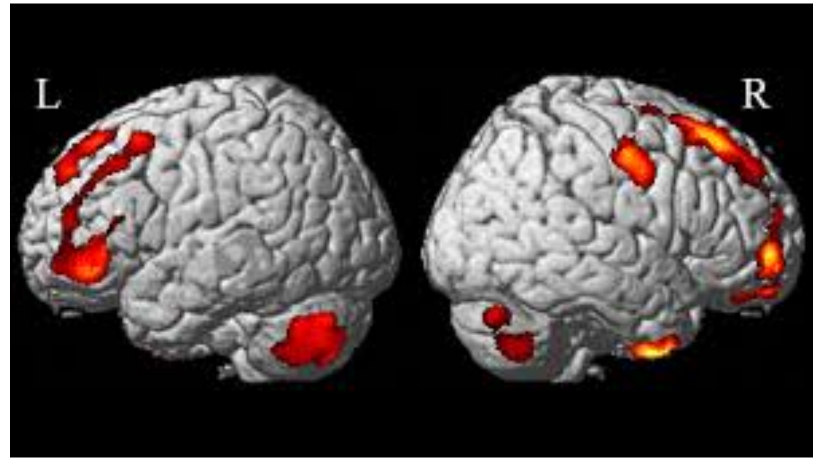


Single-cell recordings

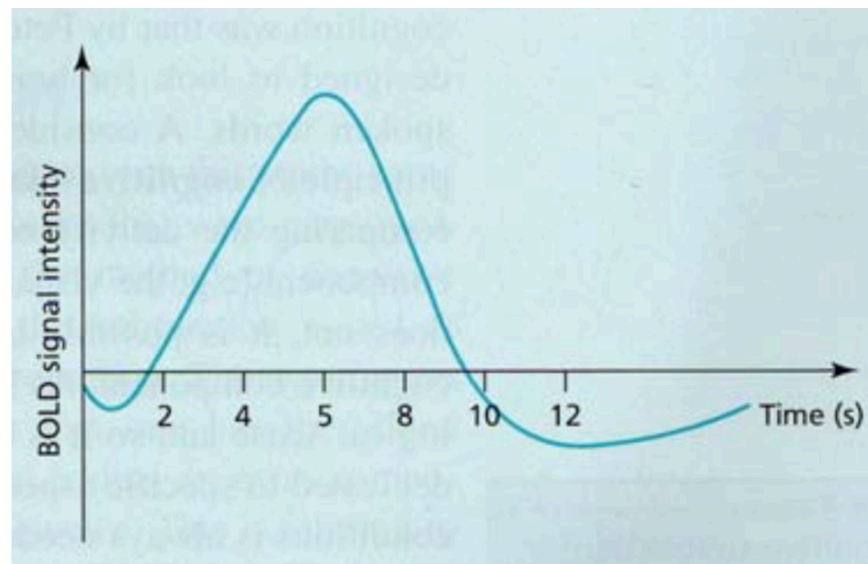
“place cells” in the hippocampus (O’Keefe & Dostrovsky, 1971)



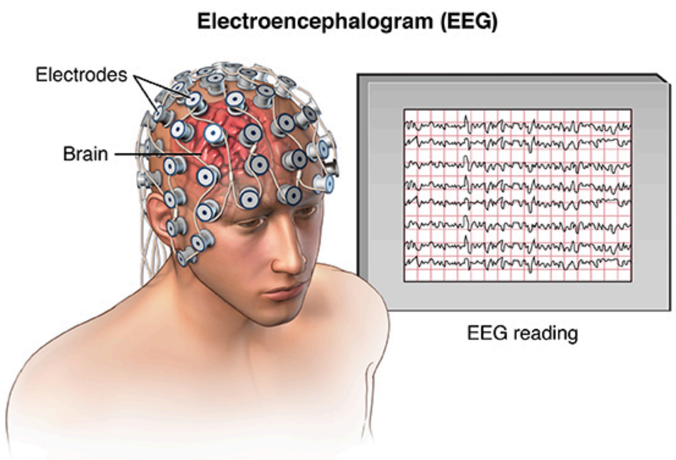
Functional MRI (fMRI)

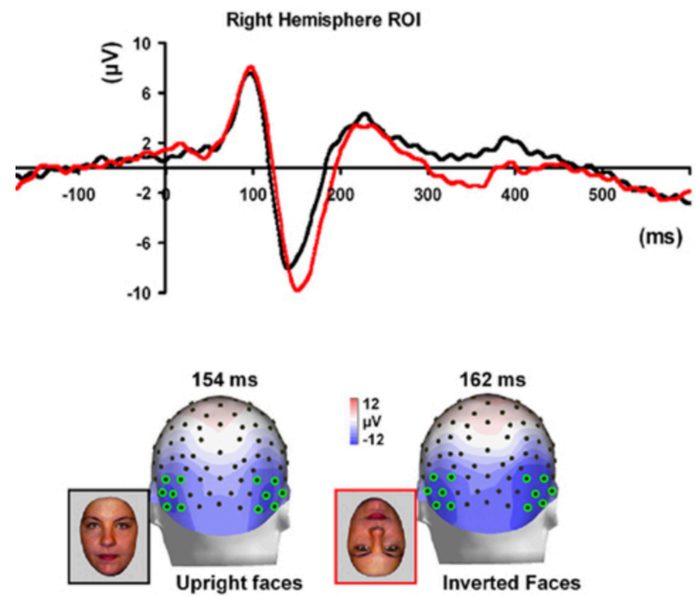


- Indirect measure of neural activity
- Neural activity -> blood oxygenation level
- Oxygenated and de-oxygenated blood have different magnetic properties
- Powerful magnets measure this
- Results -> identify brain areas engaged by some form of cognitive activity
- High spatial resolution (~1mm)
- Poor temporal resolution (seconds)



EEG (Electroencephalogram)





- Direct measure of neural activity
- Active neuronal population create electromagnetic field
- EEG detects electrical component on scalp (field must be large)
- Requires summated activity of many neurons, active synchronously
- Poor spatial resolution
- High temporal resolution (1ms)

MEG (Magnetoencephalogram)

- Direct measure of neural activity
- Detects magnetic component of neuronal activity
- Better spatial resolution
- High temporal resolution (1ms)

4. Levels of analysis

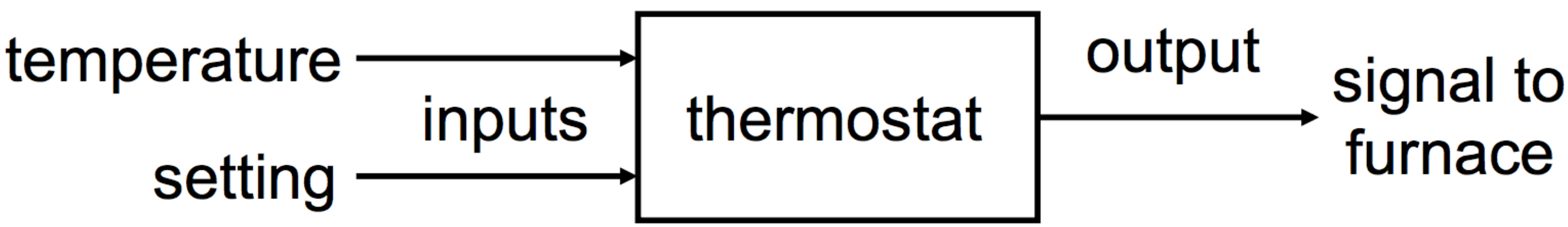
Three levels of analysis

Marr (1982)	Pylyshyn (1984)	Some textbooks
computational	semantic	content
algorithmic	syntactic	form
implementational	physical	medium

Marr (1982)	
computational	• What problem is the device solving? (Goal) • What information is required? • What is the structure of the environment? • What is the logic of the strategy by which it can be carried out
algorithmic	• What is the representation for the input and output? • What is the algorithm for the transformation? • What processes does the device execute to produce the solution?
implementational	• How are those algorithms implemented? (hardware: brain, computer)

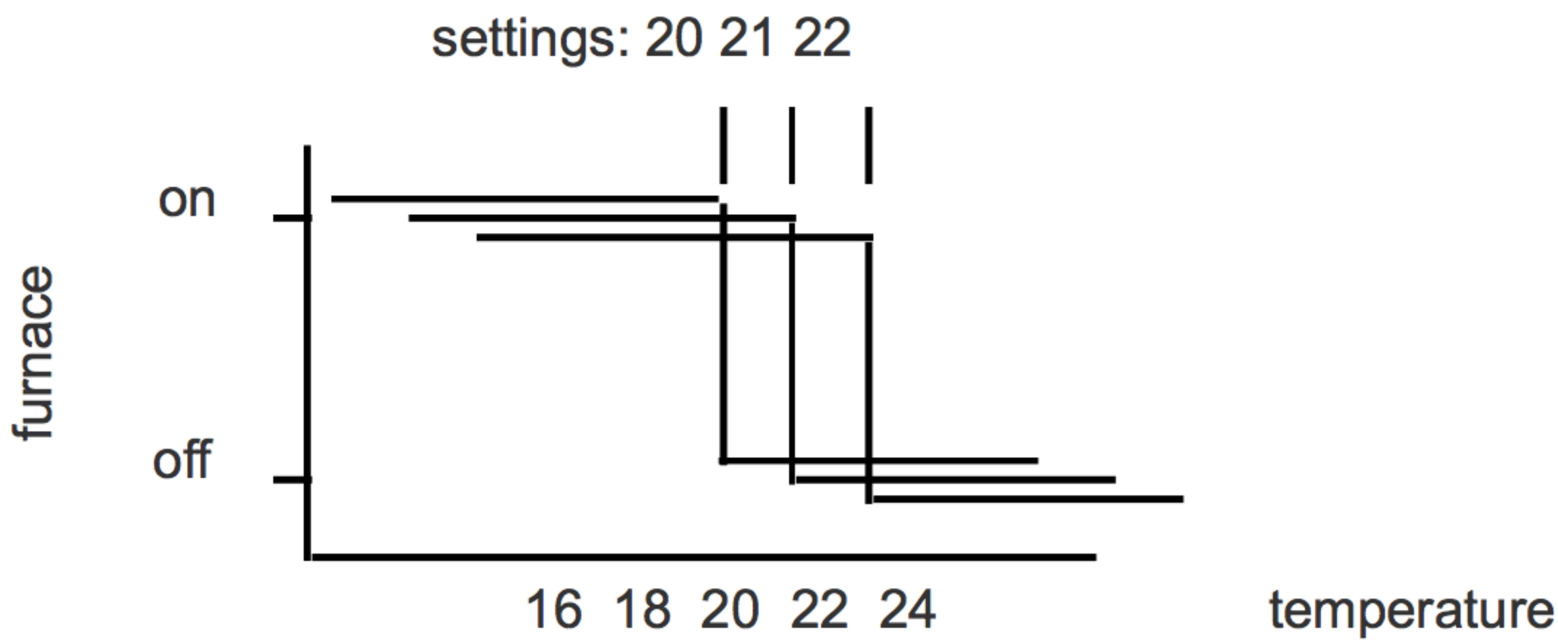
Example

1) Computation



Example

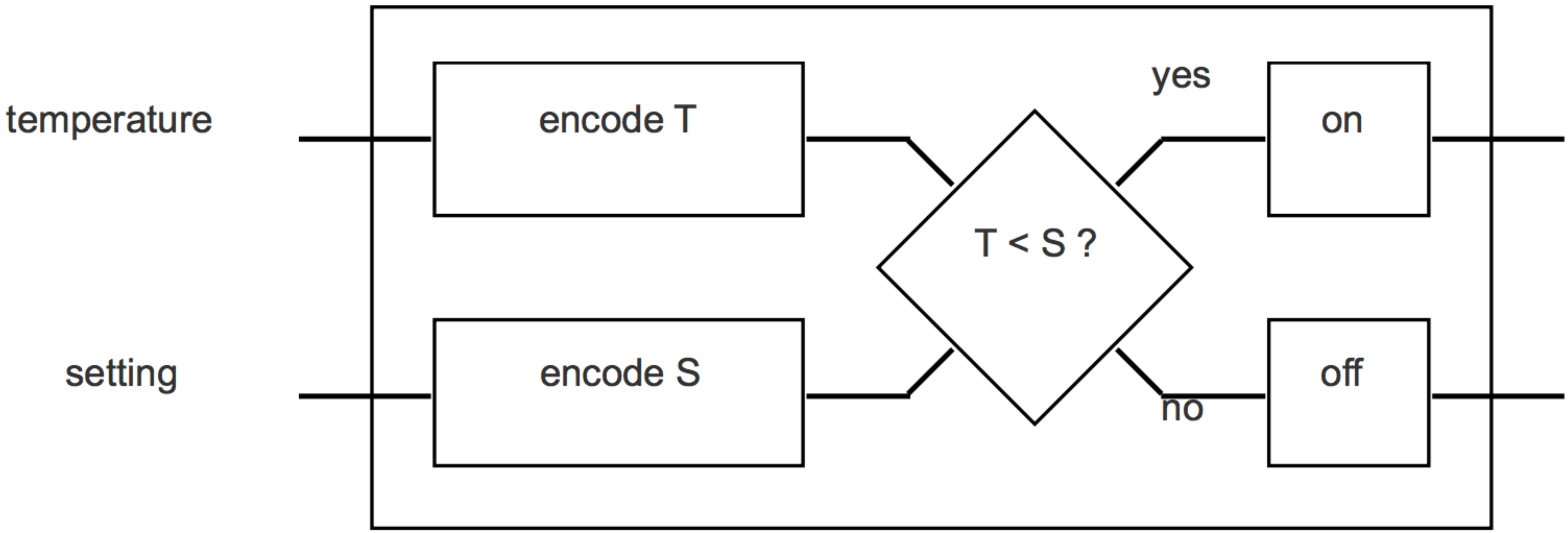
1) Computation



$$O(T, S) = \begin{cases} 1 \text{ iff } T < S \\ 0 \text{ iff } T \geq S \end{cases}$$

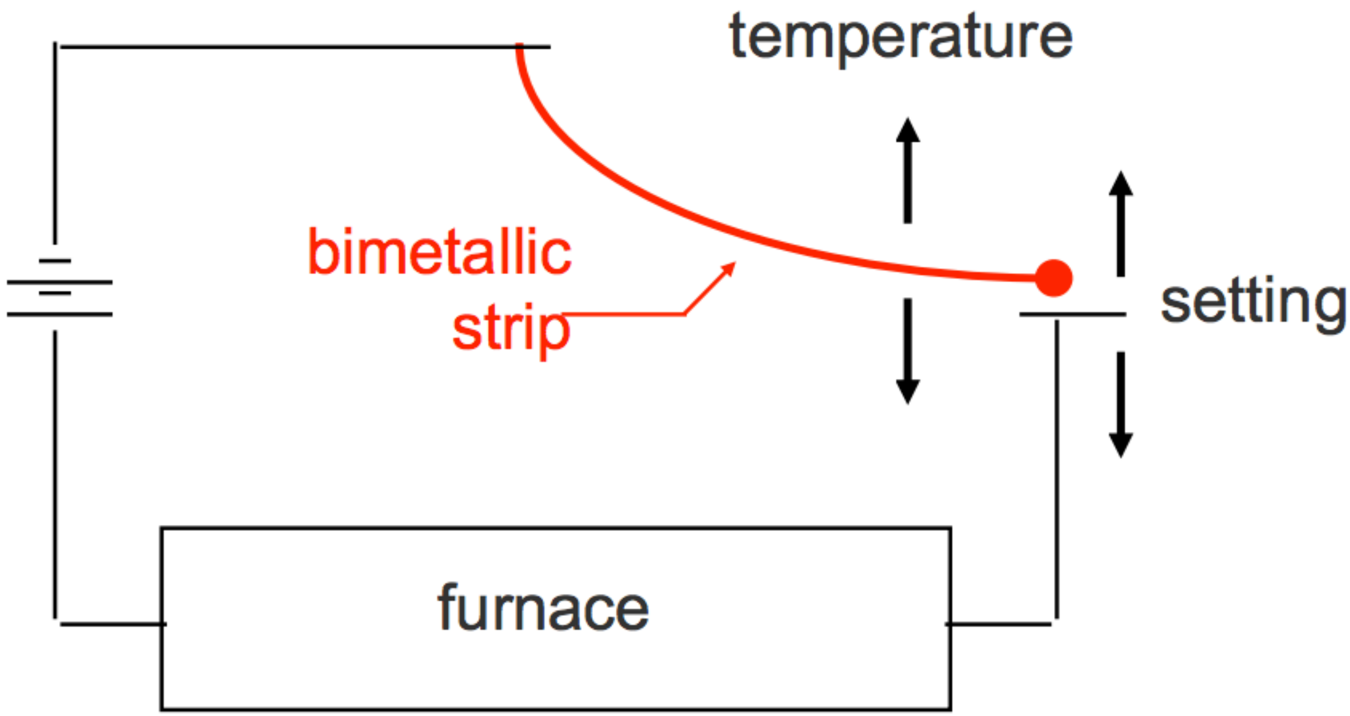
Example

2) Representation and algorithm



Example

3) Implementation



Enjoy the course!