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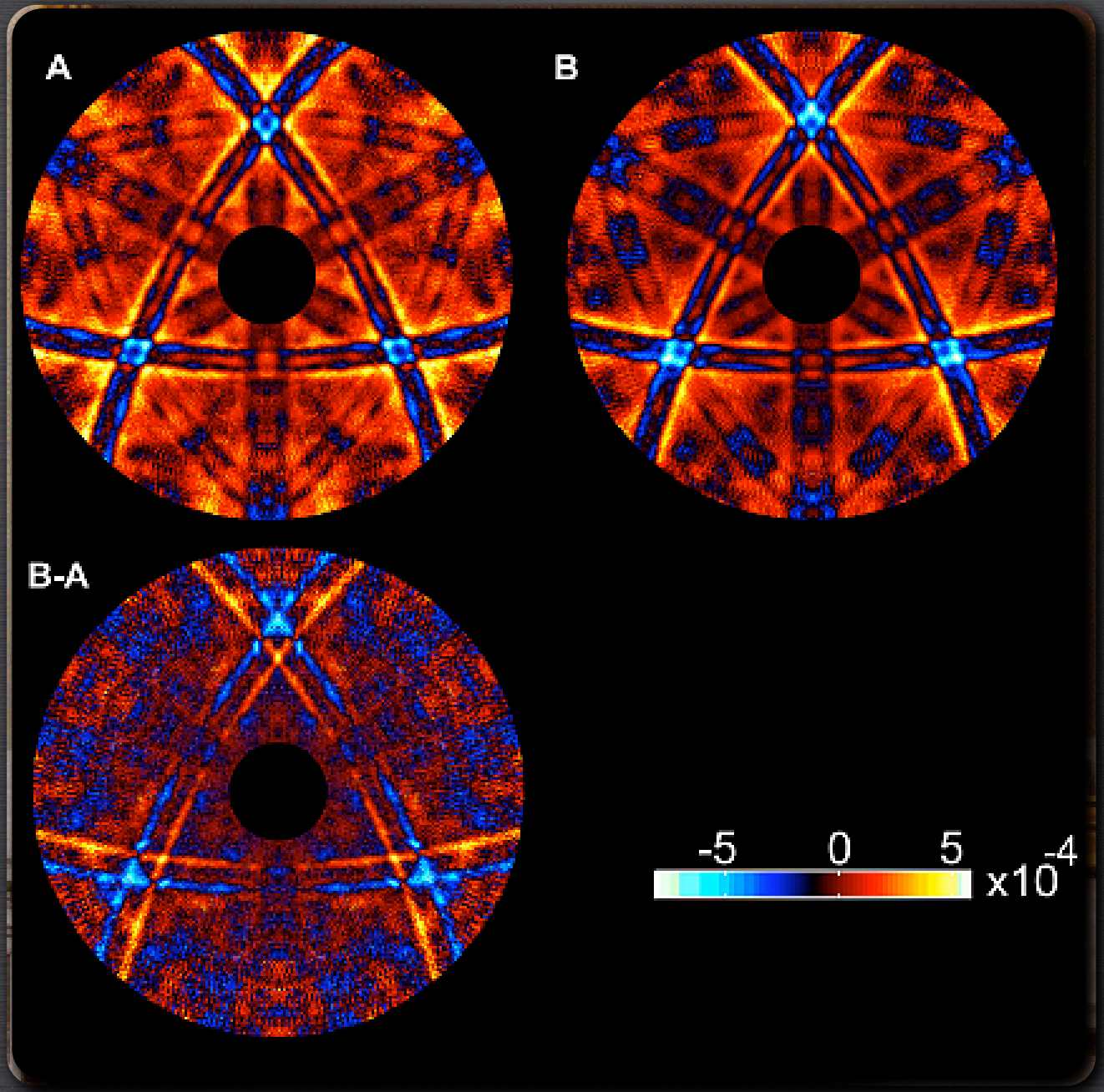
Imaging Consciousness: Space and Time in the Brain

Axel Cleeremans



X-Ray tomography of GaP crystal cells

What is Consciousness?

"Consciousness consists of those states of sensation, or feeling, or awareness, which begin in the morning when we awake from a dreamless sleep and continue throughout the day until we fall into a coma, or die, or fall asleep again, or otherwise become unconscious".

John Searle

What is Consciousness?

Nobody knows.

What Is It Like To Be a Bat?

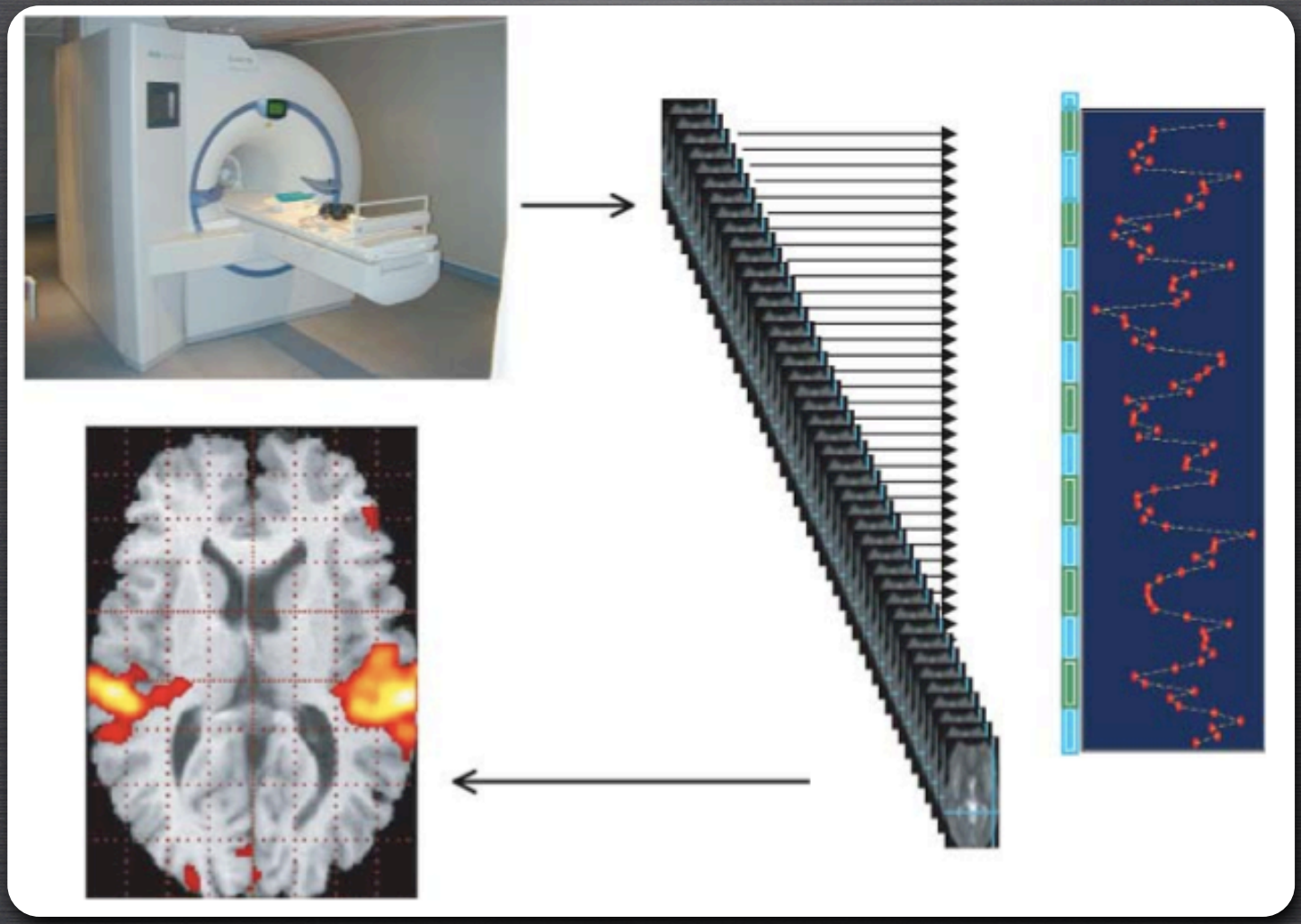
Nagel (1974): No matter how much we know about the brain of a bat, we'll never know what it feels like to chase insects at dusk

Consciousness: A Mystery?

- **Long considered as impossible to study scientifically:**
  - Dennett: Consciousness is a mystery, that is, something one does not know how to think about yet
  - Nagel: Consciousness is a private, subjective phenomenon: What is it like to be a bat? (We will never know)
  - Chalmers: Consciousness is "the hard problem". Why is one conscious?

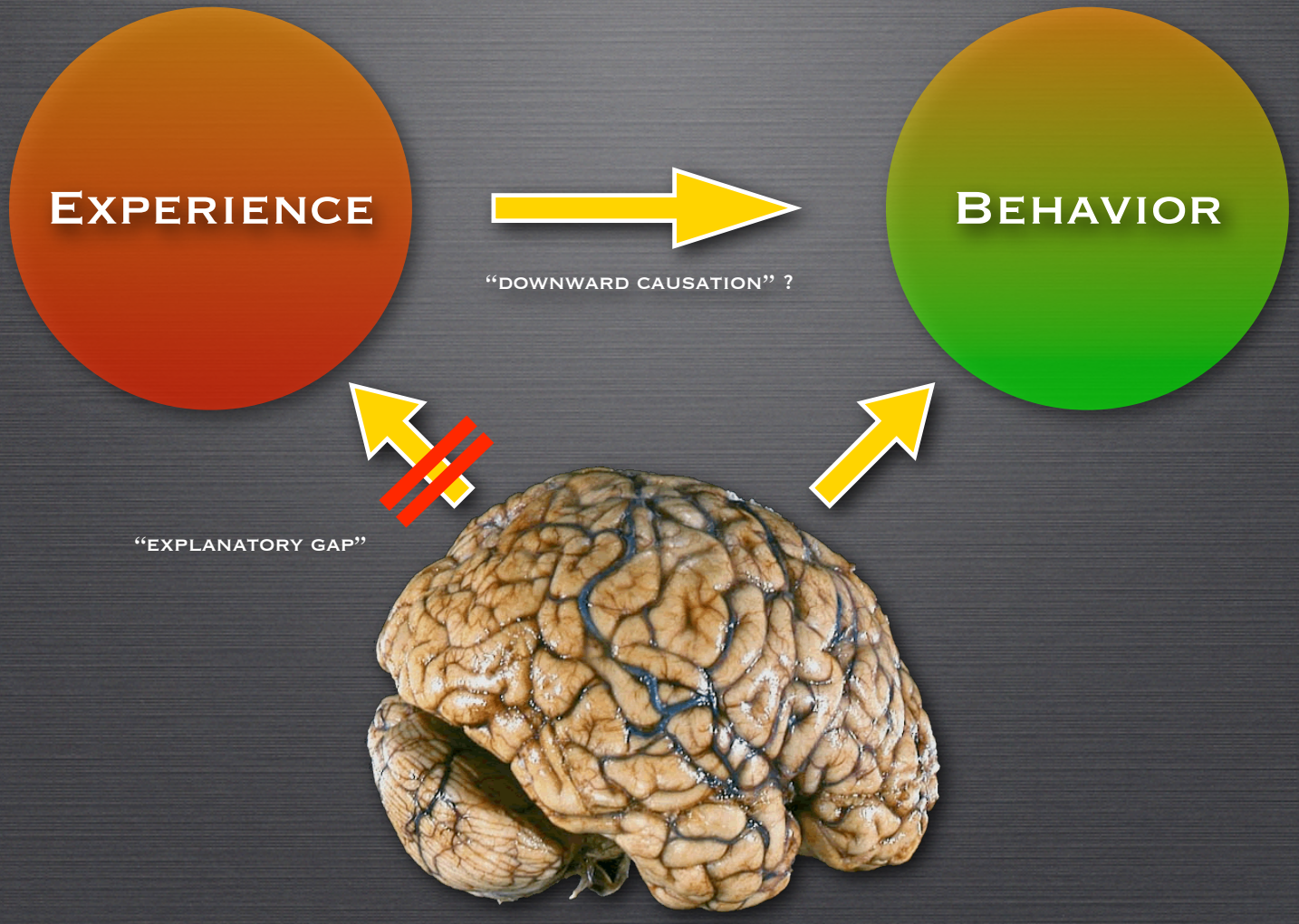
- **Consciousness is now at the forefront of cognitive neuroscience**
  - Thanks to imaging methods such as PET, fMRI, EEG/MEG, single-cell recording, thousands of studies are now dedicated to the study of the neural correlates of consciousness

fMRI




SCIENCE&VIE
SCIENCE VIE
> 46 Grippe aviaire
LES CLÉS POUR COMPRENDRE
La science aux portes de la conscience
> Des chercheurs l'ont FILMÉE en direct !
> Des AIRES CÉRÉBRALES spécifiques impliquées
> Le débat CORPS/ESPRIT relancé
> 72 Autre Terre
ÇA Y EST ENFIN !

The Challenge



The study of consciousness requires correlating subjective and objective data

Third-Person Approaches

- **Behavioral methods:**
  - Mental chronometry
  - Accuracy measures in forced-choice tasks
  - Eye tracking
- **Physiological methods:**
  - Skin conductance
  - Pupil dilation
  - Electroencephalography, Magnetoencephalography, single-cell
- **Imaging methods:**
  - Positron Emission Tomography
  - Functional Magnetic Resonance Imaging
  - Optical Imaging

First-Person Approaches

- **Verbal Reports:**
  - Introspectionism
  - Protocol Analysis
  - Subjective measures: Confidence judgments &c.
  - .... ?

Epistemological Issues

- **Third-person data:**
  - Impossibility of measuring neuronal activity directly on a large scale
  - Sheer complexity of the data
- **First-person data:**
  - Observer paradox
  - Impossibility of communicating some states of consciousness
  - Impossibility of communicating all contents of consciousness
  - Lack of appropriate formalisms to characterize verbal reports

Brain & Body

"We know two kinds of things about what we call our psyche (or mental life): firstly, its bodily organ and scene of action, the brain (or nervous system) and, on the other hand, our acts of consciousness, which are immediate data and cannot be further explained by any sort of description. Everything that lies in between is unknown to us, and the data do not include any direct relation between these two terminal points of our knowledge. If it existed, it would at the most afford an exact localization of the processes of consciousness and would give us no help towards understanding them"

Sigmund Freud

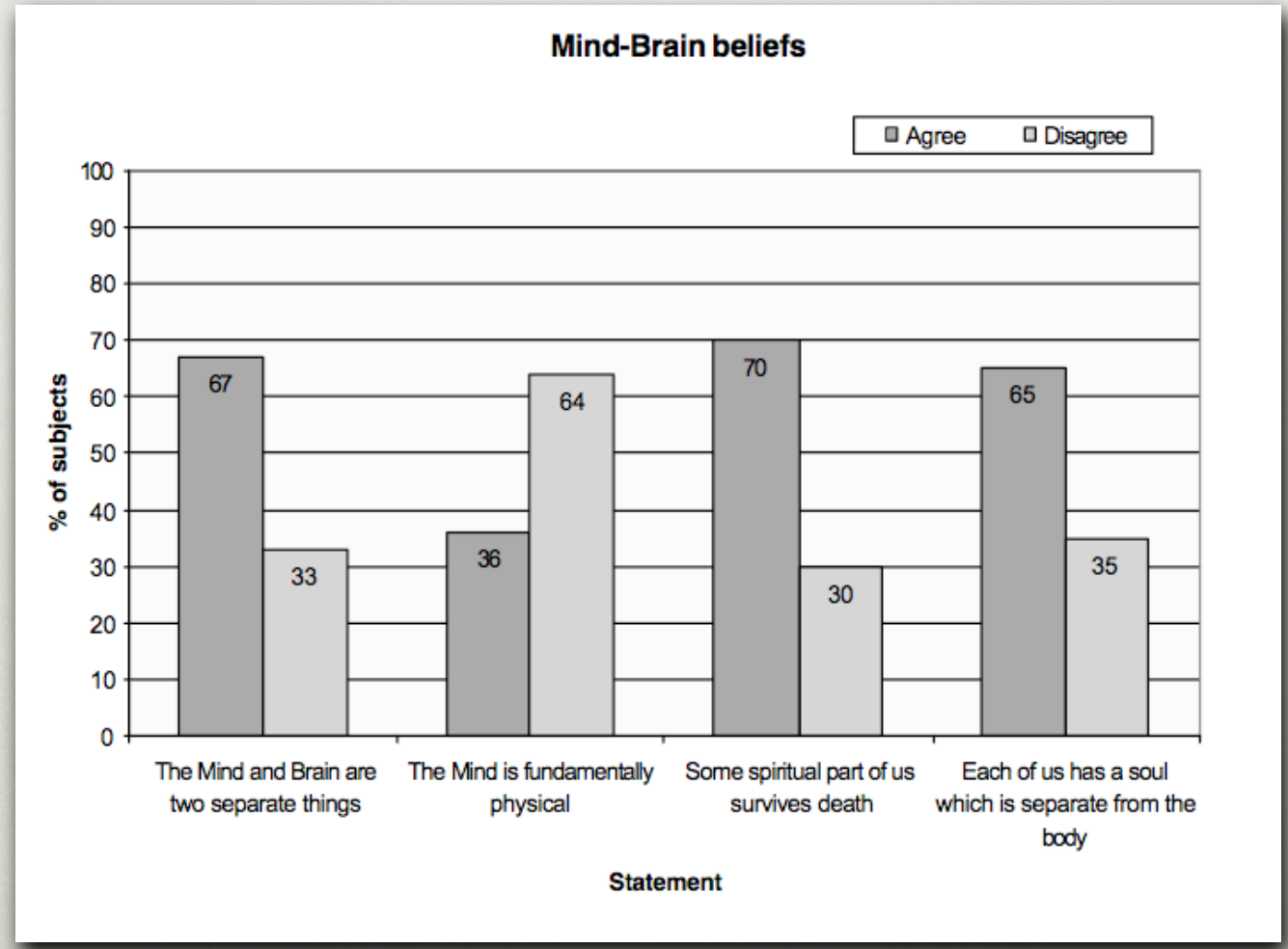
Empirical Phenomena

Towards A Science of Consciousness

- Every mental event necessarily is a brain event
- To find the neural correlates of consciousness:
  - **Use a contrastive method:**
    - Look for dissociations between information processing with and without consciousness (which requires very good behavioral paradigms)
  - **Use brain imaging techniques:**
    - Examine the brain in action (which requires sensitive imaging methods)
  - **Combine objective and subjective data:** Correlate neural activity with subjective experience so as to identify the cerebral regions specifically involved in conscious processing

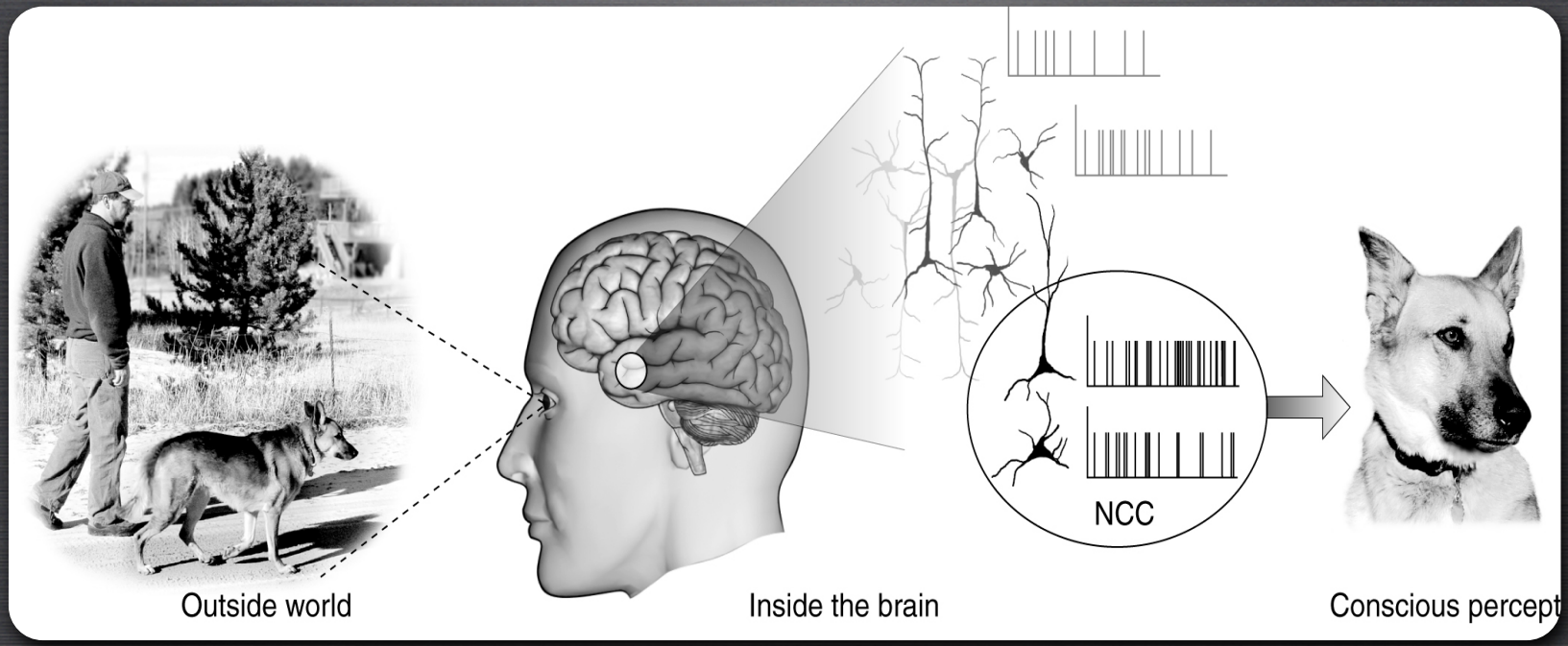
Dualism

WHAT YOU THINK



Liew, Zeman et al., 2005

Neural Correlates of Consciousness



"A major part of the programme for studying the neural correlates of consciousness must be to investigate the difference between neural activities that are associated with awareness and those that are not" (Crick & Koch; Frith et al.)

Contrastive Methods

	Perception	Memory	Action
Subjective experience changes, stimulation & behavior remain constant	Binocular rivalry	Episodic Recall	Awareness of intention
	Hallucinations	Confabulation	Delusion of control
Subjective experience remains constant, stimulation changes	Stimulation changes without awareness	Unrecognized “old” items	action without awareness
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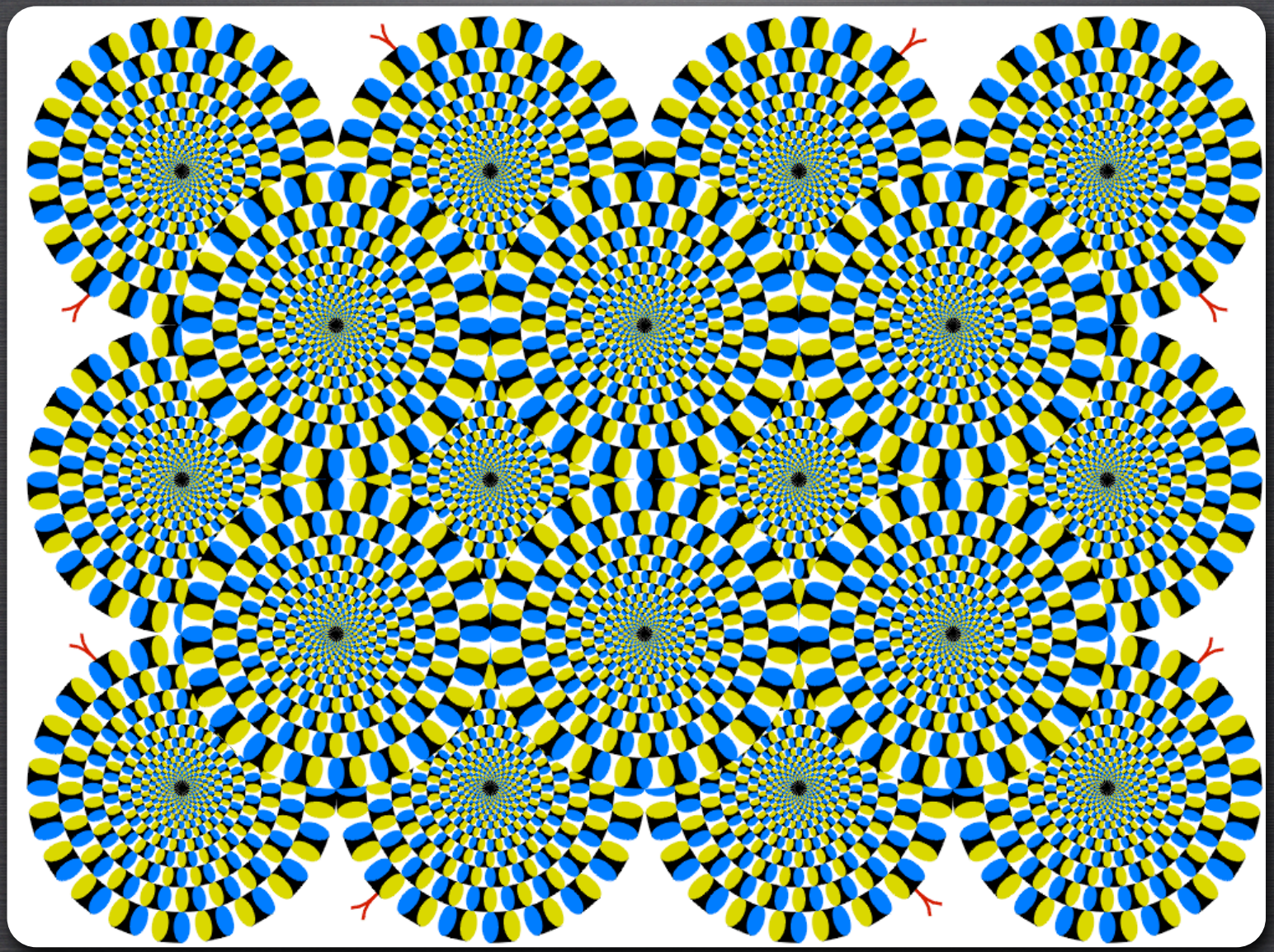
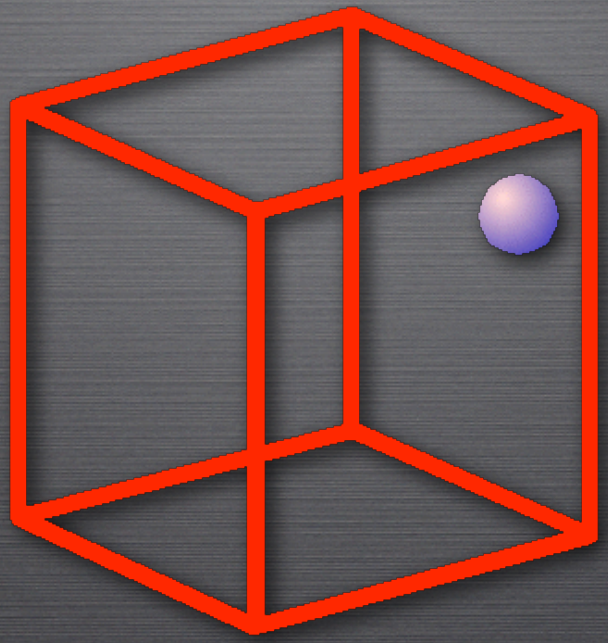
Subjective experience remains constant, behavior changes	Correct guessing without awareness	Implicit learning	Implicit motor behaviour
	Correct reaching in form-agnosia	Implicit learning in amnesia	Unintended action

A Powerful Motion Illusion



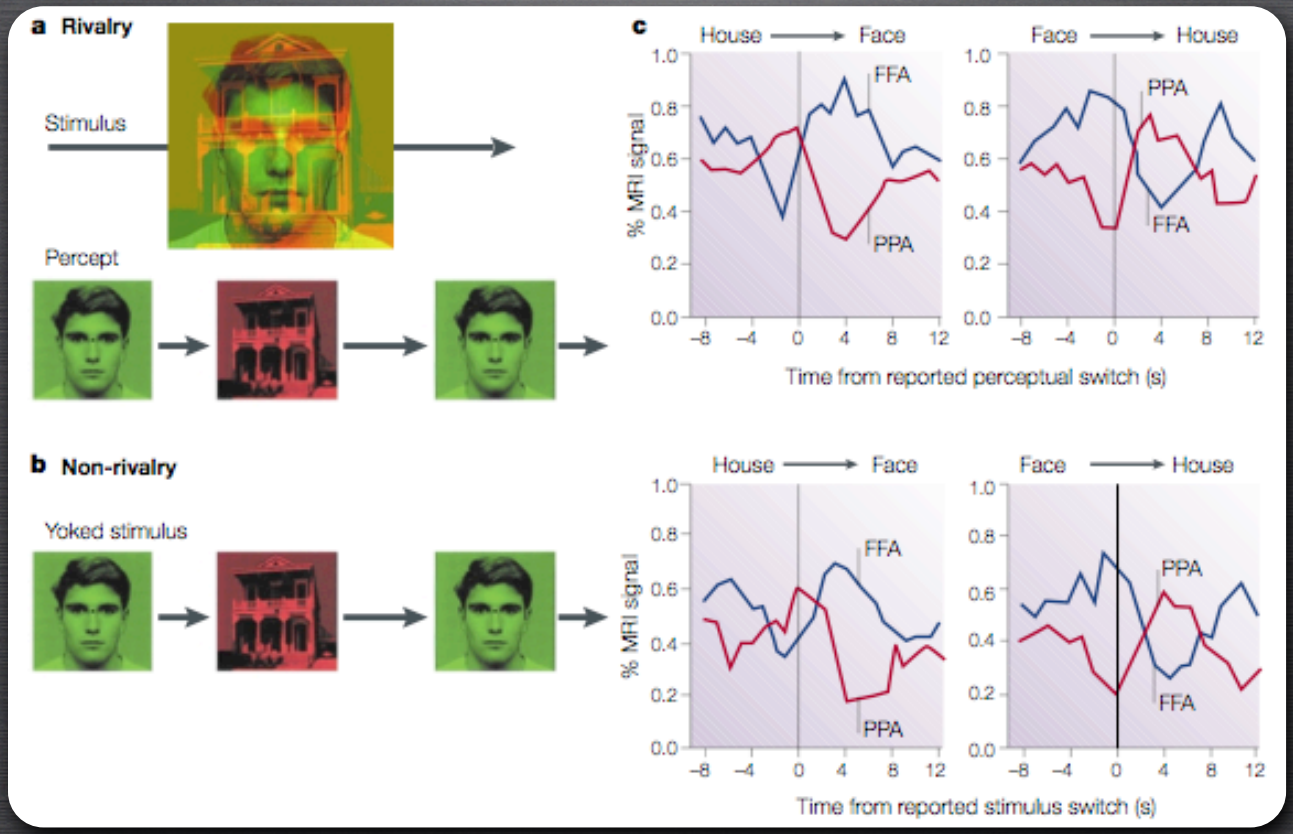
Kitaoka et al.

Bistable & Ambiguous figures



The Necker Cube

Binocular Rivalry



Face-specific or place-specific areas of the brain activate as a function of people's momentary conscious experience of an unchanging stimulus.

Kanwisher et al.

Contrastive Methods

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Change Blindness

Count the number of times the WHITE players pass the ball among each other

Change Blindness

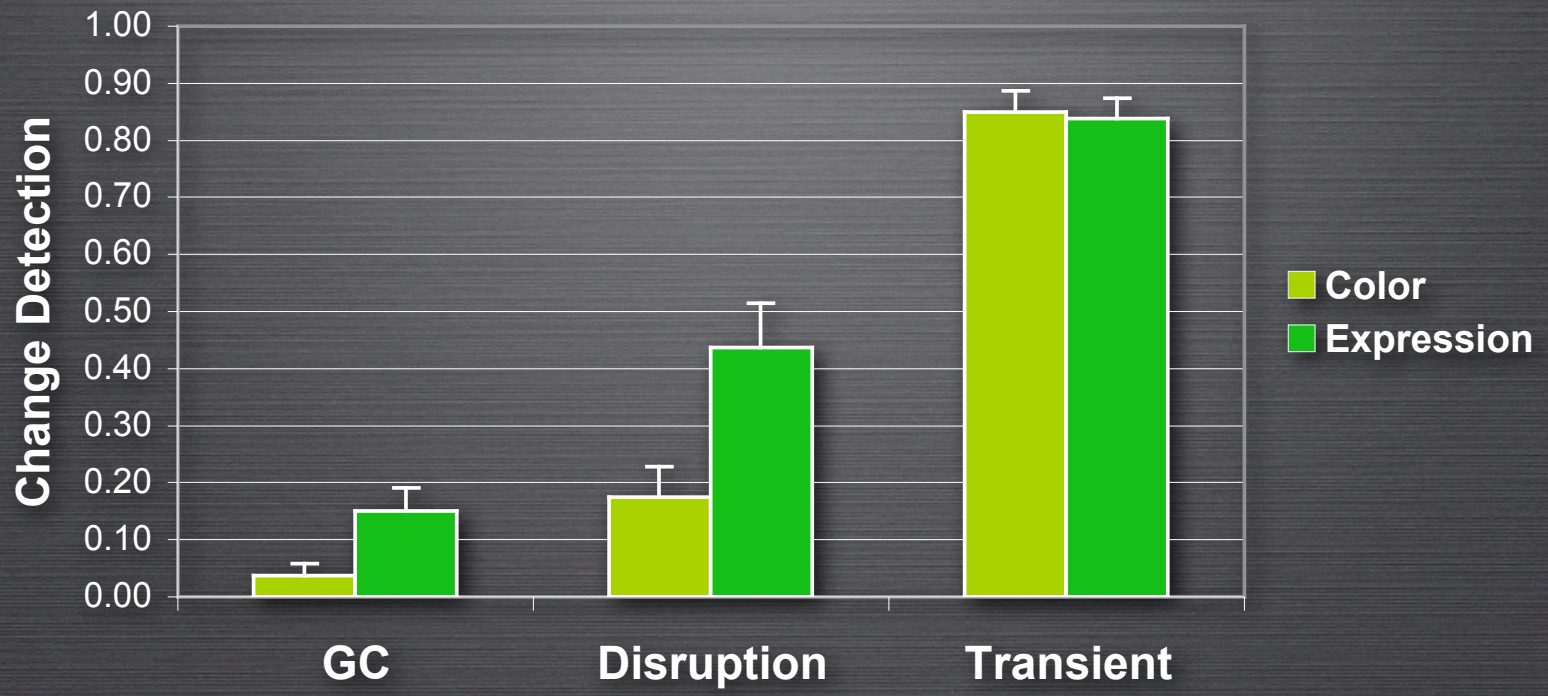
Something Is Changing Right Now in this Picture — Can You Find What?

Laloyaux, Cleeremans et al.

Change Blindness

Laloyaux, Devue, David, & Cleeremans (submitted)

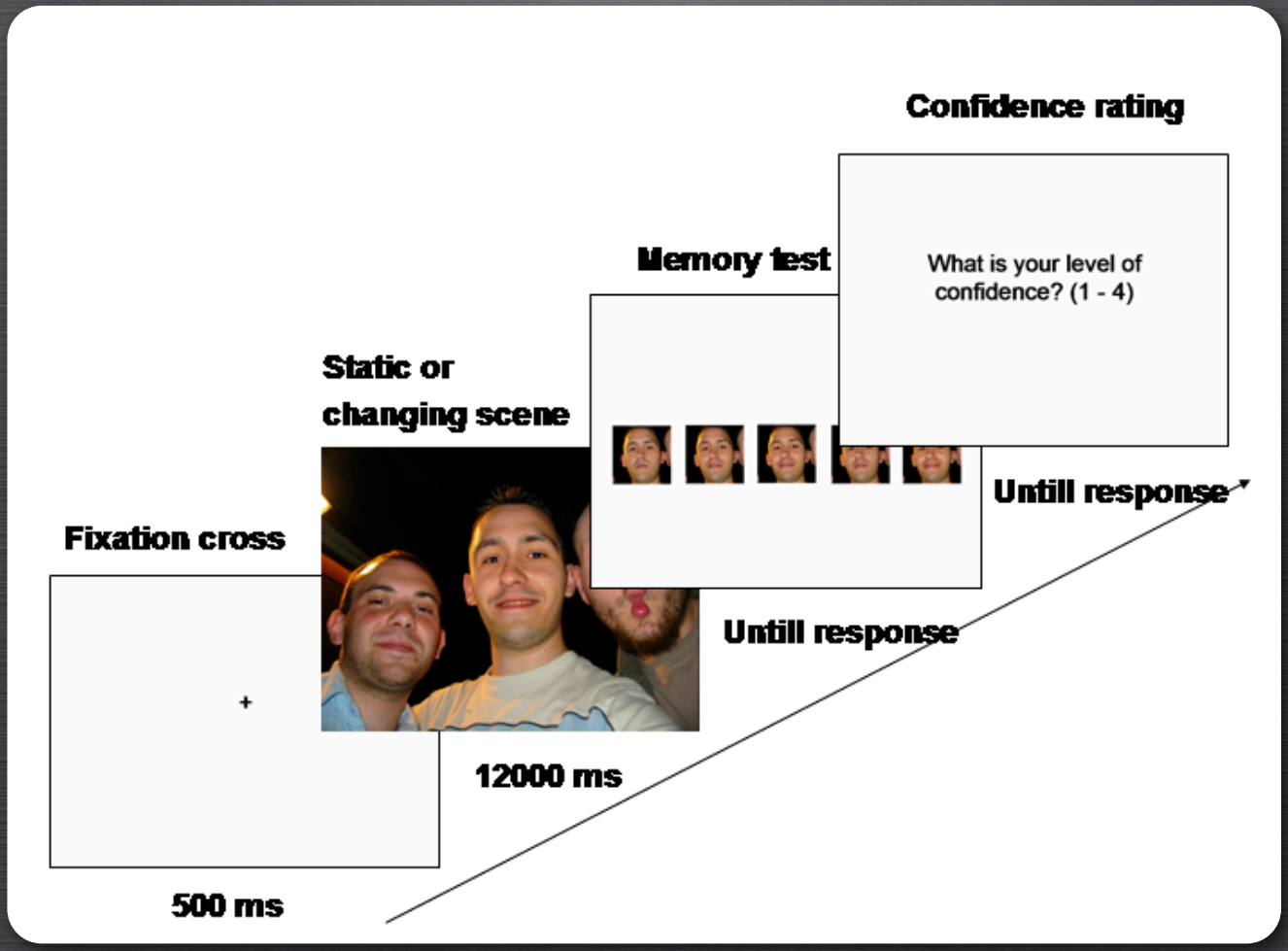
Results



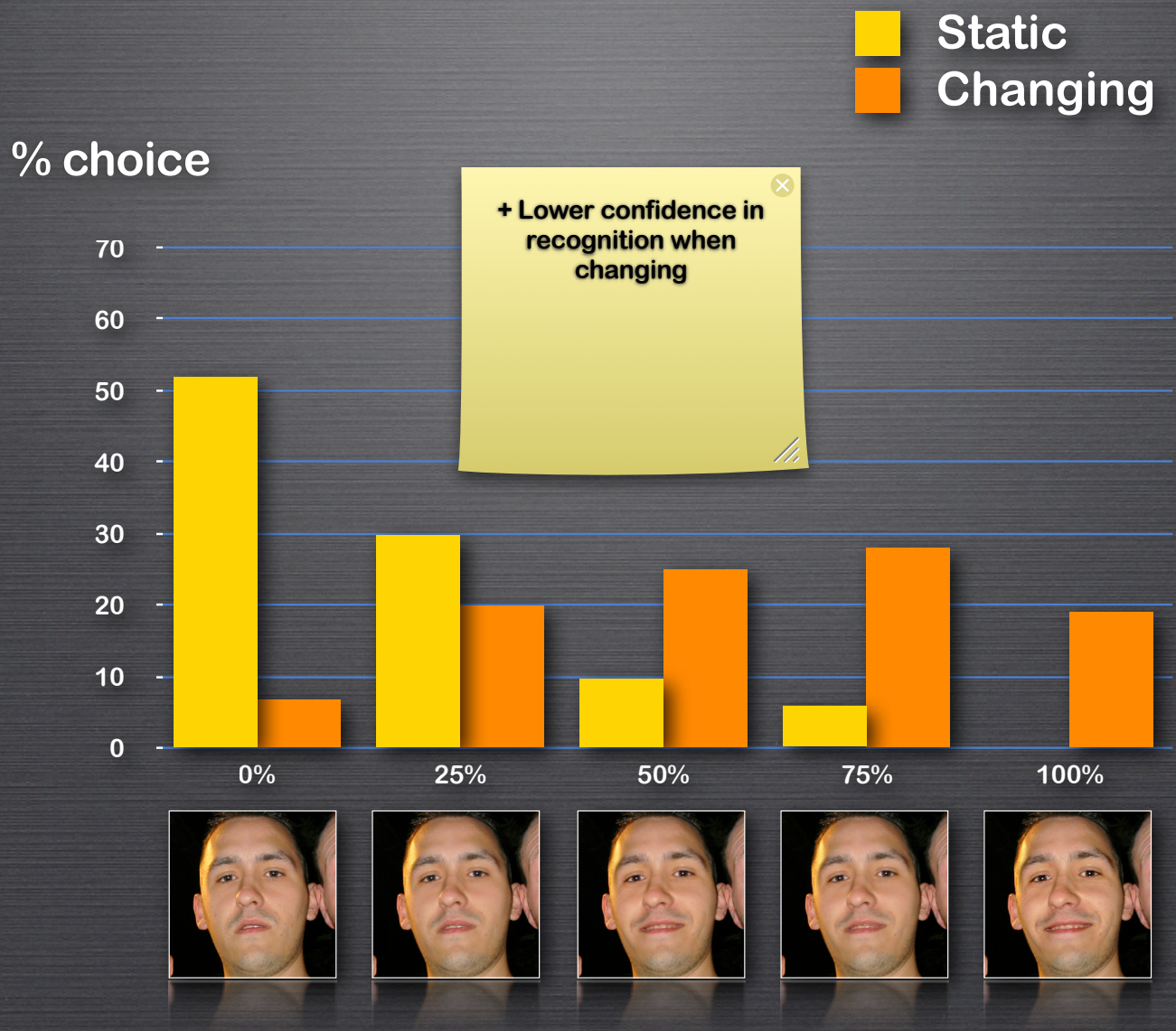
Correct detection = participants can describe the change approximately (i.e., the head), clicked on the relevant area, and indicated that they did not guess

Cédric Laloyaux

Procedure


Confidence rating
What is your level of confidence? (1 - 4)
Memory test
Static or changing scene
Fixation cross
+
Untill response
Untill response
12000 ms
500 ms

Forced-Choice Recognition



Conscious experience

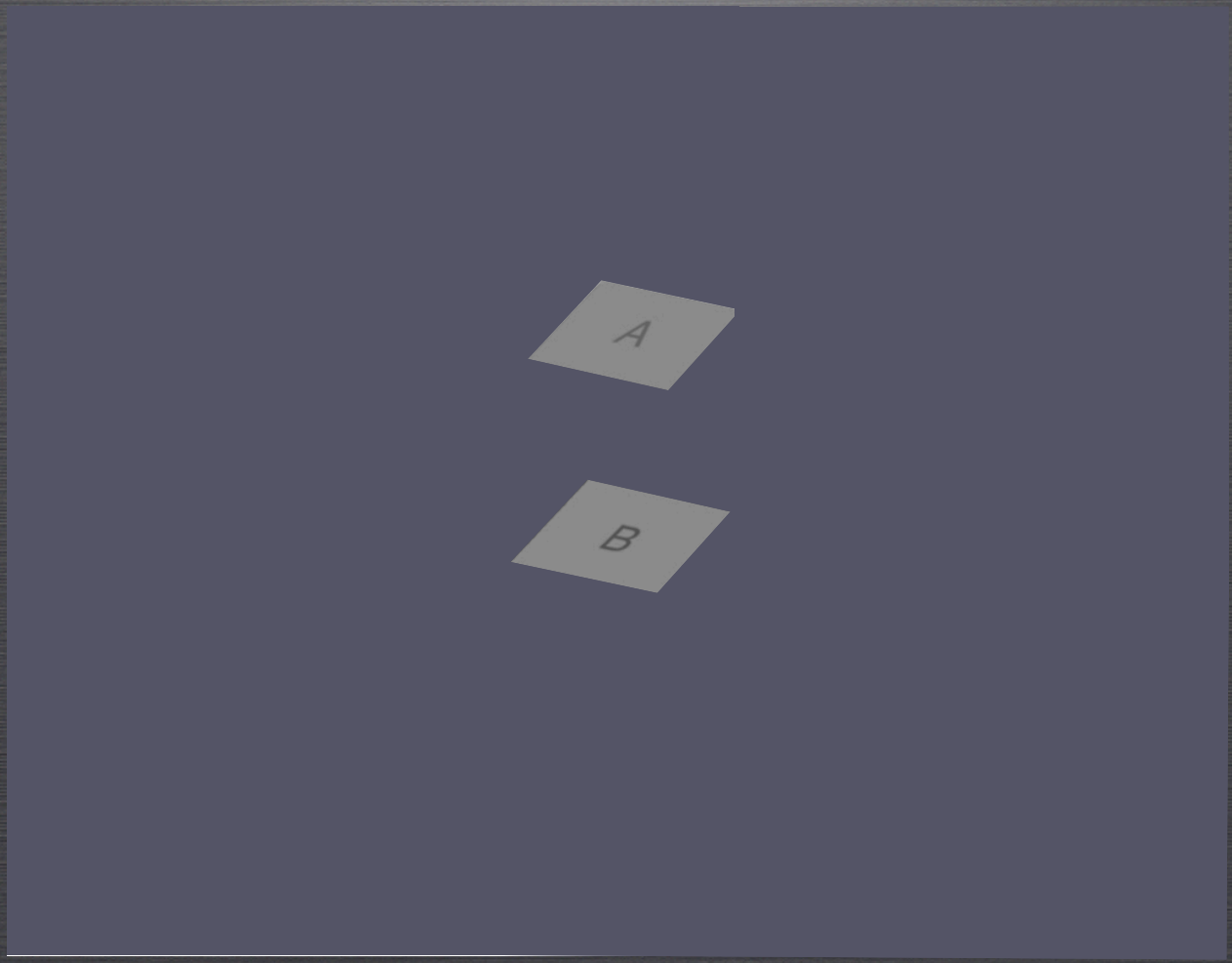
- **Such phenomena suggest that consciousness is both more limited and more constructive than one thinks**

In change blindness, actual movement fails to be consciously perceived.

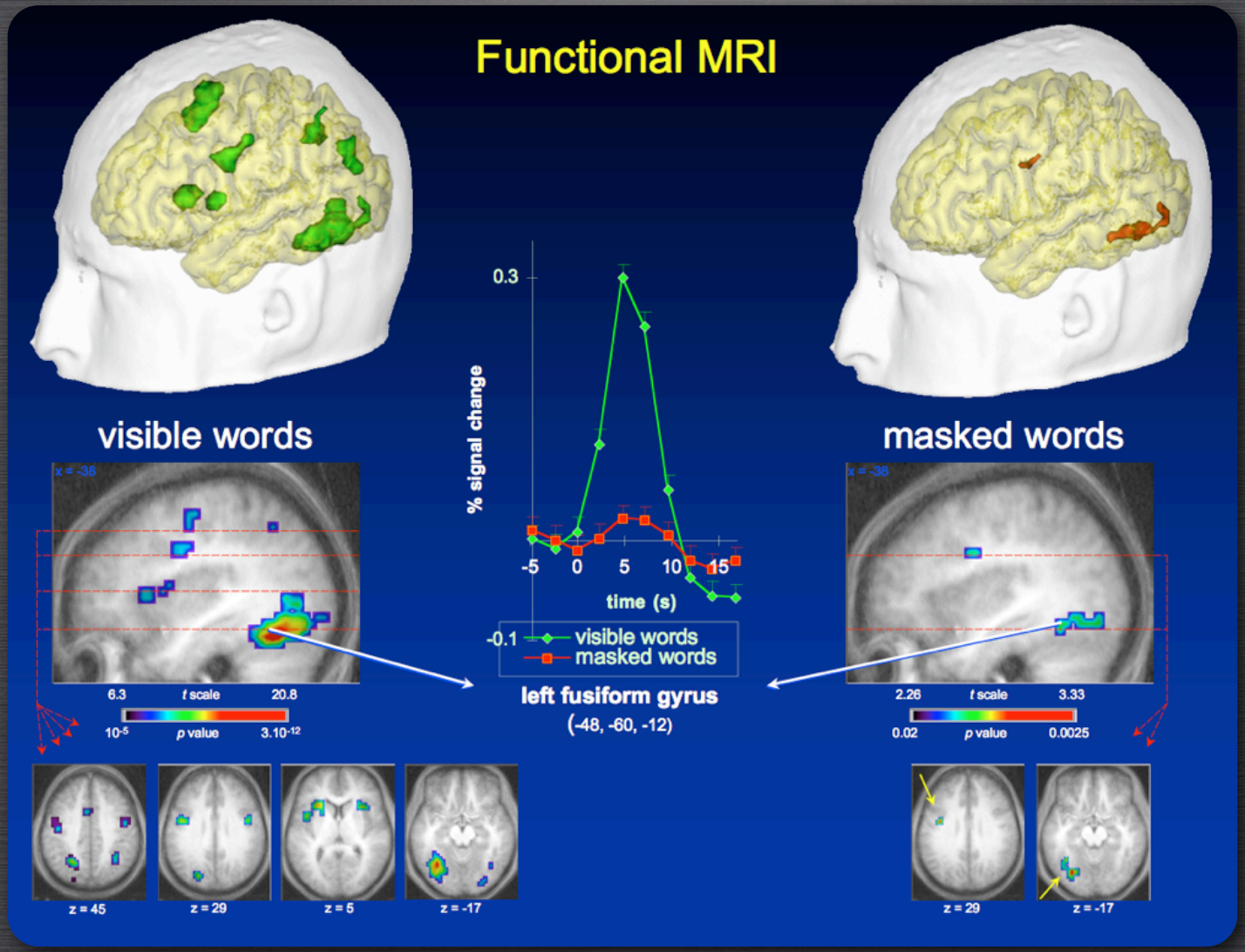
In motion illusions, movement is perceived in a motionless picture.

- **The brain constructs reality as much as it perceives it**
- **One can use such phenomena to explore how the brain produces conscious experience**

A Powerful Illusion

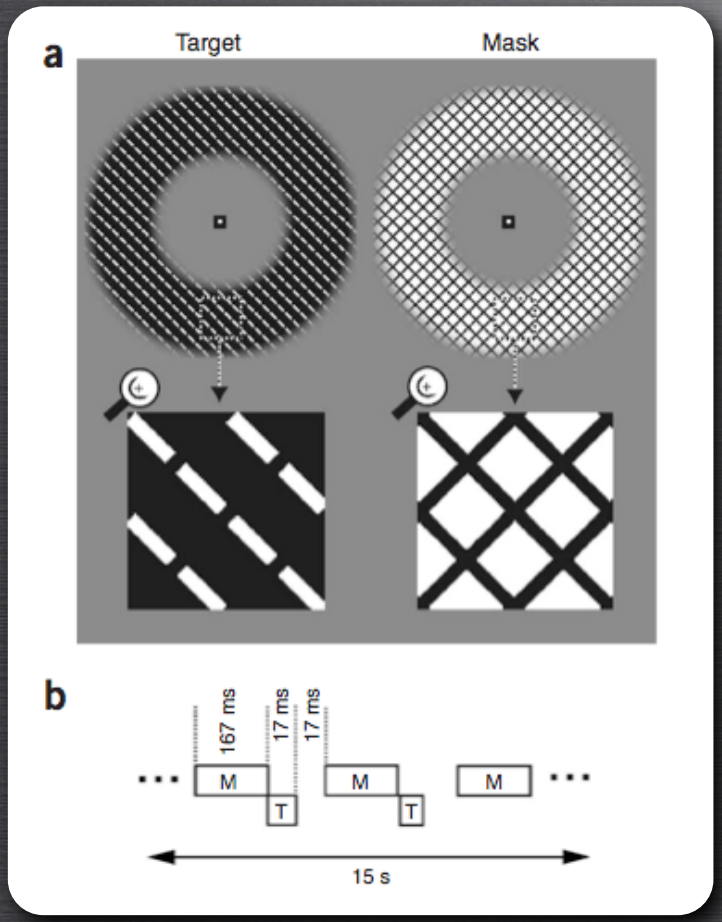


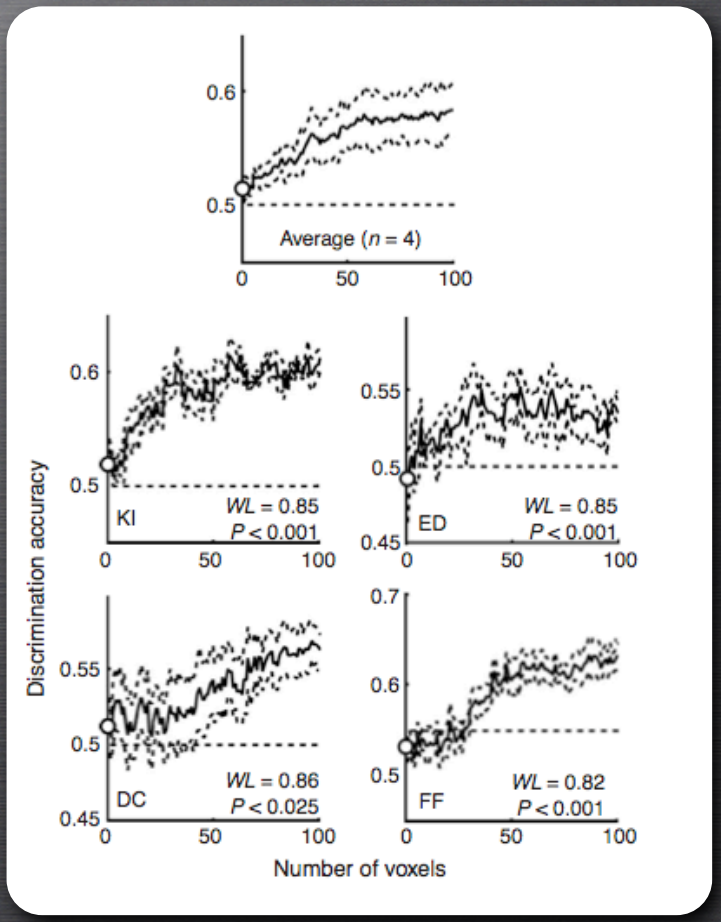
Imaging Subliminal Perception



Dehaene et al.

Mind Reading!

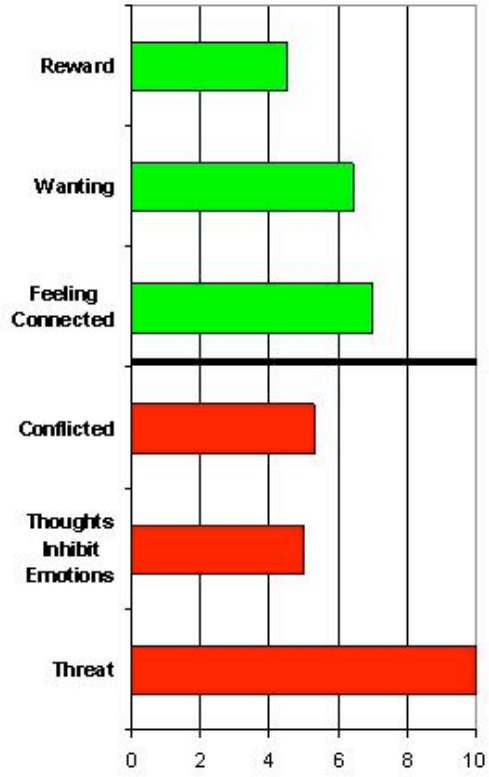




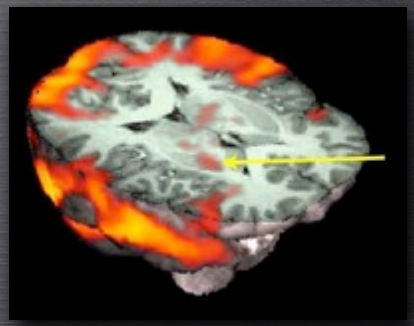
Haynes & Rees, Nature Neuroscience, 2005

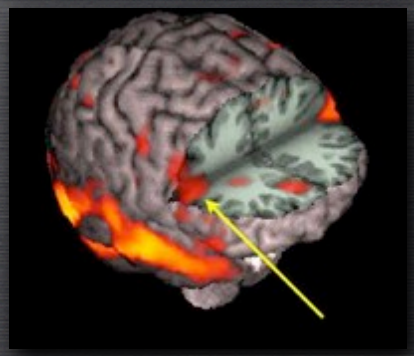
Superbowl Science

"NFL Dreamers"



Reward: Ventral striatum





Empathy: posterior inferior frontal gyrus (mirror neurons)

Contrastive Methods

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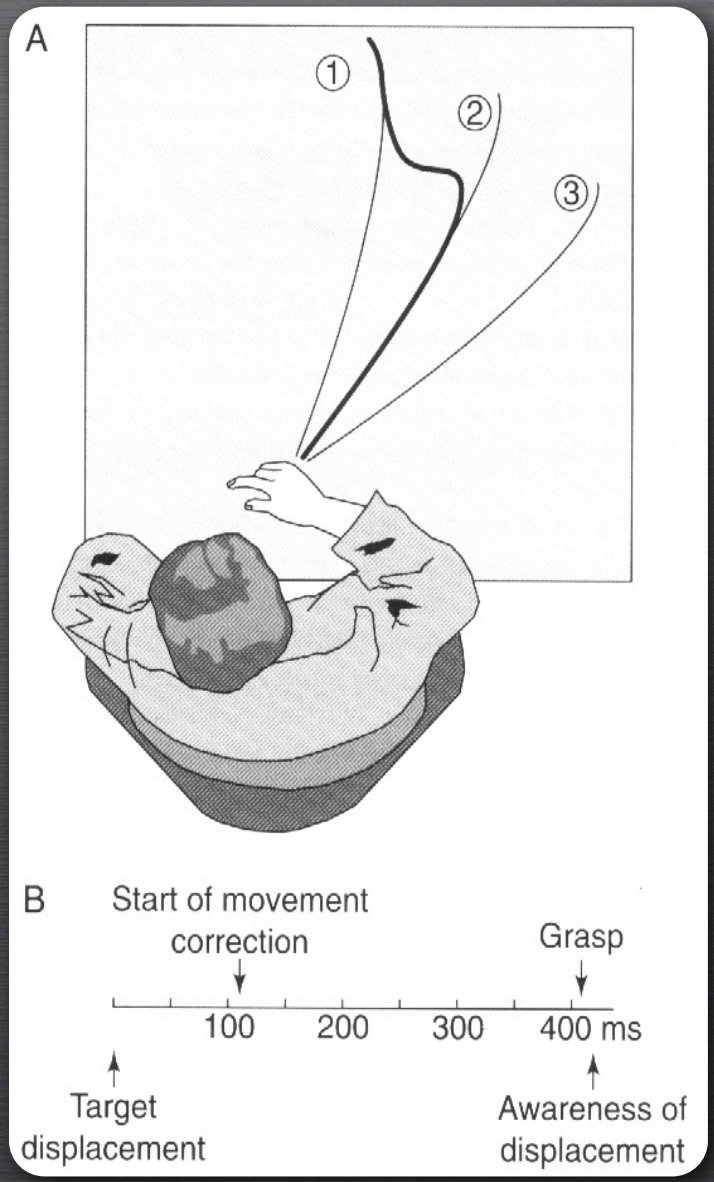
Unconscious Action



Castiello et al.

Contrastive Methods

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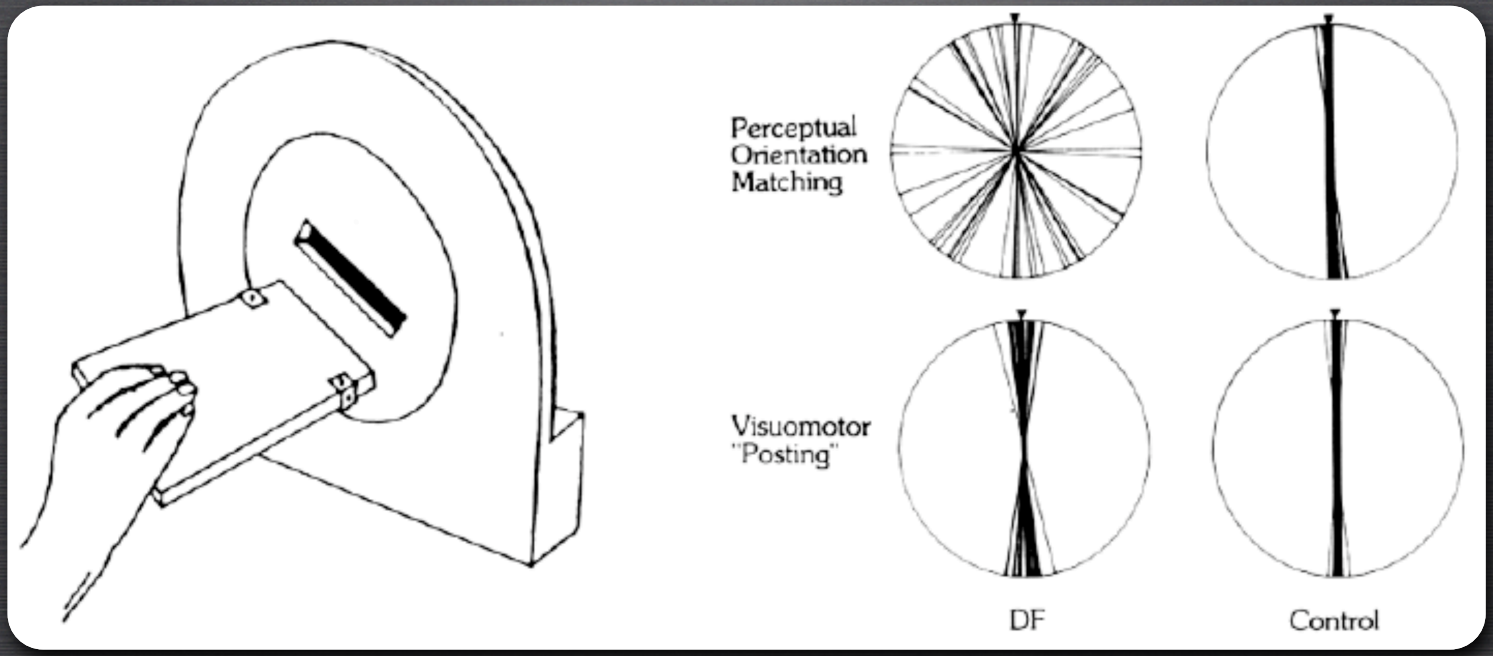
Visual Agnosia



Milner & Goodale 1991

Contrastive Methods

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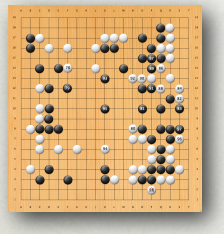
Implicit Learning



Many of the things we learn to do:

- are learned without intention,
- without verbalizable knowledge of what was learned,
- and sometimes without knowledge that we learned anything

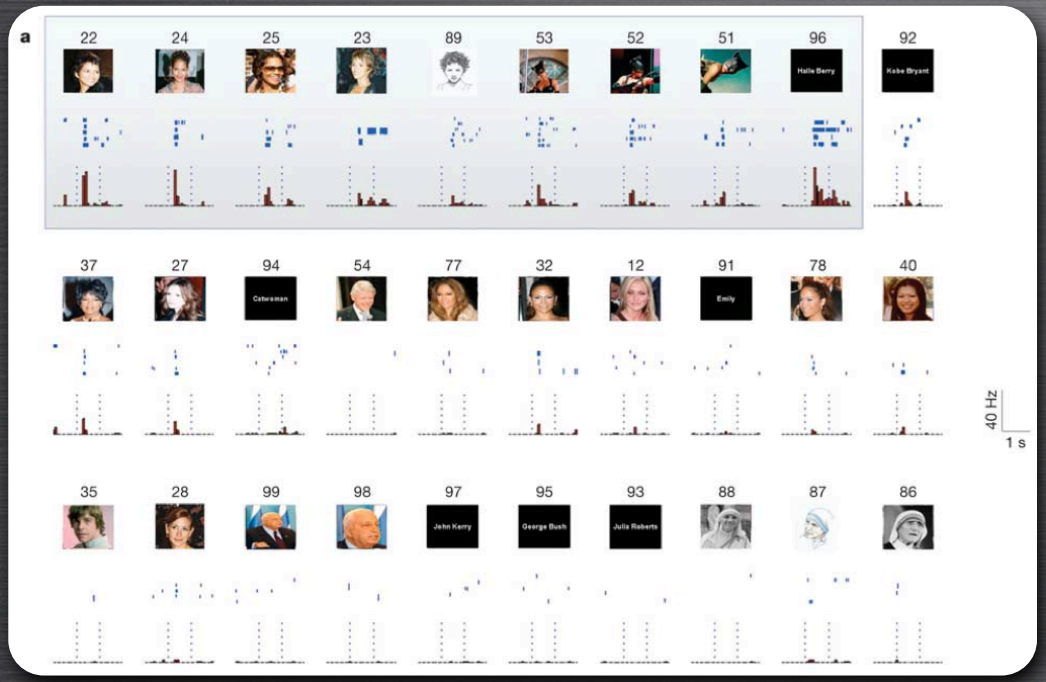
  - Learning by foetuses, by sperm cells (!)
  - memory consolidation during sleep, role of experience in shaping basic neural maps
  - subliminal priming, implicit learning
  - learning in amnesia, under anesthesia

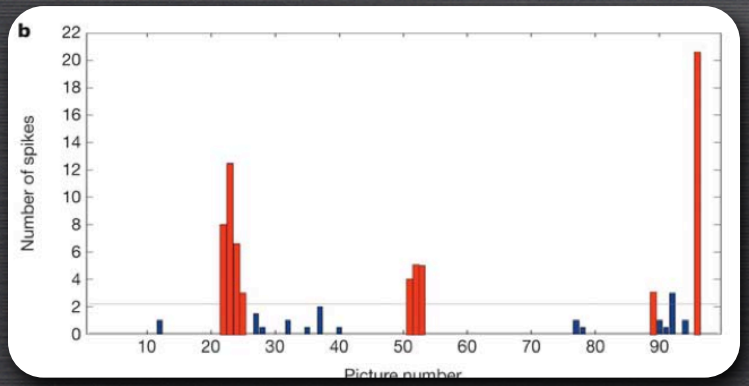
Penfield Homonculus

SENSORY HOMONCULUS

MOTOR HOMONCULUS

The Halle Berry Neuron





Single-cell Recording

Kreiman et al.

Dissociations

- **People do not realize their behaviour is influenced**
  - Dijksterhuis 2003: Have people do an arbitrary cognitive task in a room that smells of cleaning fluid. Next, offer them a crumbly biscuit during debriefing and videotape them. Result: People exposed to the cleaning fluid smell pick up more crumbs and are neater than controls.
- **People sometimes reconstruct their own behaviour**
  - Nisbett & Wilson 1977: Ask patrons in a department store to select the best pair of stockings among a series. Unknown to them, all pairs are identical. Most people choose the last pair they examined. Most motivate their choice based on quality; all deny being influenced by serial position

SEQUENCE LEARNING

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Task is choice reaction

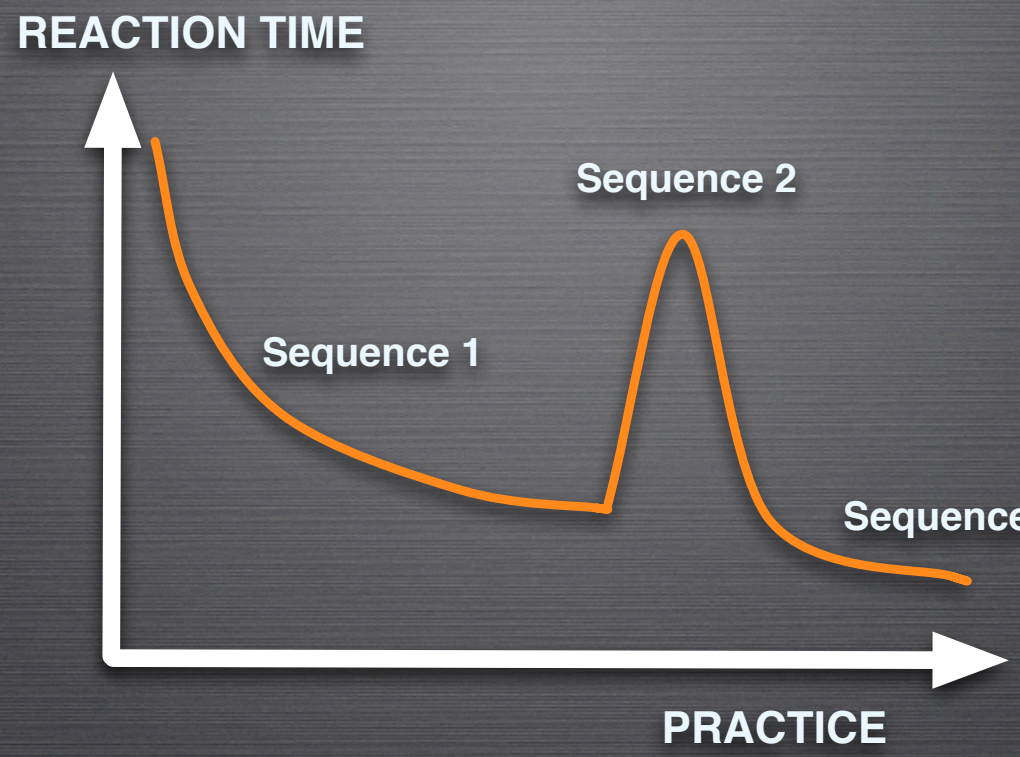
Unknown to subjects, stimuli follow a repeating sequence

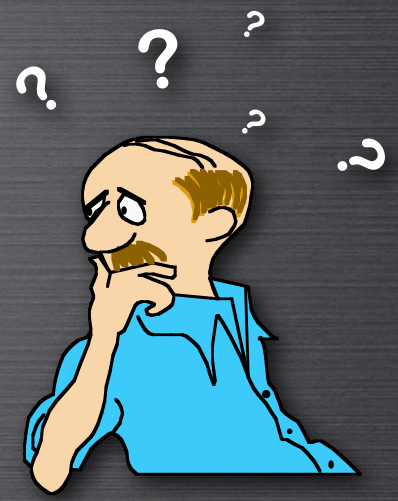
People exhibit sensitivity to the sequential structure in the absence of verbalizable knowledge about the sequence

342312143241 342312143241 … **(training)**

341243142132 341243142132 … **(transfer)**

Typical Results

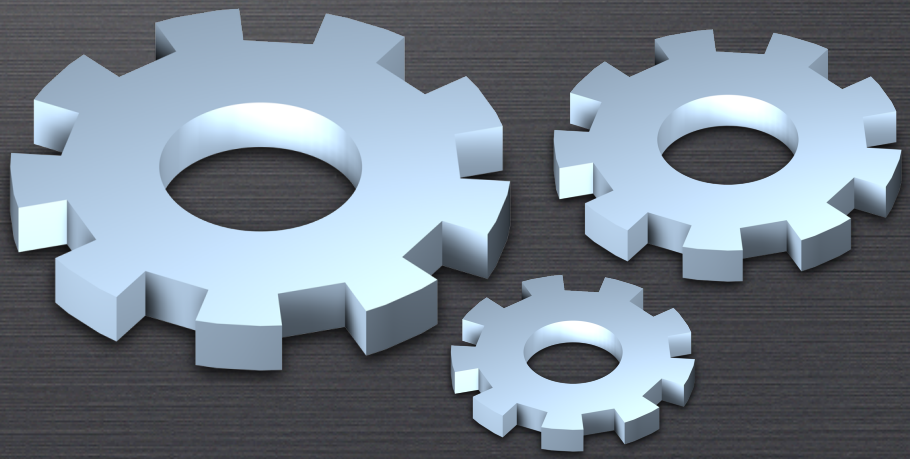




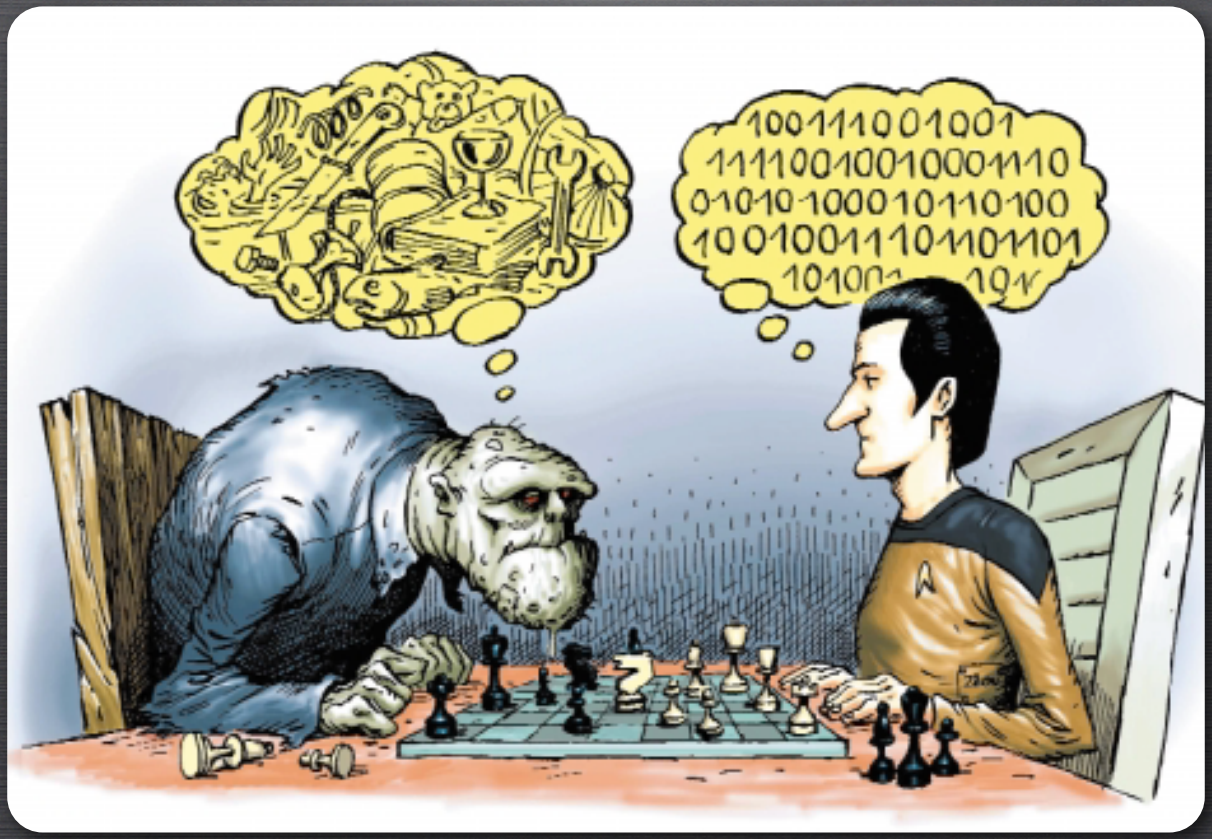
IMPLICIT LEARNING:

A change in performance that is not accompanied by a corresponding change in the ability to describe the acquired knowledge

Mechanisms



Commander Data and the Zombie



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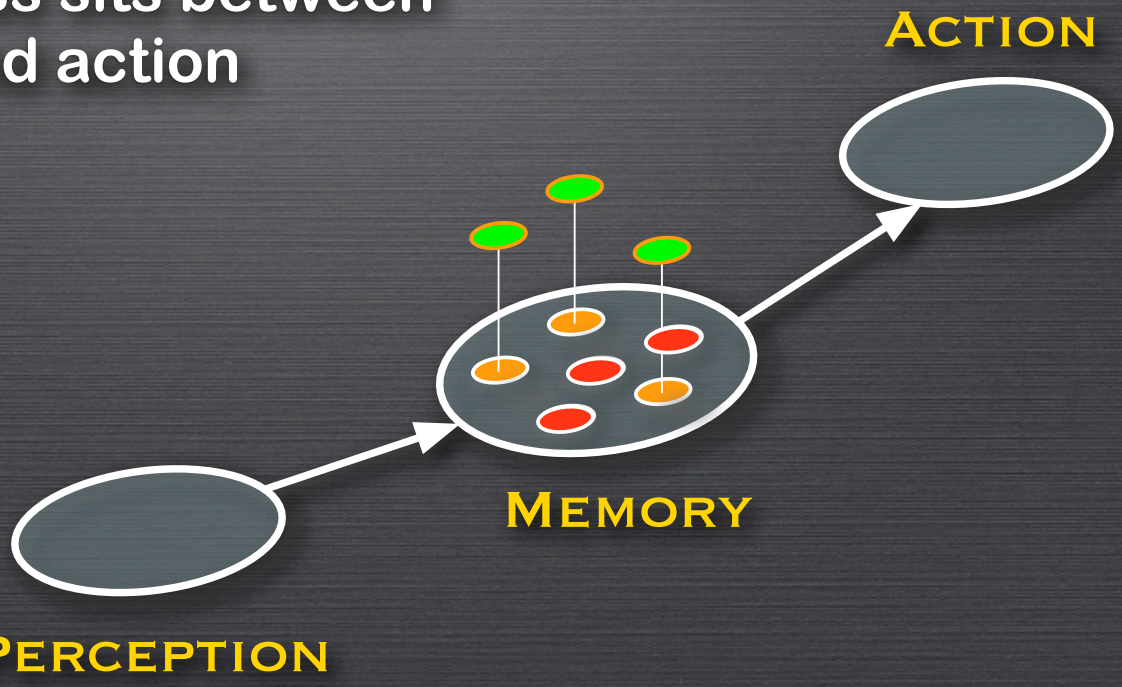
Four misconceptions about C

Consciousness is a “single thing”

Consciousness is static

Consciousness is all-or-none

Consciousness sits between perception and action



Computational Correlates of C

- What are the "computational correlates of consciousness" — computational principles through which one can contrast cognition with and without consciousness?
- Many such proposals
  - Adaptive Resonance (Grossberg)
  - Integration & differentiation (Tononi)
  - Global broadcast (Baars, Dehaene)
  - recurrence & reentrant processing (Lamme)
  - stability in time (O'Brien & Opie)
  - quantum properties of microtubules (Hammeroff)
  -

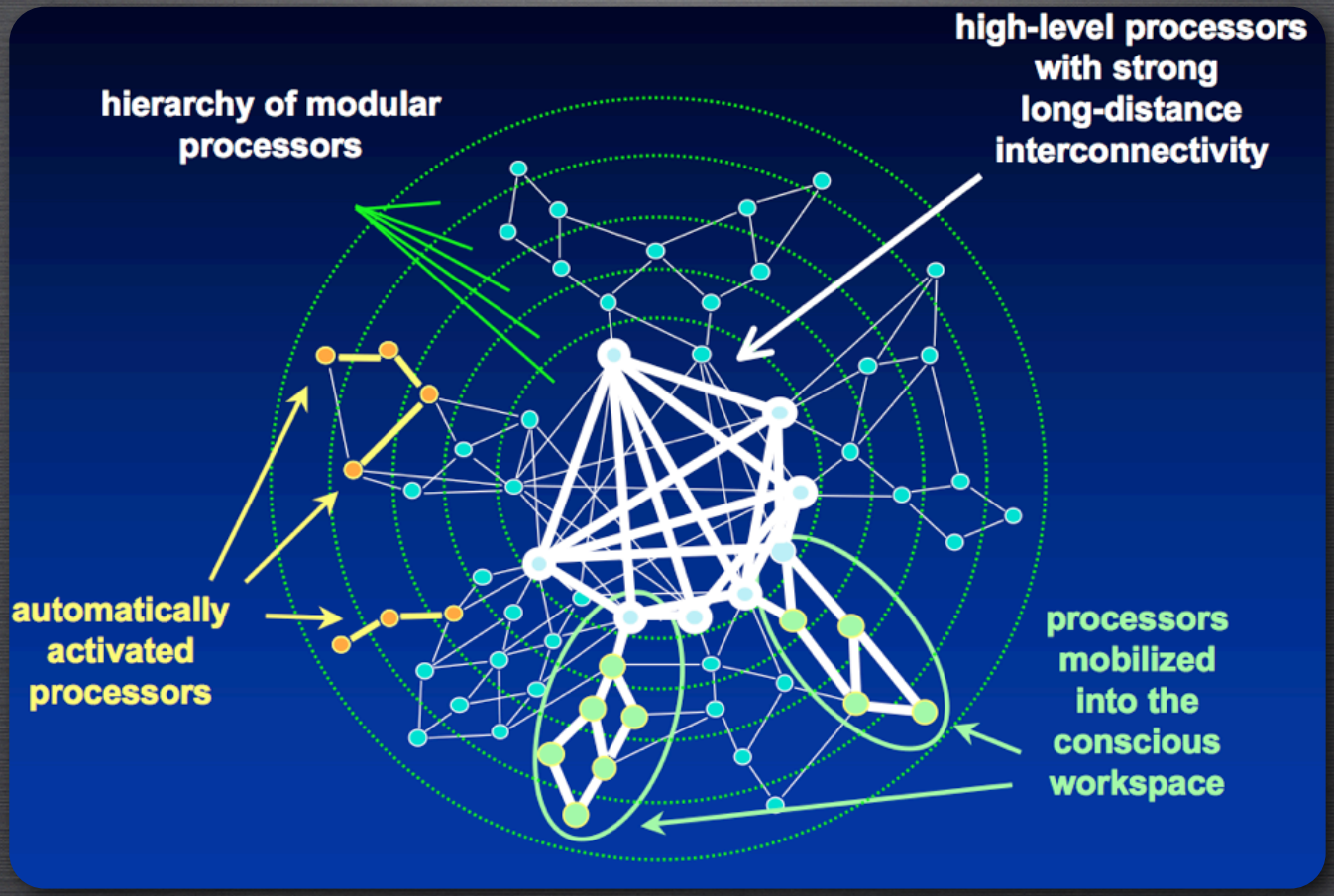
Atkinson, Thomas & Cleeremans, TiCS (2000); Maia & Cleeremans, TiCS(2005)

Mechanisms associated with C

Maia & Cleeremans, Trends in Cognitive Sciences (2005)

1. **Active representation**
   - Active neuronal firing is necessary but probably not sufficient for consciousness
2. **Global competition biased by top-down modulation**
   - Consciousness results from global competition between representations. At any moment, the winning neuronal coalition determines both conscious phenomenal experience and global accessibility. Active representations maintained by PFC are important sources of biases for this competition
3. **Global constraint satisfaction**
   - Global competition implements global constraint satisfaction. Thus, conscious experience can be seen as the result of a large-scale application of the brain's knowledge to the current situation
4. **Reentrant processing**
   - Recurrent connections are essential to implement global constraint satisfaction. They allow more global interpretations in higher-level areas to influence processing in lower-level areas
5. **Meta-representation**
   - Higher aspects of human consciousness and cognition, such as the ability to think about one's thoughts, may depend on the creation of representations that are then fed back to the same constraint satisfaction network as input, resulting in representational "re-enrichment"

CONSCIOUSNESS IS EXTENDED



The Neural Workspace:
Thalamo-cortical loops and long-distance cortico-cortical connectivity

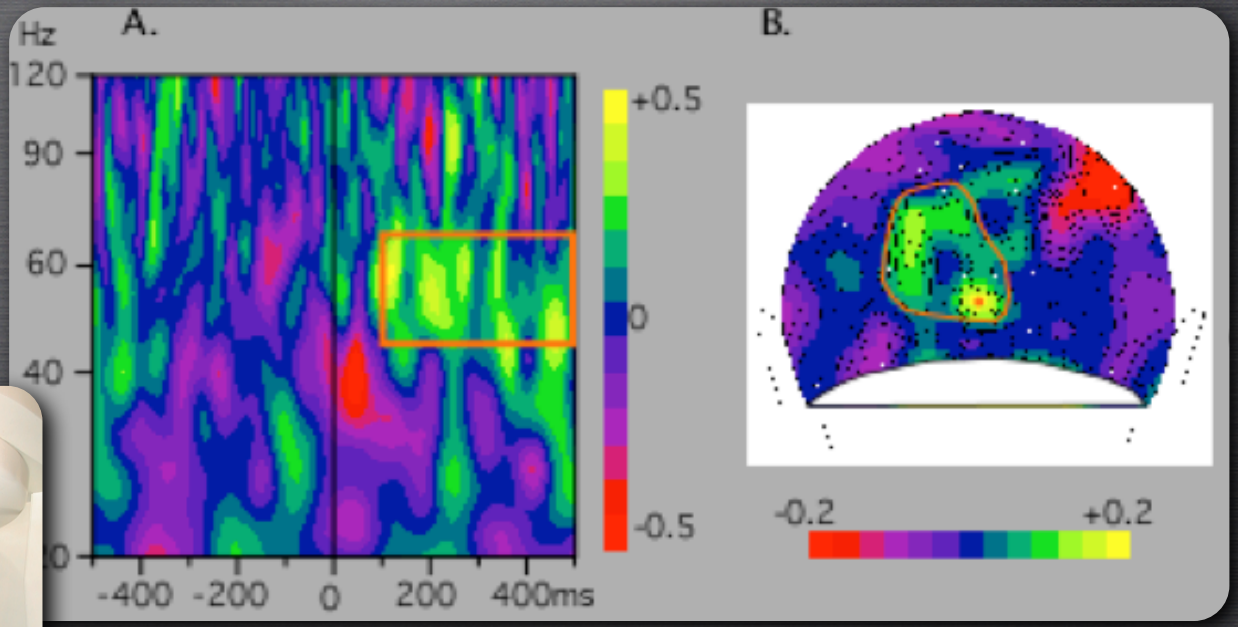
Dehaene et al.

Consciousness Takes Time

If consciousness depends on **quality of representation** and if representations emerge, as a result of **learning** mechanisms, in a biased, dynamical, recurrent system that implements global constraint satisfaction, then availability to consciousnesss should depend on time available for processing, at different scales:

- subliminal perception
- **memory & learning** (Destrebecqz et al., 2001, 2005)
- **cognitive development** (Bremner et al., submitted)
- **action** (Sarrazin, Haggard, & Cleeremans, in prep.)
- **conditioning** (Perruchet, Cleeremans & Destrebecqz, in press)

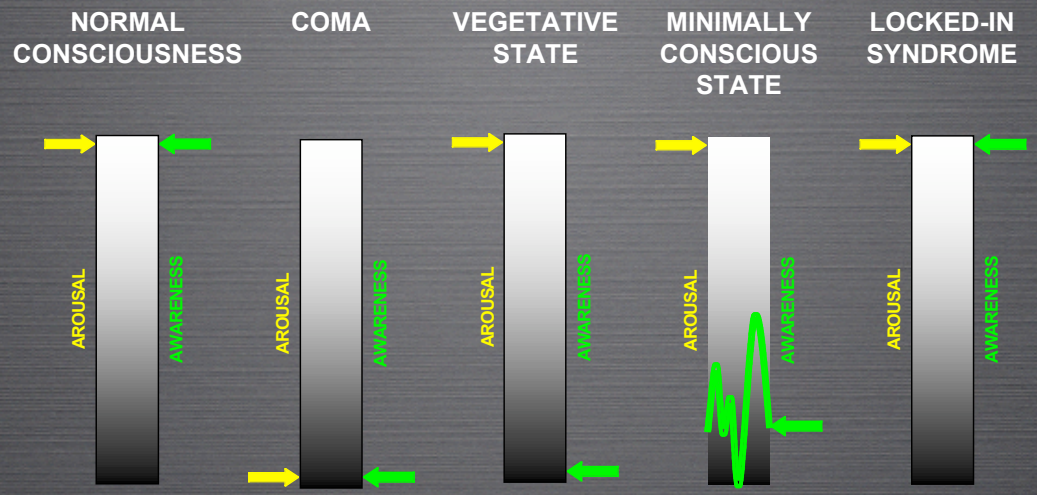
Consciousness takes time

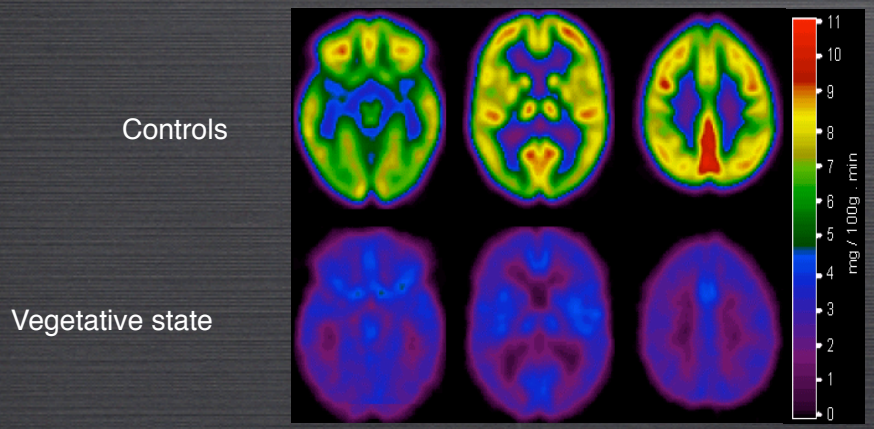


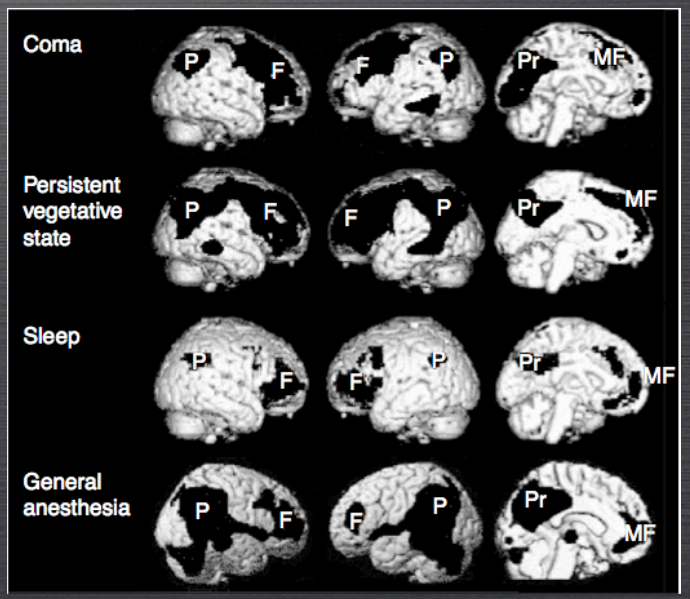
Increased gamma-band oscillations when aware

Tallon-Baudry et al.

Disruption of the workspace

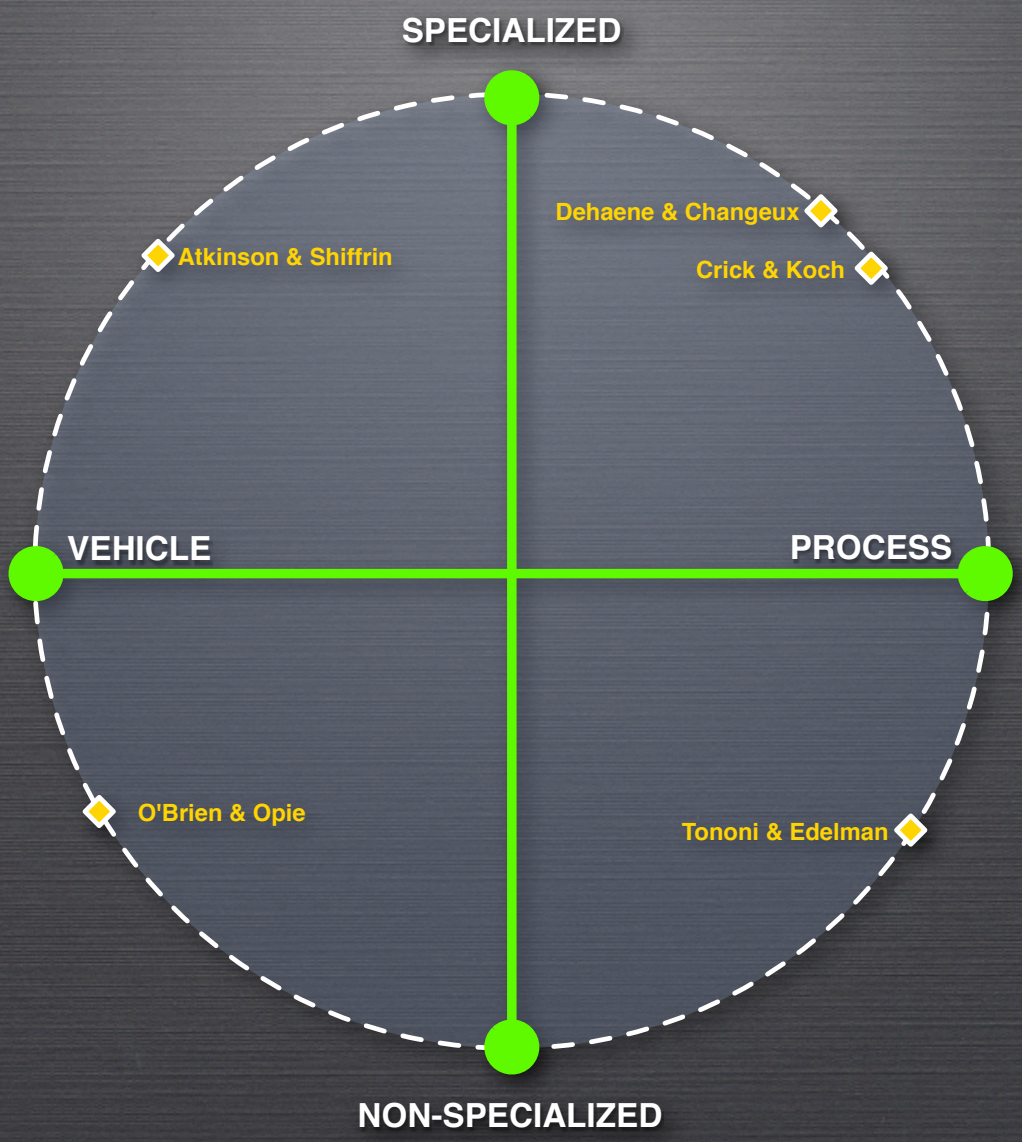


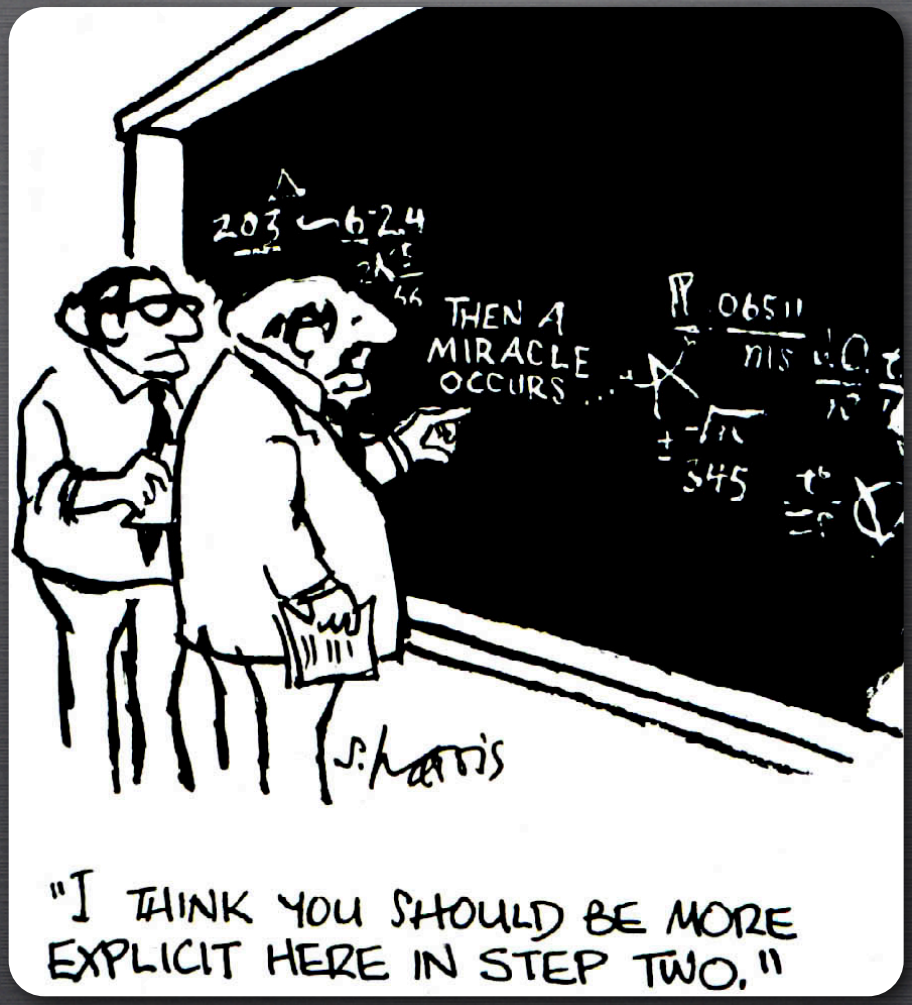




Laureys et al.

Computational theories of C




THEN A MIRACLE OCCURS...
"I THINK YOU SHOULD BE MORE EXPLICIT HERE IN STEP TWO."

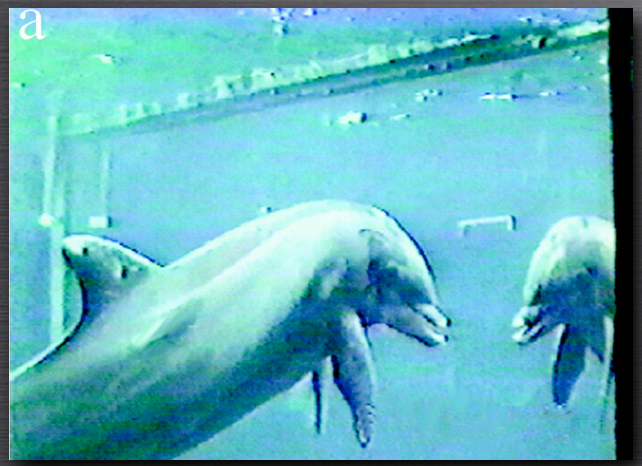
Speculations

Emotions...



(Feel like sticking your tongue out?)

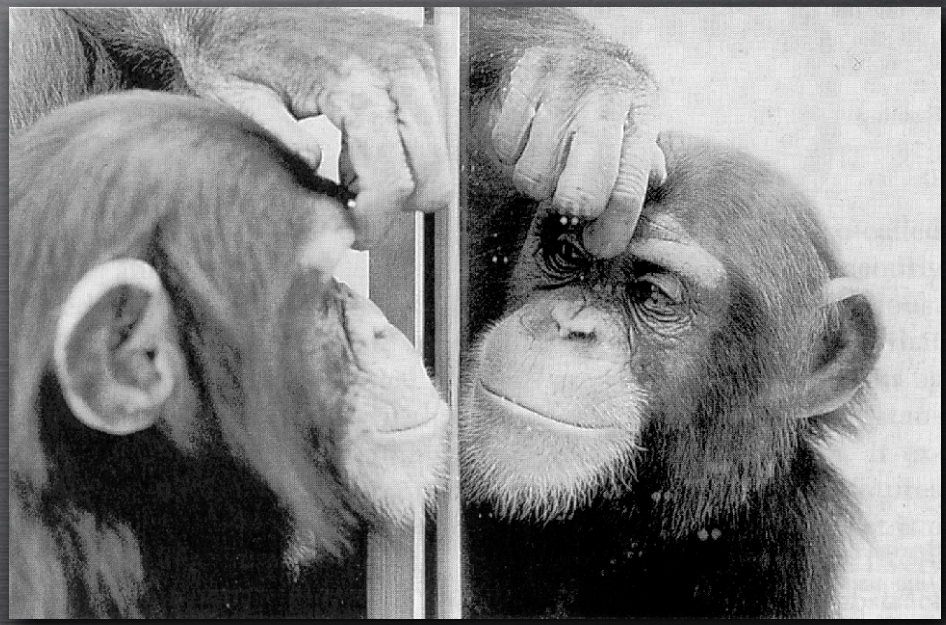
Self Consciousness



Reiss D, Marino L.

Mirror self-recognition in the bottlenose dolphin

PNAS 2001 May 8;98(10):5937-42.



Chimpanzees: self-recognition.
Gallup, GG (1970) Science 167: 86-87

Intelligent Mirrors

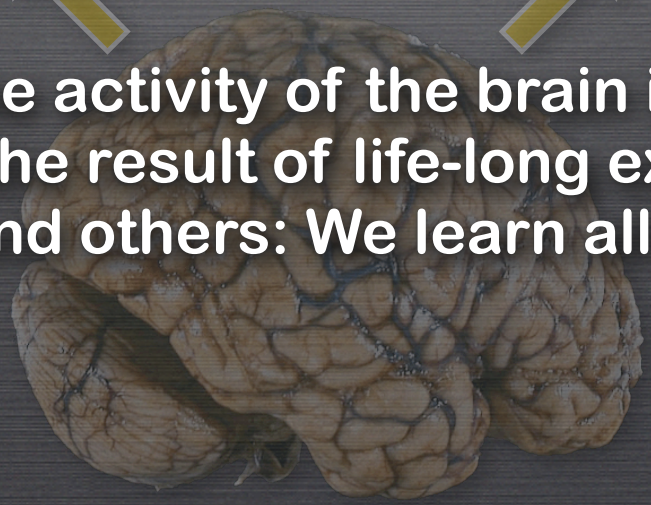
It is not the child who imitates the mother, but the mother who imitates the child!

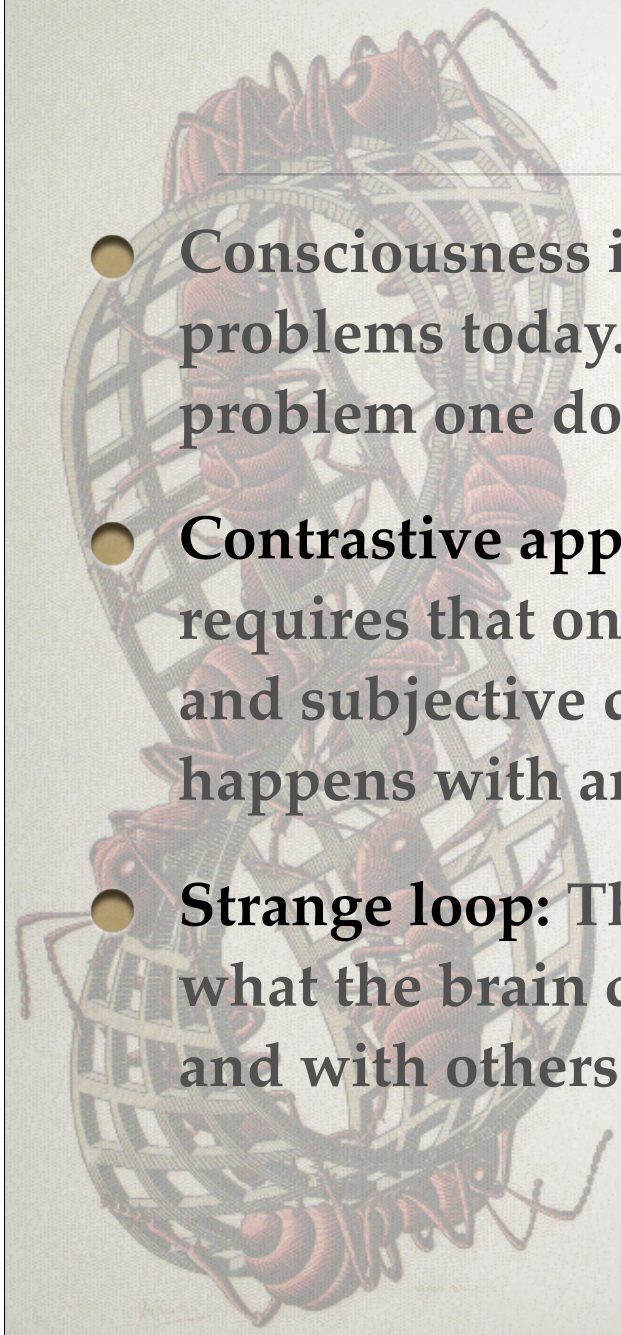
We learn to be conscious!

- We learn to be conscious selves by inferring the mental states of others based on observing the consequences of our actions
- Others act as external selves during development
- Minimal conditions for C?
  - Massive information-processing resources that are sufficiently powerful to simulate certain aspects of their own inner workings
  - A rich learning system that continuously attempts to predict future states (the consequences of its actions)
  - Immersion in a suitably rich environment from which models of yourself can be built

Free Will?

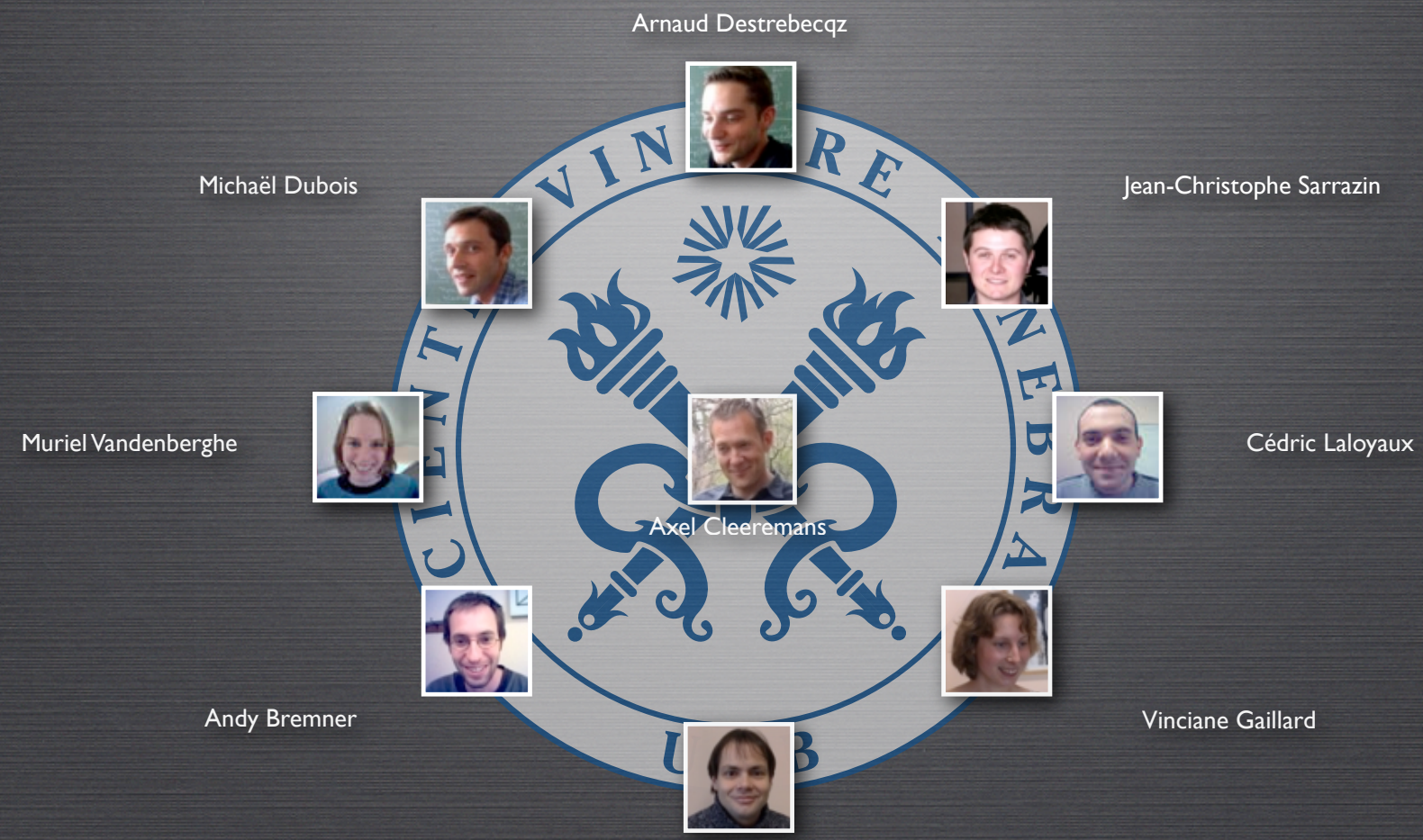
- Is the mind truly nothing more than the activity of the brain?
  - Jean-Pierre Changeux's "Neuronal Man"
  - Joe LeDoux's "Synaptic Self"
  - Dan Wegner's "The illusion of conscious will"
- Yes, but: The activity of the brain is itself nothing more than the result of life-long experience with the world and others: We learn all the time





Conclusions

- Consciousness is one of the most important scientific problems today. It is a genuine scientific challenge — a problem one doesn't know how to think about yet
- **Contrastive approach:** Understanding consciousness requires that one correlates objective data (the acting brain) and subjective data ("what it is like") by comparing what happens with and without consciousness
- **Strange loop:** The mind is "just" what the brain does, but what the brain does is shaped by experience with the world and with others



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