Cognitive (Neuro) Psychology

I. Introduction

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So far ...

- Introduction to Neurobiology
- Sensory Physiology
- Programming

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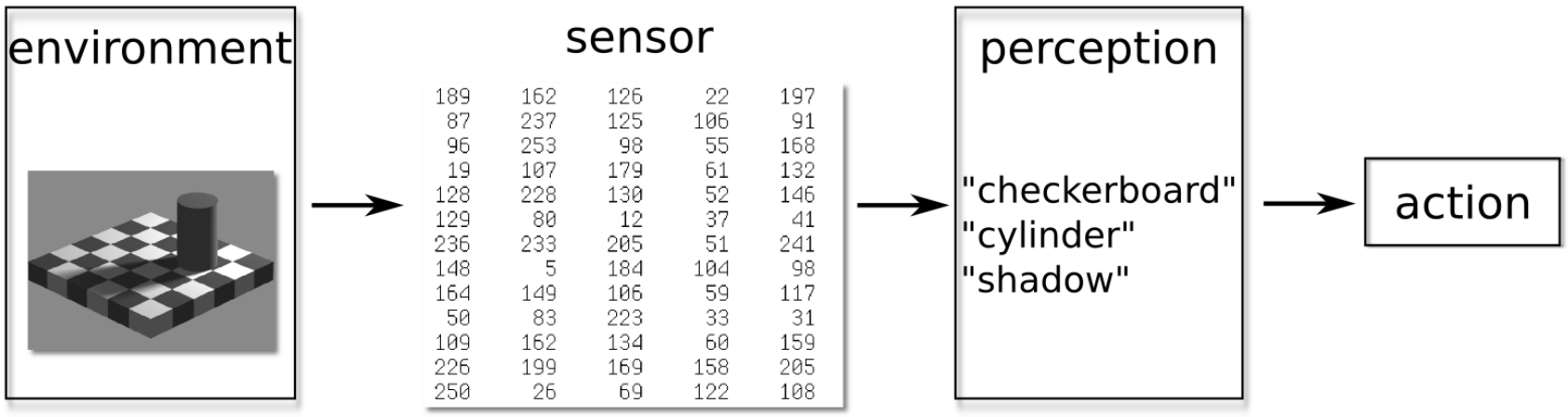
- Sensory Physiology
- Programming
- Cognitive (Neuro)Psychology

What do you expect?

Human cognition



Human cognition

Internal processes involved in making sense of the environment and deciding what action might be appropriate.
These processes include:

- attention
- perception
- learning
- memory
- language
- problem solving
- reasoning
- thinking

Thinking

You cannot observe atoms directly. We still think they exist. Why? We cannot observe thoughts in other people directly. We still think they exist. Why?

Approaches to Human Cognition

1. Cognitive Psychology
2. Cognitive Neuropsychology
3. Cognitive Neuroscience
4. Computational Cognitive Science

What is Cognitive Psychology?

Scientific attempt to understand human cognition by observing the behavior of people performing various cognitive tasks.

What is Cognitive Psychology?

- Miller (1956) - magical number 7 ± 2
- Bruner, Goodnow, & Austin (1956) - a study of thinking
- Broadbent (1958) - filter theory
- Newell & Simon (1972) - a general problem solver
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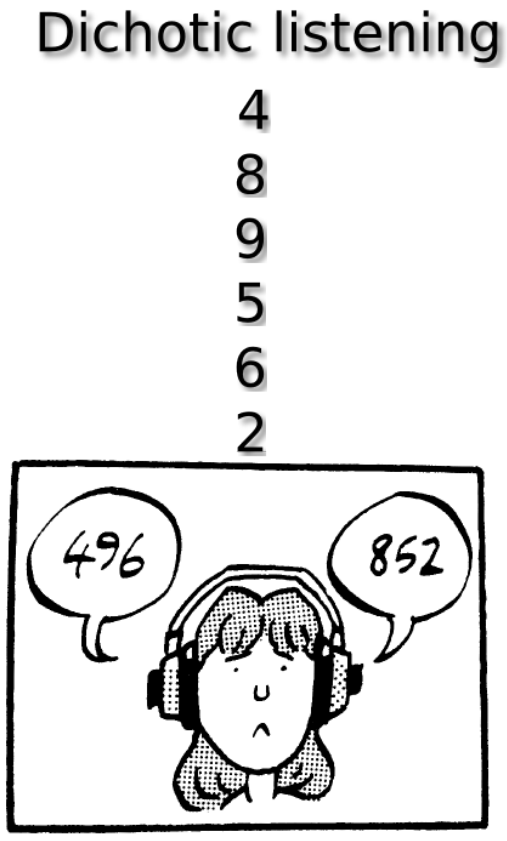

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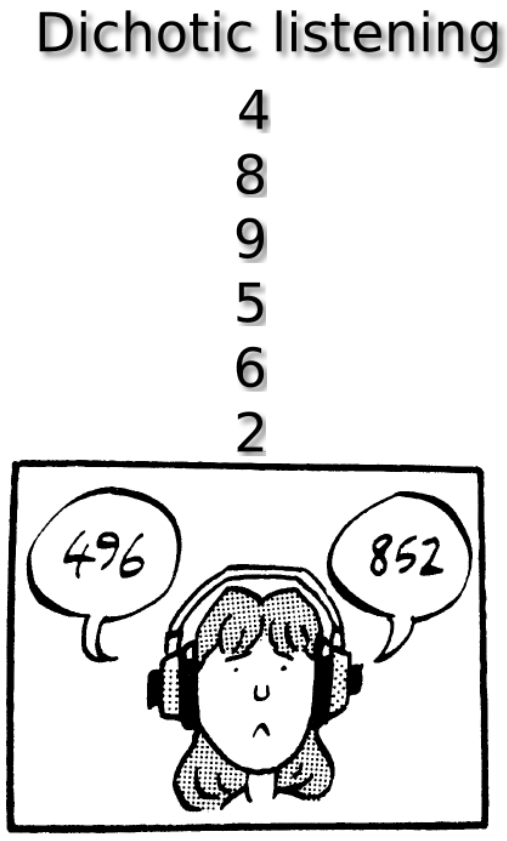
$\Rightarrow$ capacity limits



The computer metaphor

Cognition as information processing approach

bottom-up $\longleftrightarrow$ top-down processing

Thinking

In what way is your brain like a digital computer? What are the differences? Do they matter for the computer metaphor?

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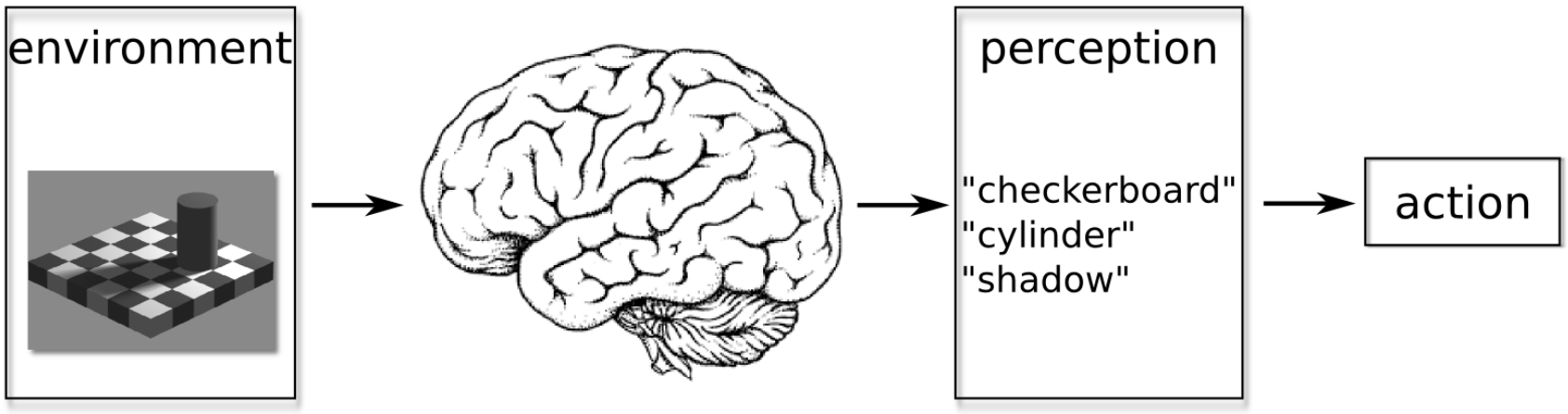
- Cognitive Science - Cognitive Systems - Artificial Intelligence

Human cognition



Cognitive Neuropsychology

Idea: look at patterns of cognitive performance (intact and impaired) shown by brain-damaged patients

! the principle aim is not to learn about the brain, but to elucidate the functional architecture of cognition

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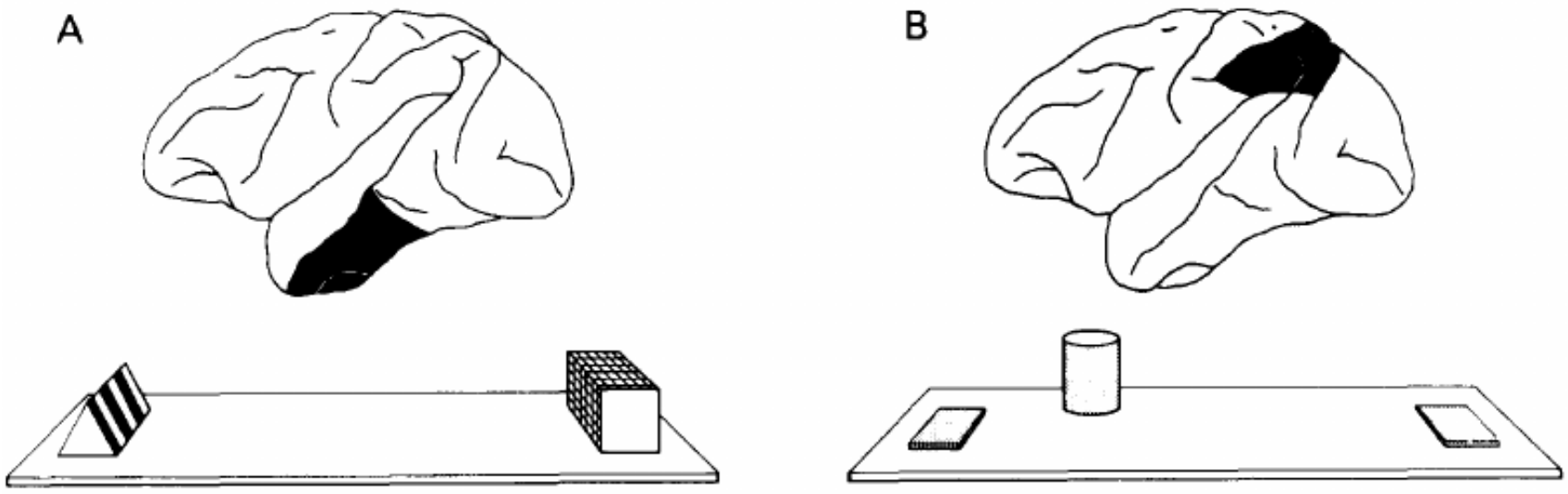
Assumptions:

- Modular organization: functional & anatomical
- Subtractivity: brain damage impairs modules does not add them

Double dissociation

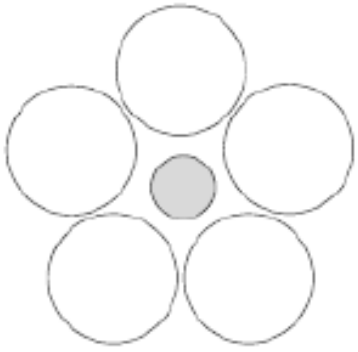


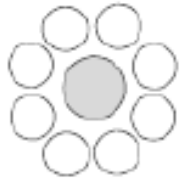
Mishkin, 1983

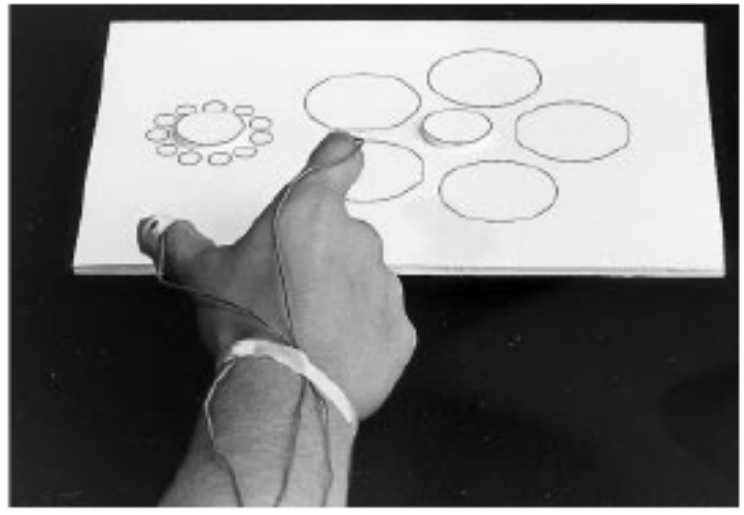
A lesions in ventral stream impair object identification, but not localization

B lesions in dorsal stream impair object localization, but not identification

Dissociation

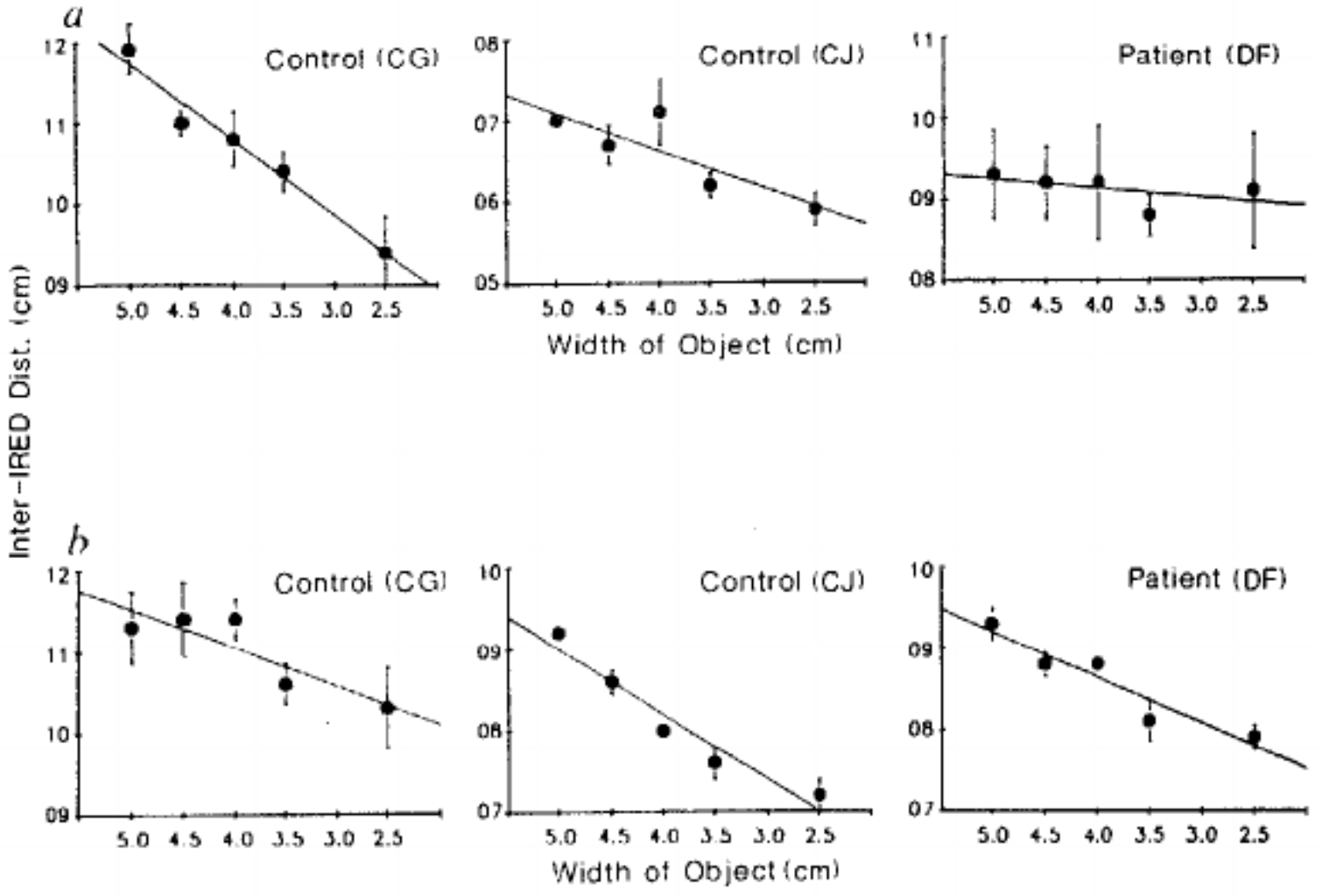






- damage ventrally in lateral occipital region

Dissociation



Goodale et al., 1991

Cognitive Neuropsychology - A critical evaluation

- different patients have different and diffuse lesions
- patients often impaired in more than one function, secondary effects
- interruption of a function by a lesion does not mean that the function is localized in the respective area
- strongest evidence comes from double dissociations but is not fool-proof
- functions may still be distributed over the brain and not localized in one area - why?

Cognitive Neuroscience

- 1928 - 1947 Penfield stimulated brains during brain surgery

  "those fingers and my thumb gave a jump" - stimulation near central sulcus

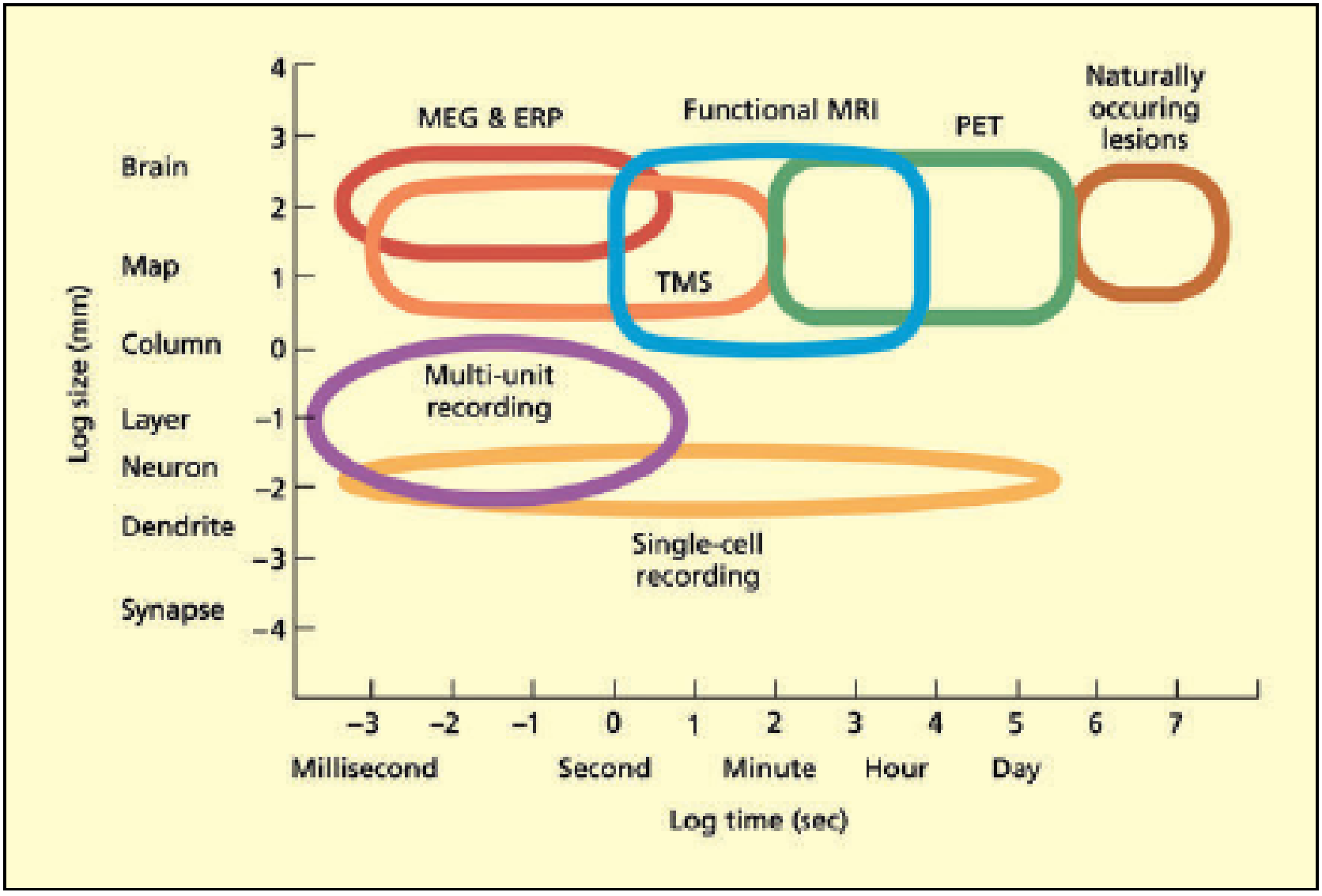
$\Rightarrow$ How are mental processes such as thoughts, memories and perceptions organized and implemented by the brain?

Cognitive Neuroscience

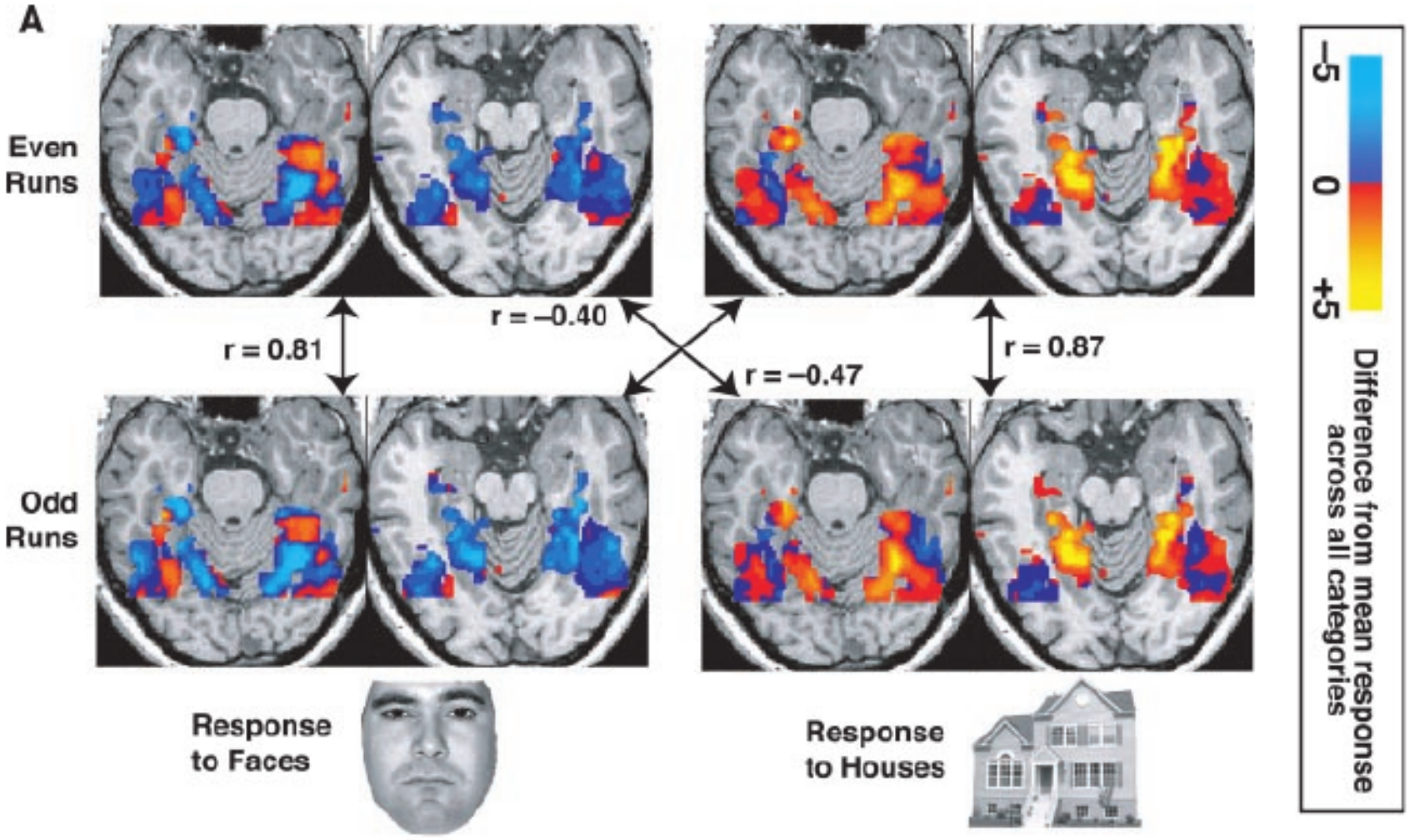
THE DIFFERENT METHODS USED IN COGNITIVE NEUROSCIENCE

Method	Method type	Invasiveness	Brain property used
EEG/ERP	Recording	Non-invasive	Electrical
Single-cell (and multi-unit) recordings	Recording	Invasive	Electrical
TMS	Stimulation	Non-invasive	Electromagnetic
tDCS	Stimulation	Non-invasive	Electrical
MEG	Recording	Non-invasive	Magnetic
PET	Recording	Invasive	Hemodynamic
fMRI	Recording	Non-invasive	Hemodynamic

Cognitive Neuroscience



fMRI - decoding



Cognitive Neuroscience - a critical evaluation

- blobology - activation in a small area is interpeted as the ’love’ area
- reverse inference - infer involvement of a cognitive process based on activation within a given brain area
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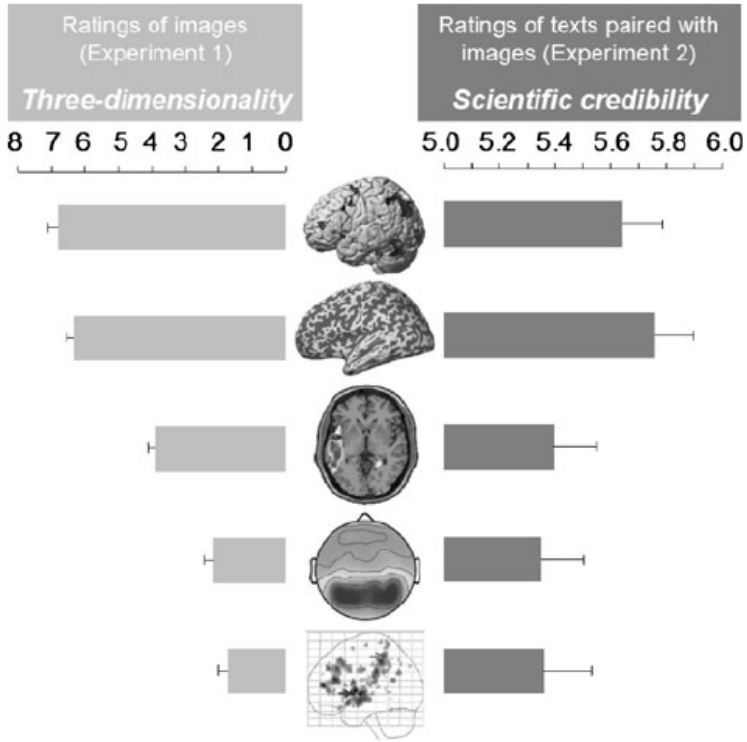

Keehner et al., 2011

Computational Cognitive Psychology

- program computers to mimic aspects of human cognitive functioning

!AI construct systems that produce intelligent behavior but bear little resemblance to those used by humans e.g. deep blue

- a good computational model shows us how a given theory can be specified and allows us to predict behavior in new situations
- requires the researcher to be explicit about a theory in a way a verbal theory does not
- specific $\longleftrightarrow$ generic

What does it mean to understand something, e.g. perception?

What does it mean to understand something, e.g. perception?

Neurophysiology

Psychology

Computational Neuroscience

Neuropsychology

Pharmacology

Robotics

...

Mini-Symposium

Do We Know What the Early Visual System Does?

Matteo Carandini,[1] Jonathan B. Demb,[2] Valerio Mante,[1] David J. Tolhurst,[3] Yang Dan,[4] Bruno A. Olshausen,[6] Jack L. Gallant,[5,6] and Nicole C. Rust[7]

[1]Smith-Kettlewell Eye Research Institute, San Francisco, California 94115, [2]Departments of Ophthalmology and Visual Sciences, and Molecular, Cellular, and Developmental Biology, University of Michigan, Ann Arbor, Michigan 48105, [3]Department of Physiology, University of Cambridge, Cambridge CB2 1TN, United Kingdom, Departments of [4]Molecular and Cellular Biology and [5]Psychology and [6]Helen Wills Neuroscience Institute and School of Optometry, University of California, Berkeley, Berkeley, California 94720, and [7]Center for Neural Science, New York University, New York, New York 10003

We can claim that we know what the visual system does once we can predict neural responses to arbitrary stimuli, including those seen in nature. In the early visual system, models based on one or more linear receptive fields hold promise to achieve this goal as long as the models include nonlinear mechanisms that control responsiveness, based on stimulus context and history, and take into account the nonlinearity of spike generation. These linear and nonlinear mechanisms might be the only essential determinants of the response, or alternatively, there may be additional fundamental determinants yet to be identified. Research is progressing with the goals of defining a single "standard model" for each stage of the visual pathway and testing the predictive power of these models on the responses to movies of natural scenes. These predictive models represent, at a given stage of the visual pathway, a compact description of visual computation. They would be an invaluable guide for understanding the underlying biophysical and anatomical mechanisms and relating neural responses to visual perception.

Key words: contrast; lateral geniculate nucleus; luminance; primary visual cortex; receptive field; retina; visual system; natural images

What does it mean to understand something?

C. elegans

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- complete knowledge of the components of its biological hardware
  - 302 nerve cells, 'wiring diagram' completed
  - 600 gap junctions, 5000 chemical synapses, neurotransmitters and neuromodulators known
  - 19099 genes completely sequenced

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- complete knowledge of the components of its biological hardware
  - 302 nerve cells, 'wiring diagram' completed
  - 600 gap junctions, 5000 chemical synapses, neurotransmitters and neuromodulators known
  - 19099 genes completely sequenced
- "Surprisingly little progress has been made in understanding these (behavioral) responses"

[after Mausfeld, 2003]

What does it mean to understand something?

What does it mean to have understood visual perception?

[Marr, 1982, 2010]

What does it mean to understand something?

What does it mean to have understood visual perception?

- visual perception as an information processing system
- complex systems should be understood at several different levels
- use every bit of information, every approach, every technique that is available to us

[Marr, 1982, 2010]

What is the problem in vision?

http://swiked.tumblr.com/post/112073818575/guys-please-help-me-is-this-dress-white-and

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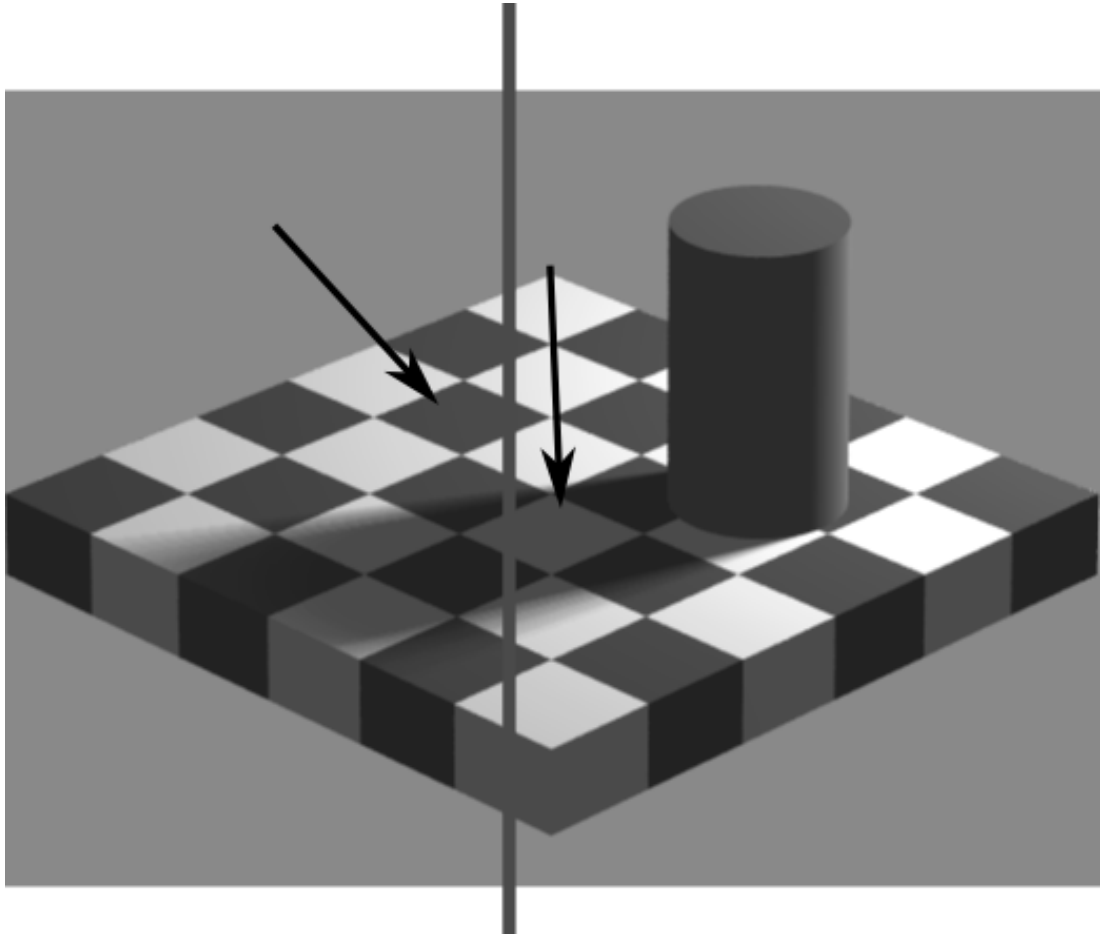
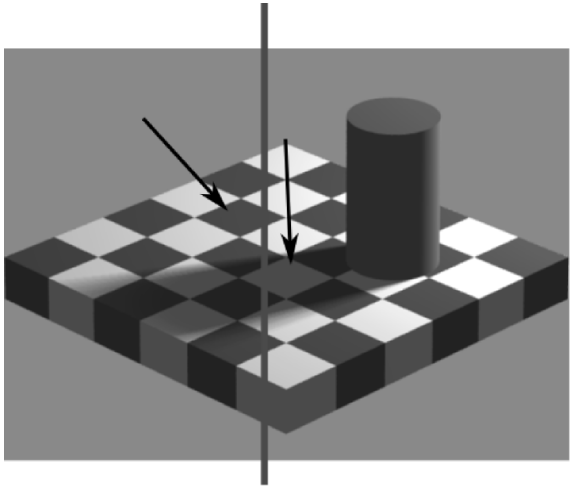
Hurlbert & Brainard, 2015; Gegenfurtner et al., 2015

The retinal input is ambiguous



[after Adelson, 1995]

How does the visual system resolve sensory ambiguity?



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3	30	156	81	87	117	112
171	96	132	30	87	213	78
136	17	139	11	16	151	110
89	25	58	39	8	29	46
38	128	161	9	59	25	15
33	18	40	77	59	132	67
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84	12	81	0	85	140	146
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"black"

"white"

"checkerboard"

"cylinder"

"shadow"

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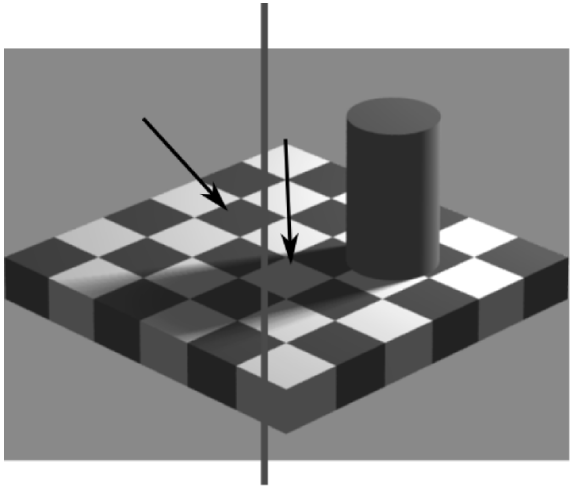

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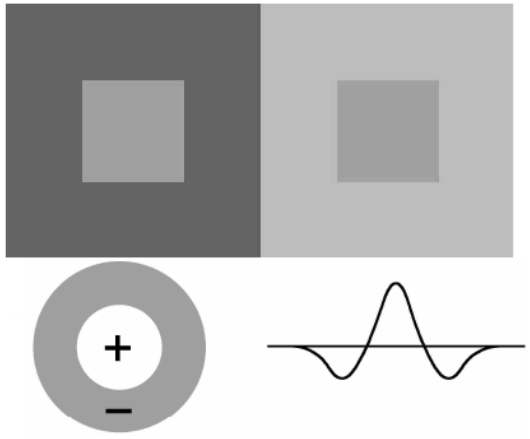
- computation



[Adelson, 2000]

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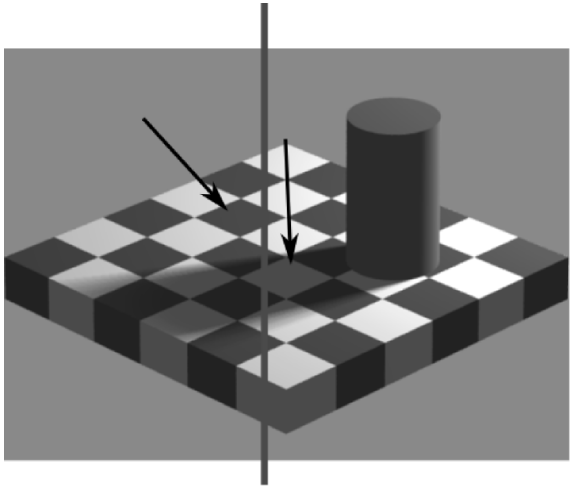

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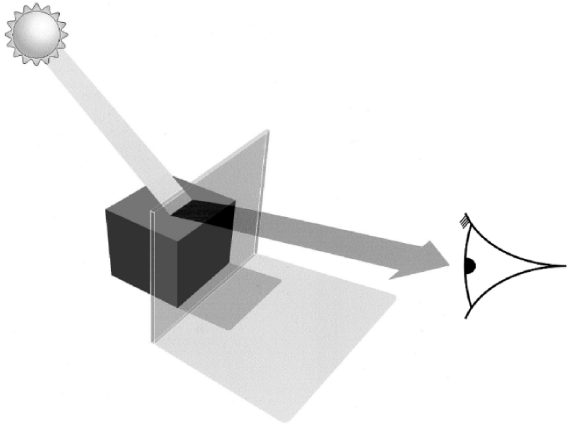
$\Rightarrow$ computational goal

Computational goal

$I(x, y)$

- geometry
- reflectance

- illumination
- viewpoint



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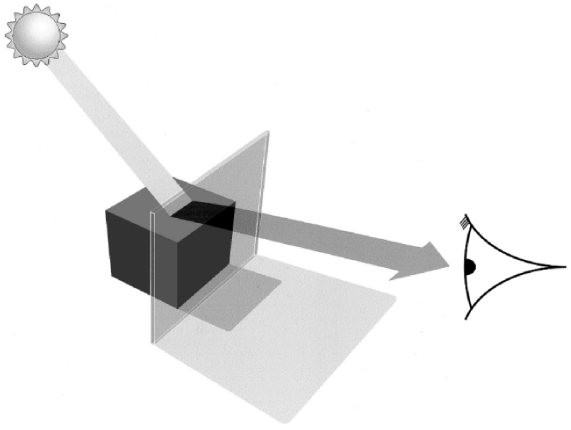

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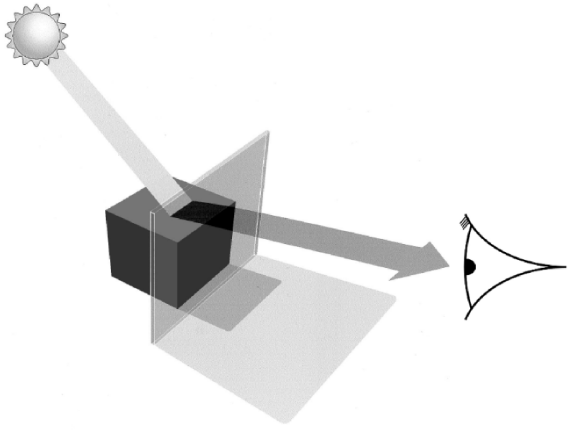

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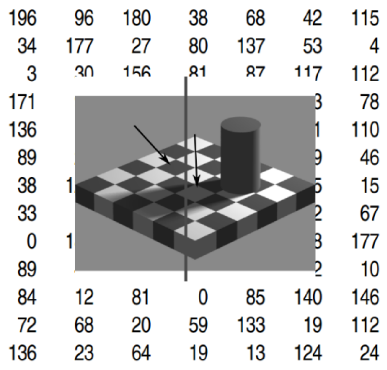

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$\Rightarrow$ create representations in which coincidental fluctuations are separated from changes that are diagnostic for **invariant** object properties

Marr's three levels

Computational theory	What is the goal of the computation, why is it appropriate, and what is the logic of the strategy by which it can be carried out?
Representation and algorithm	How can this computational theory be implemented? In particular, what is the representation for the input and output, and what is the algorithm for the transformation?
Hardware Implementation	How can the representation and algorithm be realized physically?

[Marr, 1982, 2010]

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$\rightarrow$ Understanding perception requires answers at all levels

[Marr, 1982, 2010]

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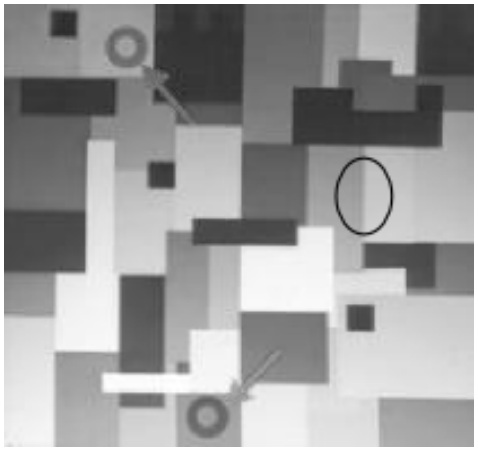
“[...] trying to understand perception by studying only neurons is like trying to understand bird flight by studying only feathers: It just cannot be done. In order to understand bird flight, we have to understand aerodynamics; only then do the structure of feathers and the different shapes of birds’ wings make sense.” [Marr, 2010, p. 27]

Example



computational goal:

- separate illumination from reflectance changes

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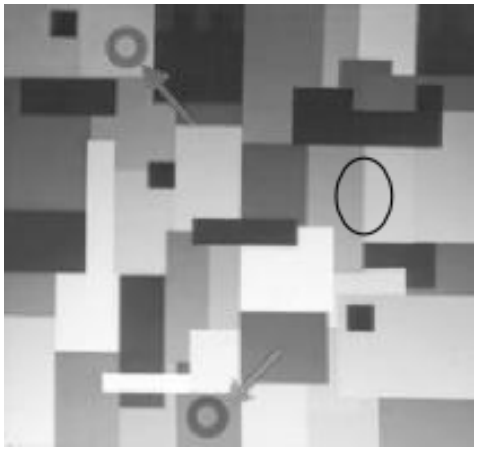

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$\rightarrow$ separate gradual from sharp intensity changes

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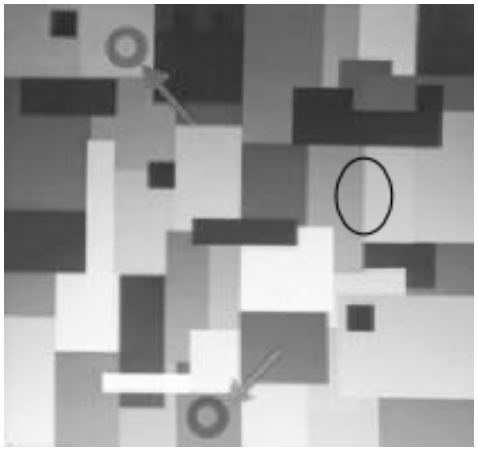

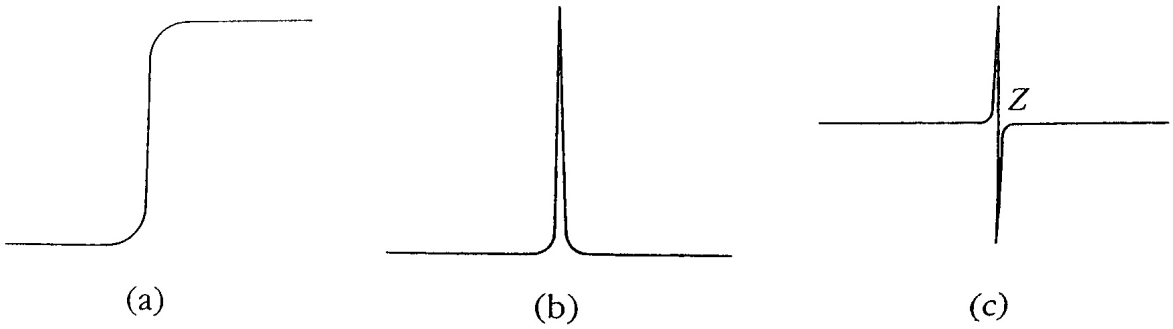

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- intensity steps in an image (a) are peaks in the first derivative (b) across the steps, or zero-crossings in the second derivative (c)

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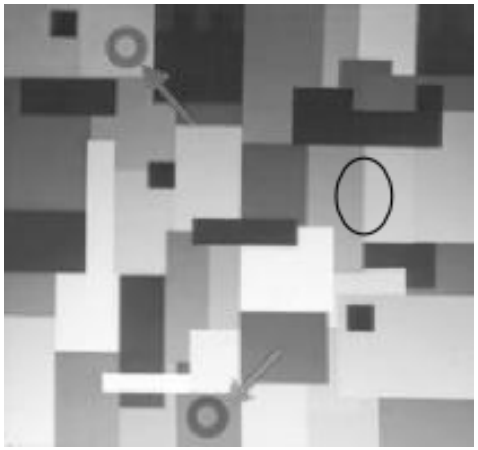

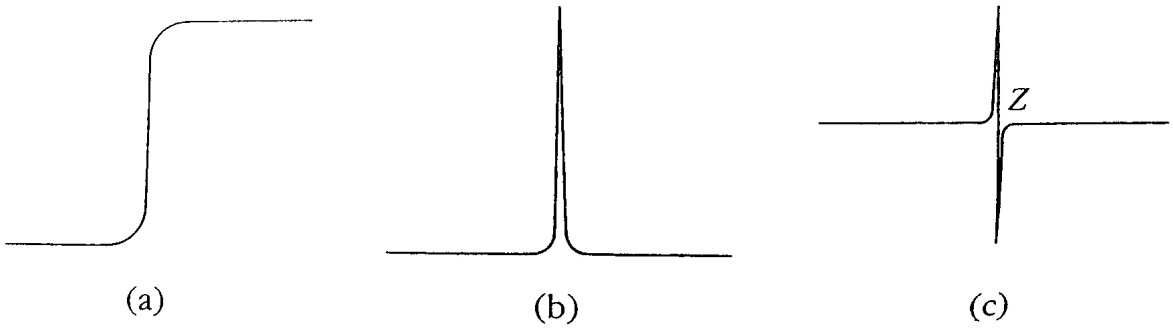

computational goal:

- separate illumination from reflectance changes

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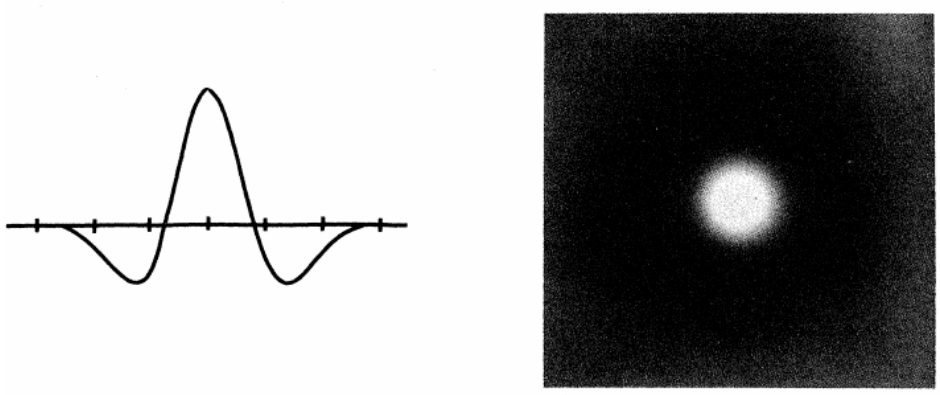
- intensity steps in an image (a) are peaks in the first derivative (b) across the steps, or zero-crossings in the second derivative (c)
- intensity steps can efficiently be detected with a differential operator

Example



- the second derivative can be found by filtering the image with a Mexican hat function (Marr-Hildreth algorithm)

= algorithmic level

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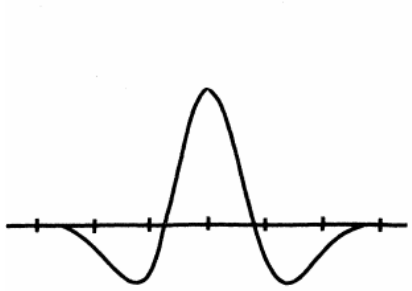

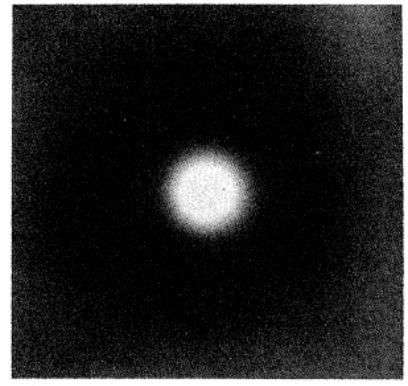

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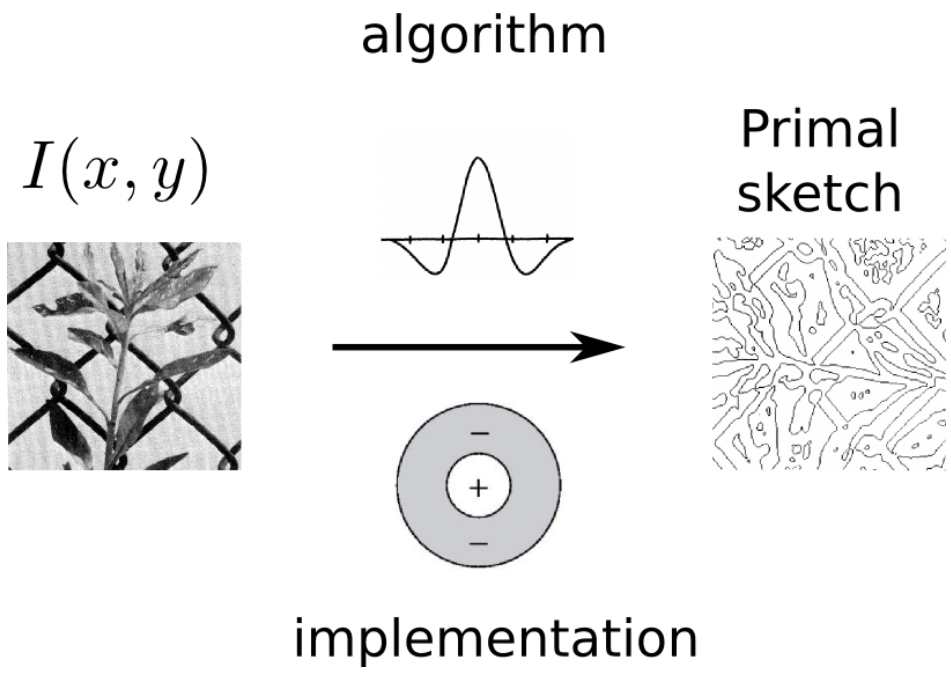
= algorithmic level

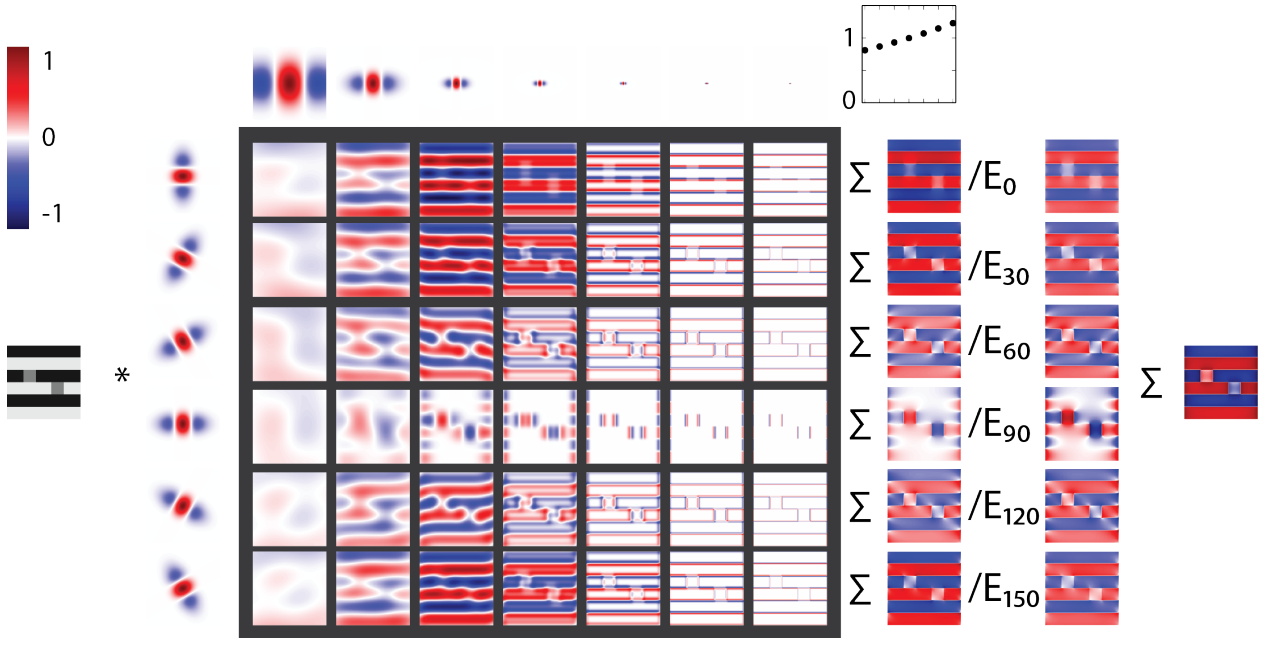
- resemblance to concentric center-surround organization of neurons in the LGN

= implementational level

From images to the primal sketch

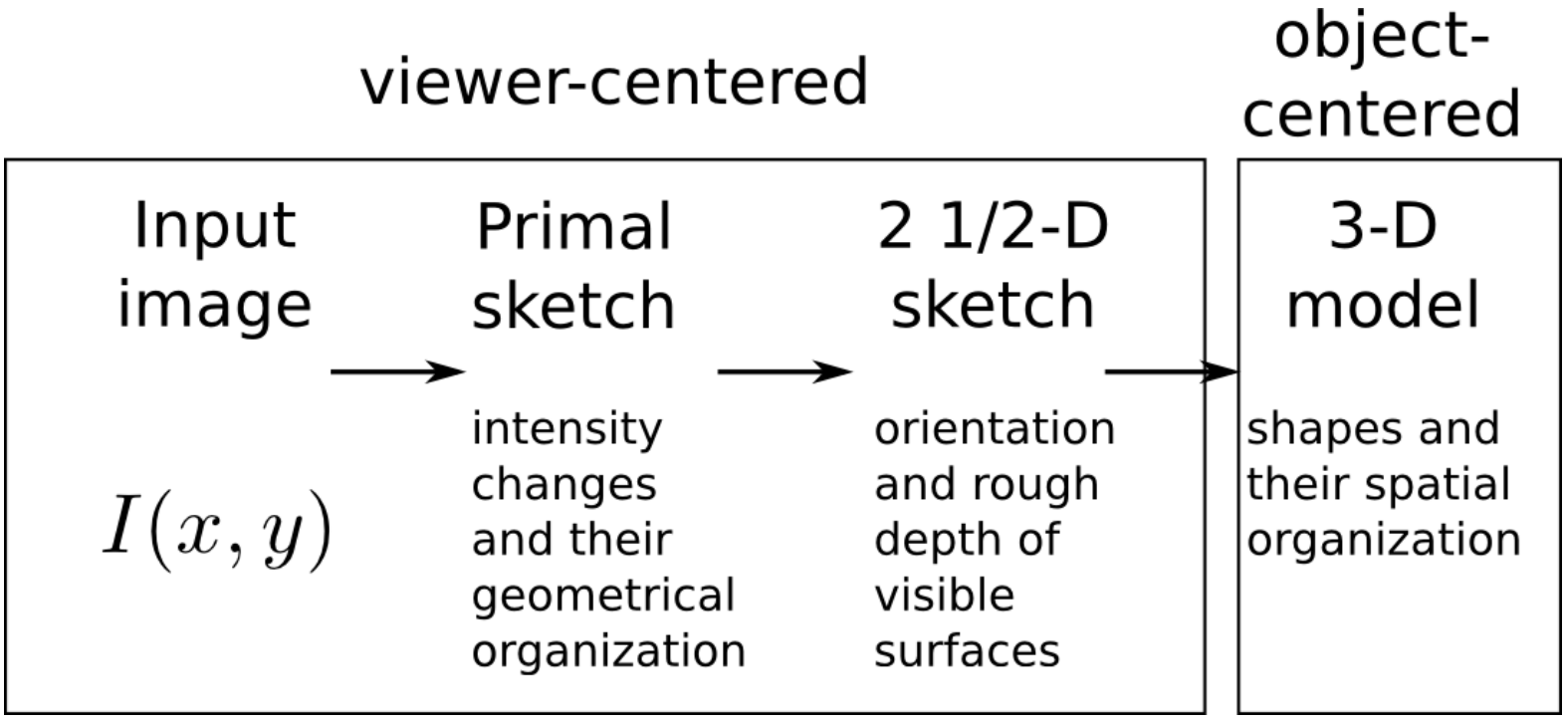


From images to the primal sketch



Blakeslee & McCourt, 1999, 2004; Dakin & Bex, 2003, Robinson et al., 2007; Otazu et al., 2008

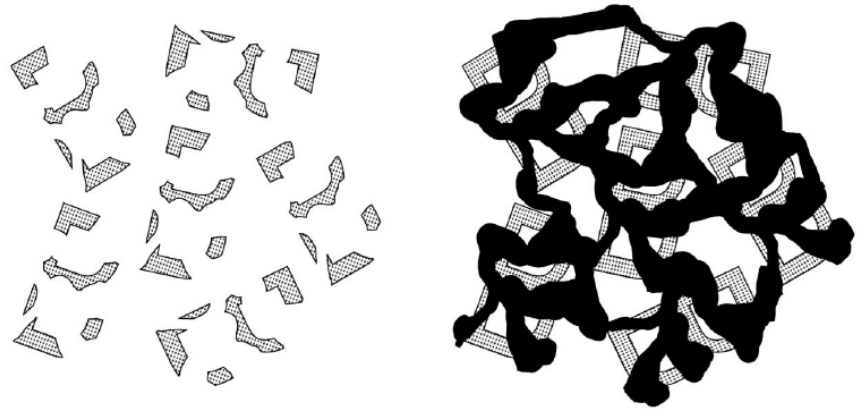
From images to 3D-objects



Summary

- Cognitive Psychology is the experimental study of human cognition
- Cognitive Psychology combines a number of different approaches including behavioral experiments, computational modelling and the study of the brain
- Cognitive Psychology focusses on the study of human cognition and as such is a subfield of Cognitive Science which also considers other cognitive agents
- The study of Human Cognition becomes increasingly transdisciplinary recognizing the **usefulness of a diverse set of different approaches**

Tutorial: how to measure perception?



Tutorial: how to measure perception?

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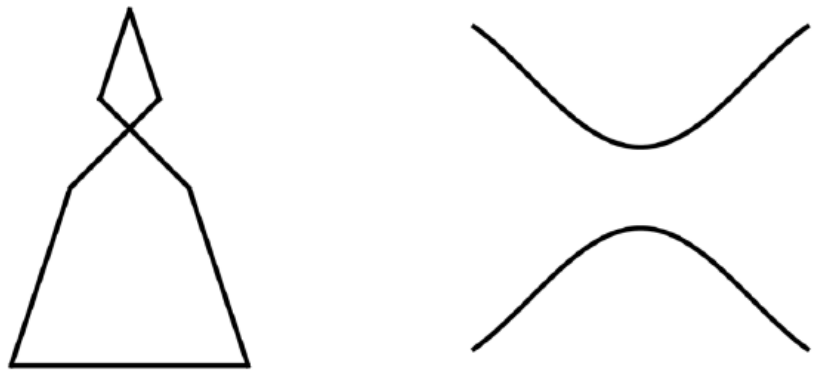

Thinking

How can you find out what's happening in someone's head? In normal life? In science?

References

- Eysenck & Keane
- Ward, J. (2010). The student's guide to cognitive neuroscience (2nd ed.). Taylor & Francis, Psychology Press: Hove and New York.