Visual Object Recognition
Computational Models and Neurophysiological Mechanisms
Neuro 130/230. Harvard College/GSAS 78454

Consider a machine that can pass the general Turing tests for vision (i.e., that can answer ANY question about ANY image and those answers are indistinguishable from human answers).

Would that machine have “visual consciousness”, like you and me?

Most graded homework should have been returned to you already. All homework will be returned in the next two weeks.

Please fill in course evaluations after the class

Final exam due Dec 14th

Visual Object Recognition
Computational Models and Neurophysiological Mechanisms
Neurobiology 230. Harvard College/GSAS 78454

Class 1 [09/01/2021]. Introduction to Vision

Note: no class on 09/06/2021

Class 2 [09/13/2021]. Natural image statistics and the retina

Class 3 [09/20/2021]. The Phenomenology of Vision

Class 4 [09/27/2021]. Learning from Lesions

Class 5 [10/04/2021]. Primary Visual Cortex

Note: no class on 10/11/2021

Class 6 [10/18/2021]. Adventures into *terra incognita*

Class 7 [10/25/2021]. From the Highest Echelons of Visual Processing to Cognition

Class 8 [11/01/2021]. First Steps into in silico vision [Will Xiao]

Class 9 [11/08/2021]. Teaching Computers how to see

Class 10 [11/15/2021]. Computer Vision

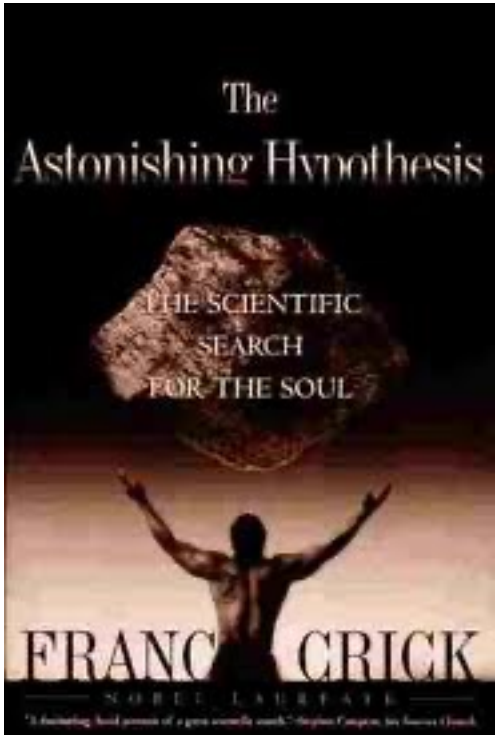
Class 11 [11/22/2021]. Connecting Vision to the rest of Cognition

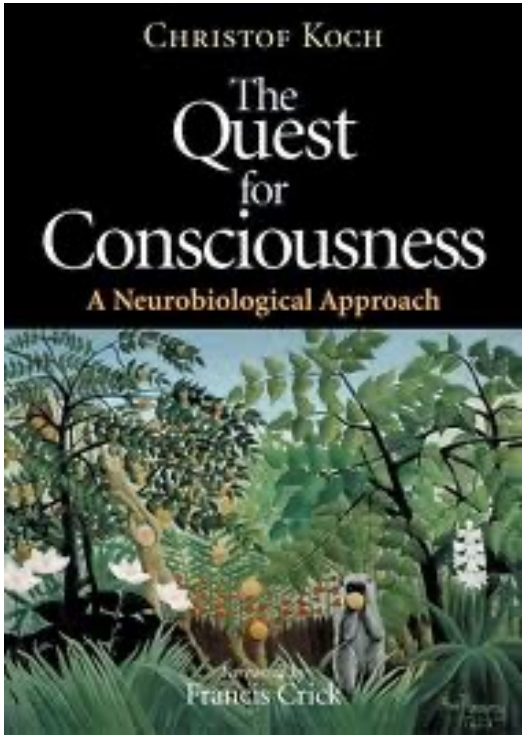
Class 12 [11/29/2021]. Visual Consciousness

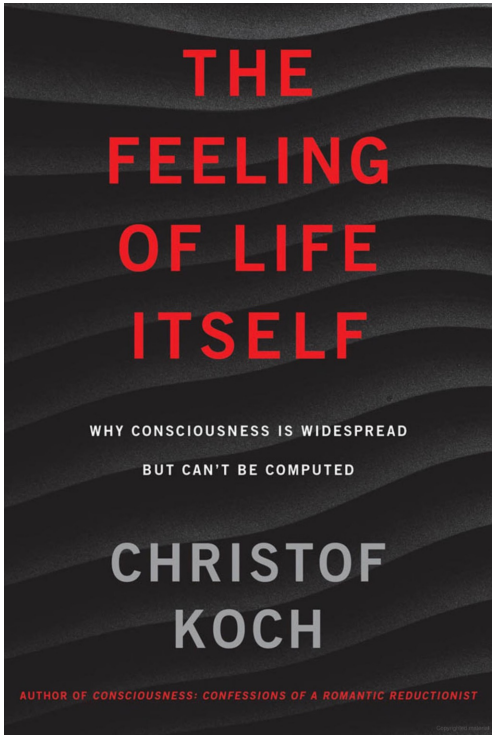
FINAL EXAM, PAPER DUE 12/14/2021. No extensions.

The Turing test for vision

Towards the neural correlates of consciousness







Hidden in plain sight: a pragmatic definition of consciousness

https://www.youtube.com/watch?v=IGQmdoK_ZfY

Hidden in plain sight: a pragmatic definition of consciousness

Resnik et al 1997

Hidden in plain sight: a pragmatic definition of consciousness

How can a physical system give rise to consciousness?

How can consciousness be explained in terms neurons and their interactions?

How can a physical system have *qualia*?

Why are humans conscious and not just a bunch of zombies?

Do other animals also have consciousness? How did consciousness evolve?

A (non-exhaustive) list of possible answers

- "Religious" answers. E.g. "… consciousness requires a non-physical soul…" (Plato; The bible; Descartes (modern form of dualism: *res extensa* and *res* cogitans); Aristotle, Thomas Aquinas, Karl Popper, Sigmund Freud, John Eccles)
- Science cannot understand consciousness (the "mysterian" approach)
- There is no such thing as consciousness. It's just an illusion. (e.g. Dennett)
- We need new (as yet undiscovered) laws to explain consciousness (e.g. Roger Penrose)
- Consciousness requires behavior (and language) (e.g. Cotterill)
- Consciousness is an epiphenomenon

Some basic working assumptions

We are conscious (it is not an illusion or an epiphenomenon)

Some other animals are also conscious

We start with simple questions that we can try to study rigorously

We start with vision. Hopefully, we will be able to extrapolate some of what we learn from vision to other sensations (e.g. pain, smell, self-awareness)

We need an explicit representation

Only parts of the brain will correlate with the contents of consciousness. We search the *neuronal correlates of consciousness* (NCC)

We leave out many interesting topics for now: Dreams, Lucid dreaming, Out of body experiences, Hallucinations, Meditation, Sleep walking, Hypnosis, Self awareness. Qualia, Feelings

Crick and Koch. Nature Neuroscience 2003

NCC: neuronal correlates of consciousnes

A minimal[1] set of neuronal events and mechanisms jointly sufficient[2] for a specific conscious percept[3]

[1] "Minimal": A solution such as "the whole healthy human brain can experience consciousness" is not very informative.

[2] "Sufficient": We are not looking for "enabling" factors such as the heart or the cholinergic systems arising in the brainstem

[3] "Specific conscious percept": e.g. seeing a face (as opposed to being conscious/unconscious)

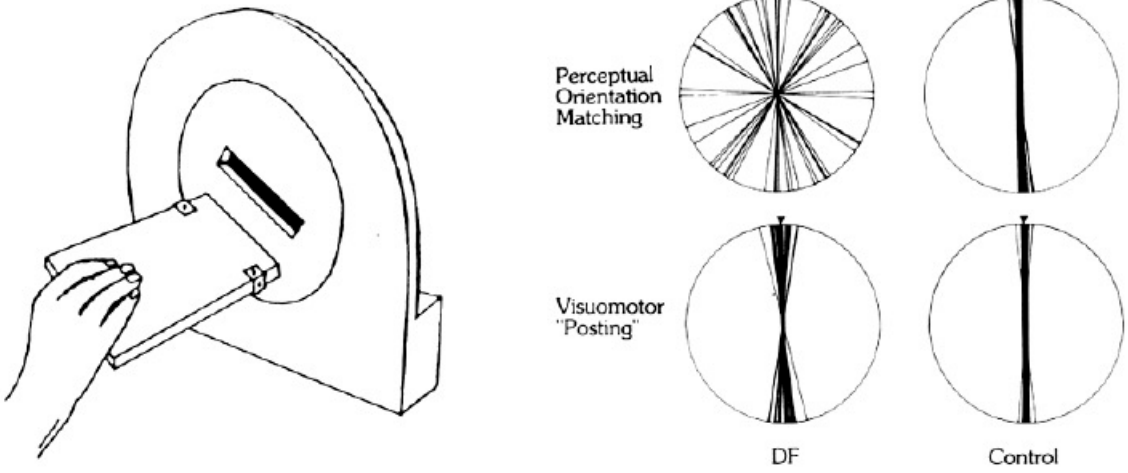
Koch. The quest for consciousness

“Zombie modes”: not all brain activity leads to consciousness

Rapid, transient, stereotyped and unconscious responses

In a zombie mode the main flow of information is feed-forward

Zombie modes are very fast and useful

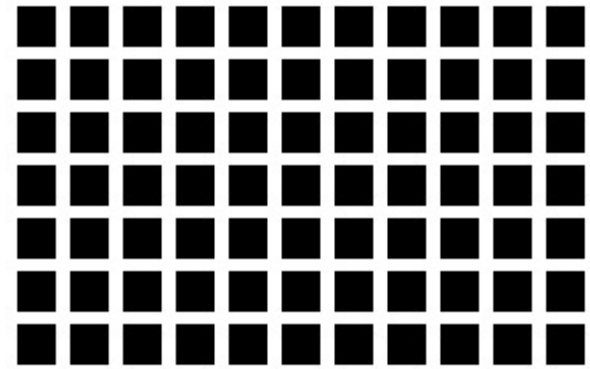


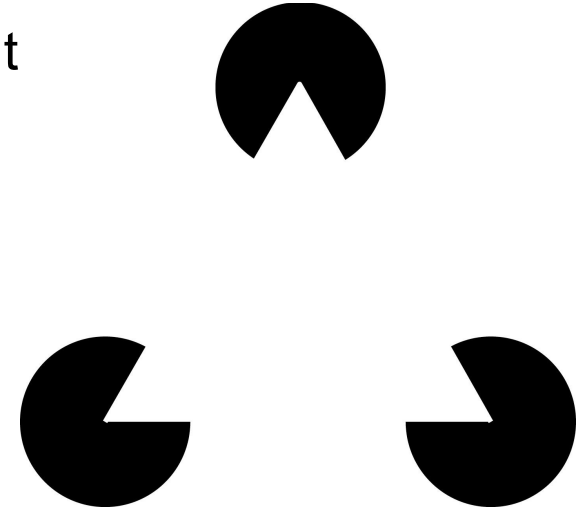
Goodale, M. and A. Milner (1992) Separate visual pathways for perception and action *Trends in Neurosciences* **15**:20-25

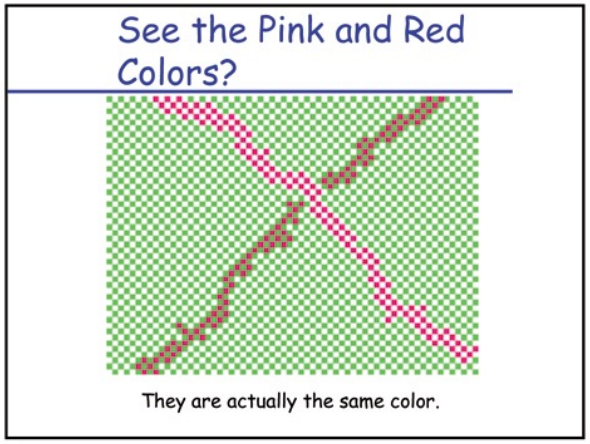
The NCC representation must be *explicit*

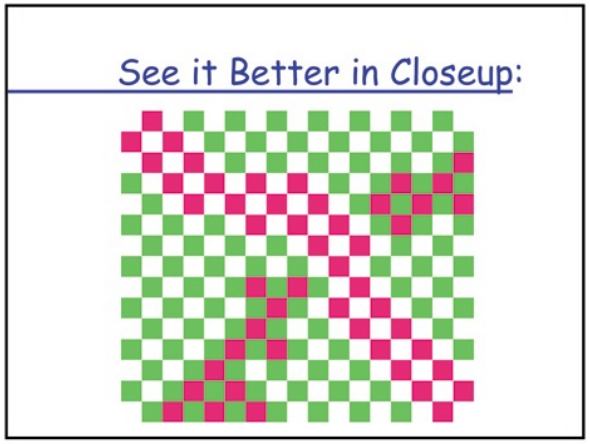
Explicit: A single layer of neurons can deliver the answer

An explicit representation is necessary but not sufficient









We are not aware of the entire visual field

We have the illusion that we "see" the whole visual field.

But: inattentional blindness illusion!

Attention filters information[1].

Consciousness may generally require attention

But consciousness may happen in the absence of attention[2]

Two mechanisms for attention: bottom-up (saliency) and top-down (cognitive)

[1]Desimone and Duncan (1995). *Annual Review of Neuroscience*

[2]Li et al. (2002) *Proc Natl Acad Sci USA*

More demos

Filling in
http://smc.neuralcorrelate.com/illusions-and-demos/dy

Change blindness
http://nivea.psycho.univ-paris5.fr/CBMovies/FarmsFlickerMovie.gif
https://www.youtube.com/watch?v=FWSxSQsspiQ

Selective attention and basketball passes
http://www.youtube.com/watch?v=vJG698U2Mvo
https://www.youtube.com/watch?v=IGQmdoK_ZfY

Person swapping experiments
http://www.youtube.com/watch?v=ElLnNalL4xY

Change blindness in a movie
http://www.youtube.com/watch?v=ubNF9QNEQLA

Change Blindness (using flicker)
(from J. Kevin O'Regan -- http://nivea.psycho.univ-paris5.fr)

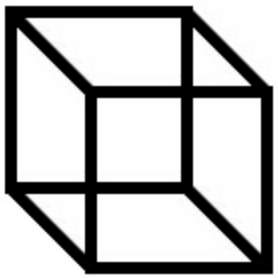
CB during Mudsplashes (O'Regan, Rensink & Clark, 1999)

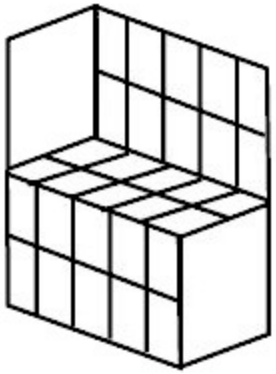
A framework to define the NCC (Crick and Koch)

1. The nonconscious *Homunculus*
2. A lot can be done in *zombie mode*
3. The NCC involve *coalitions of neurons*
4. An *explicit* representation is needed
5. Higher levels first
6. The NCC require strong driving projections
7. Consciousness comes in snapshots
8. Attention and binding
9. The NCC may involve specific firing patterns
10. Penumbra, meaning and qualia

Crick and Koch 2003

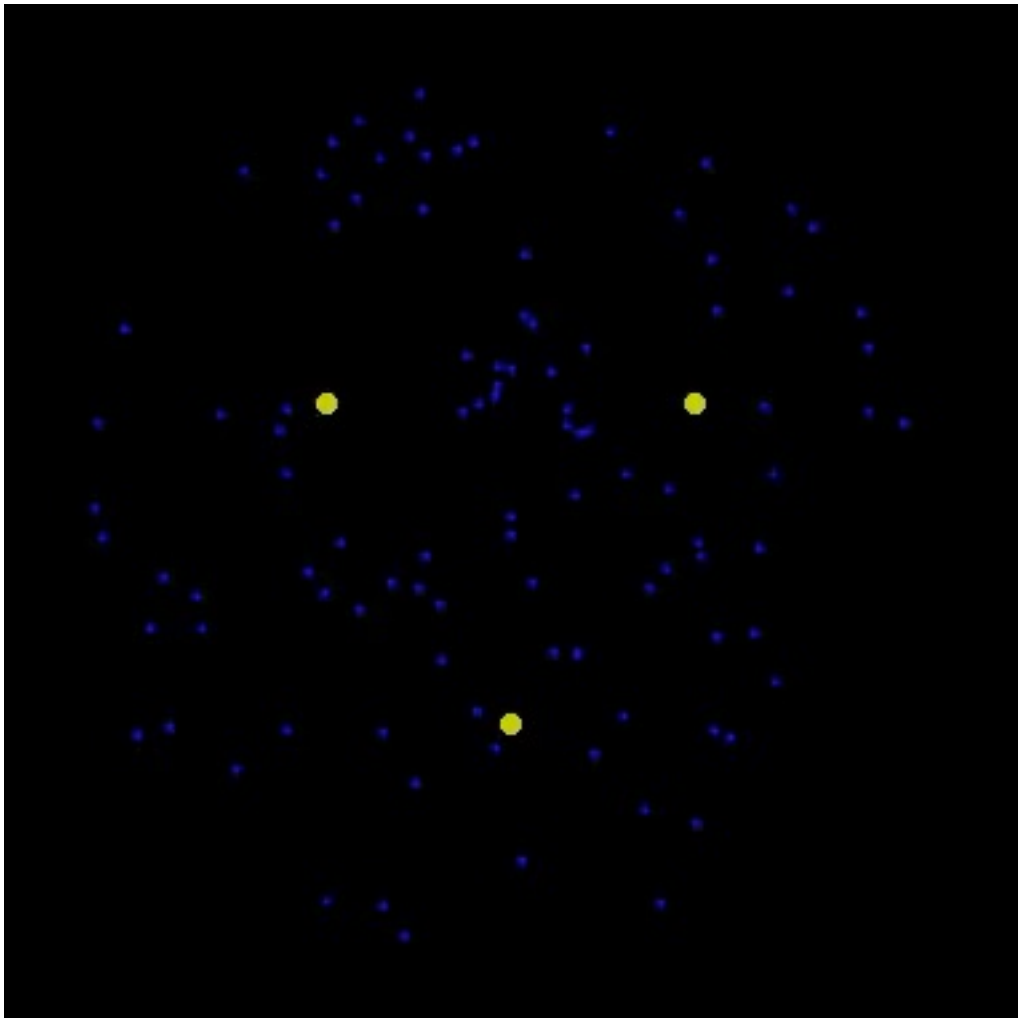
Experimental paradigms to examine the neural correlates of visual consciousness



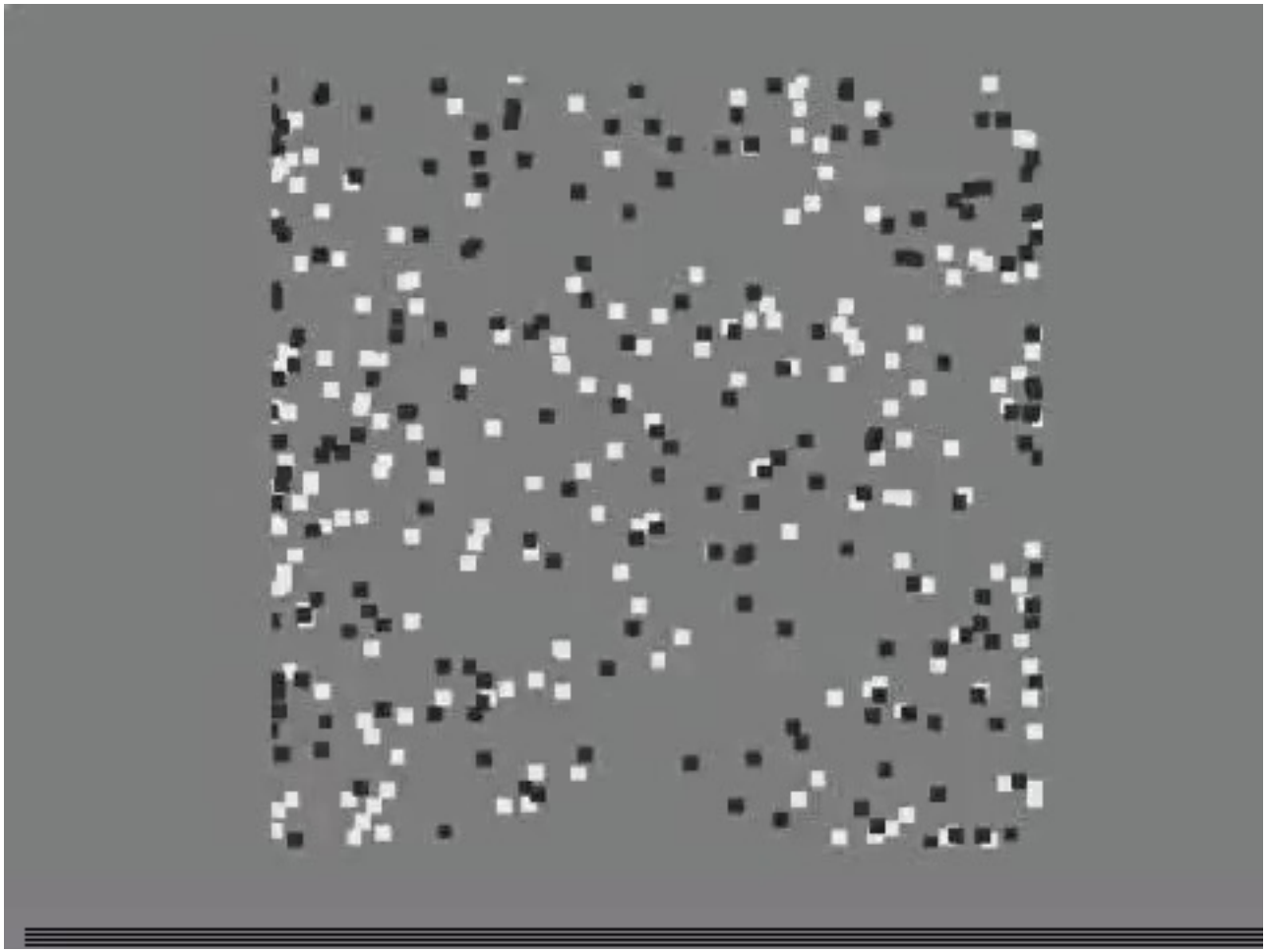


Difficulty: where/how/when to search for the neural correlates?

Experimental paradigms to examine the neural correlates of visual consciousness

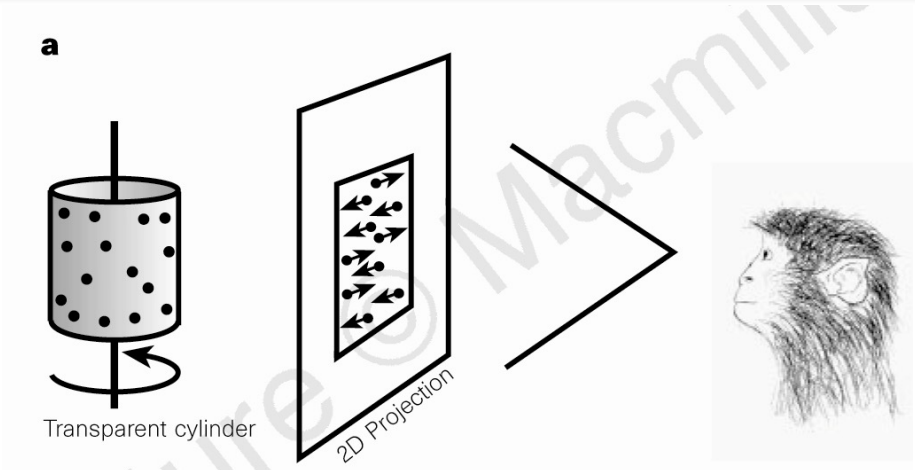


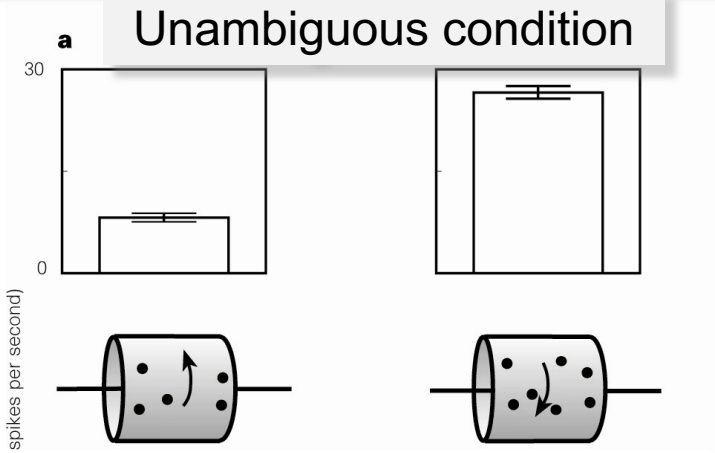
Bistable percepts example: ambiguous structure from motion



Bradley, D. C., G. C. Chang, et al. (1998). "Encoding of 3D structure from motion by primate area MT neurons." Nature **392**: 714-717.

Neurons in area MT following the percept

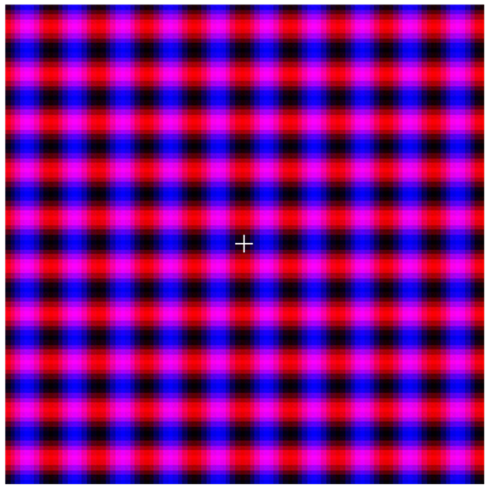




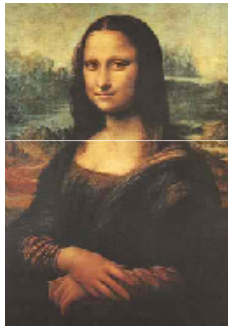
Bradley, D. C., G. C. Chang, et al. (1998). "Encoding of 3D structure from motion by primate area MT neurons." Nature **392**: 714-717.

Bistable percepts

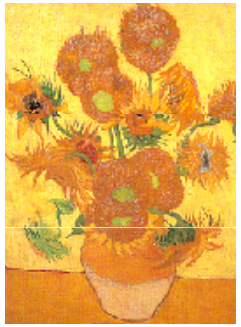
Monocular rivalry (weaker)



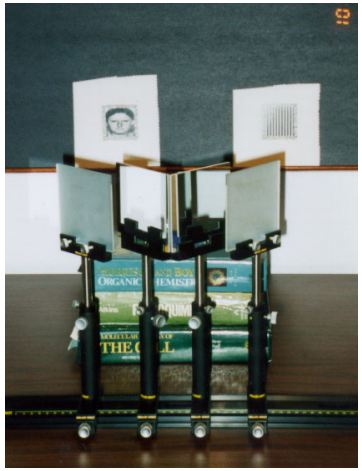
Binocular rivalry (stronger)



Right eye



Left eye



Helmholtz haploscope

perception

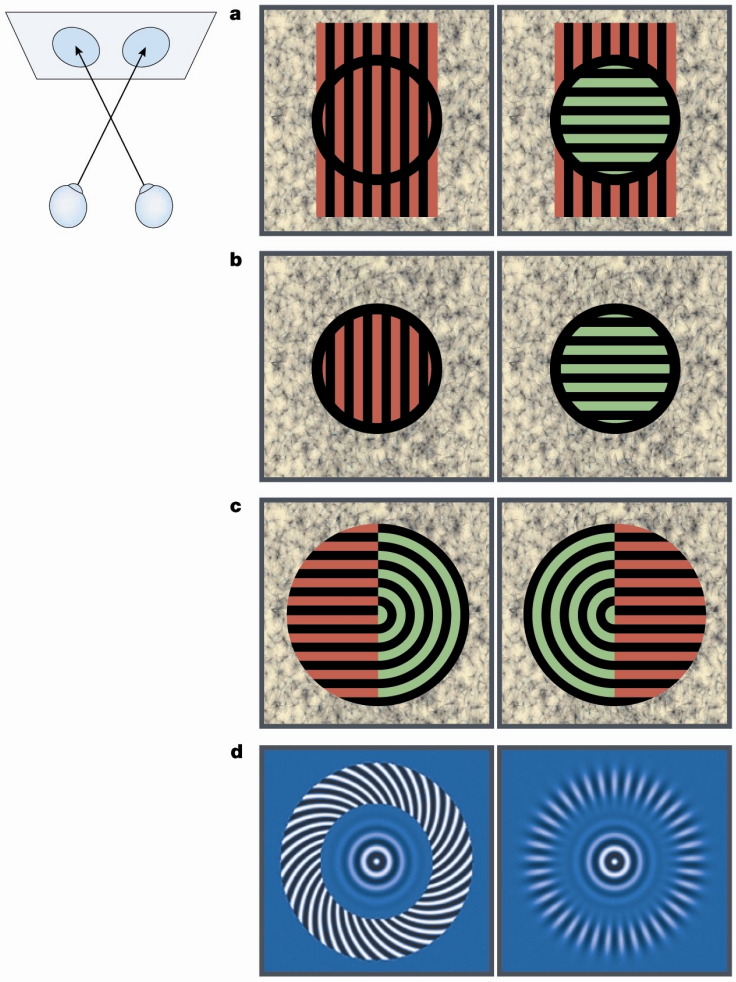
Different stimuli are presented to the right and left eyes

The input is constant

Perception alternates between one percept and the other

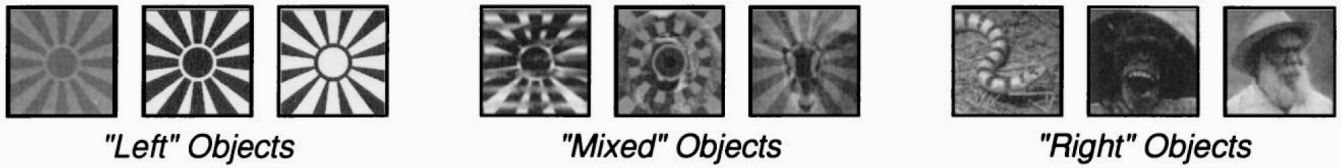
What are the neuronal changes responsible for the perceptual alternation?

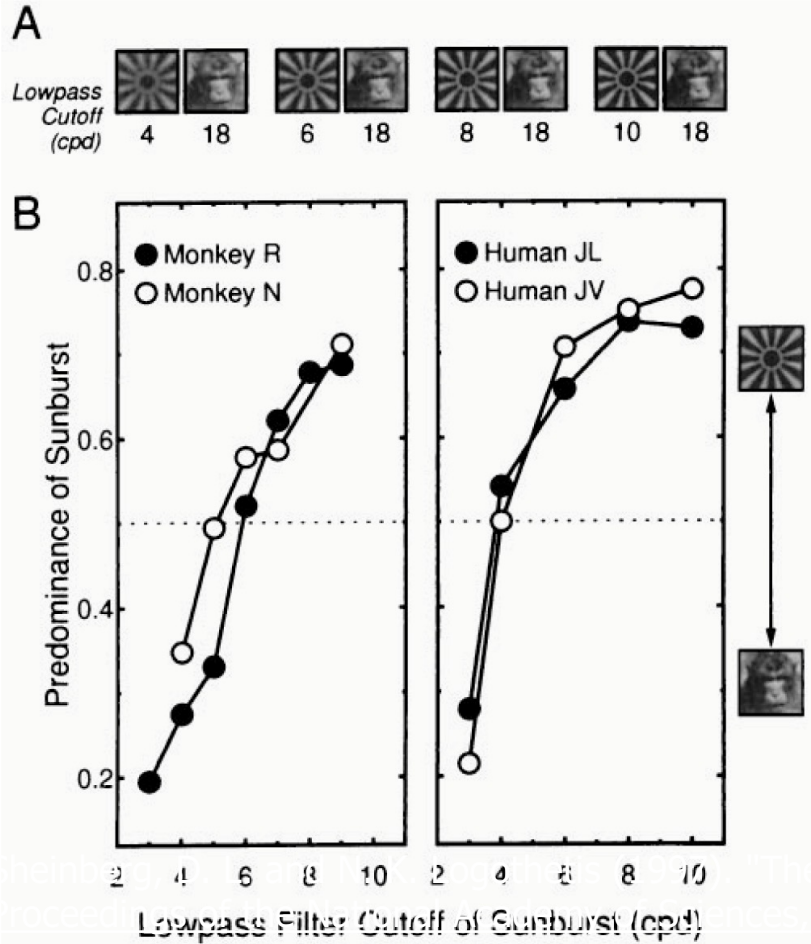
Binocular rivalry: competition between percepts (as opposed to competition between eyes)

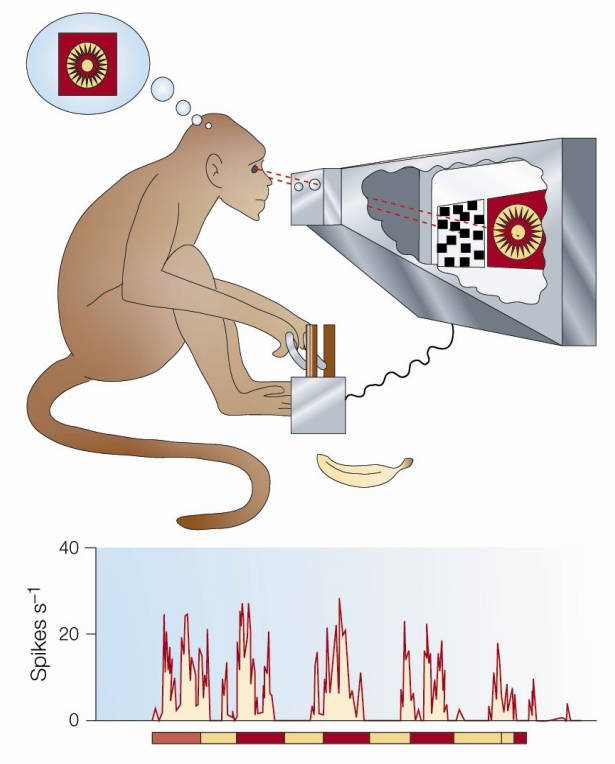


Blake, R. and N. Logothetis (2002). "Visual competition." Nature Reviews Neuroscience **3**: 13-21.

Binocular rivalry can be studied in both humans and monkeys

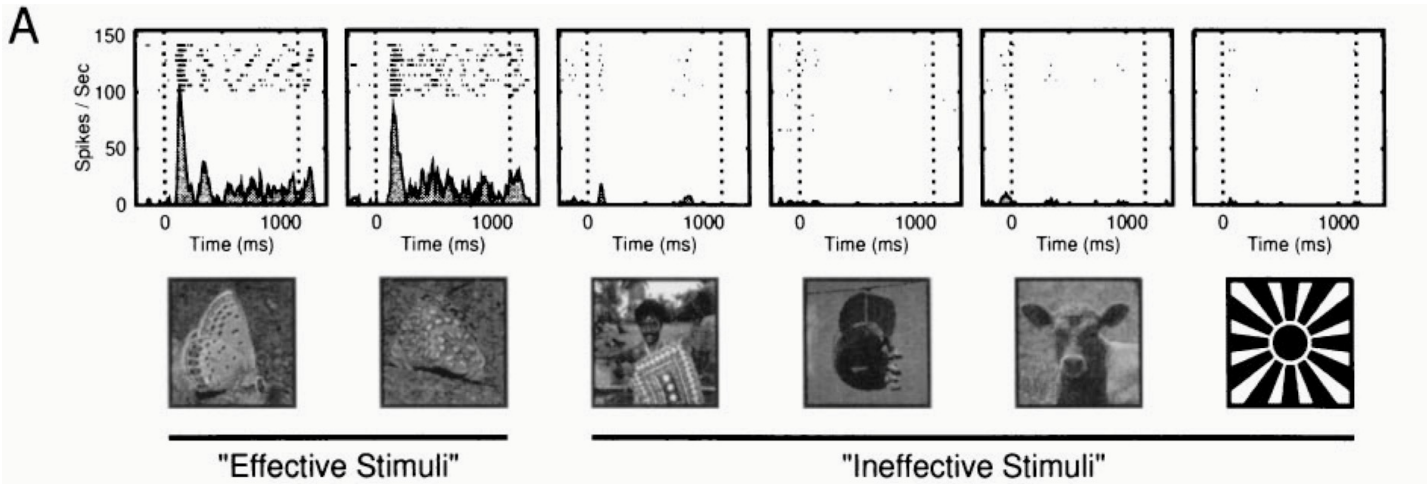






Myerson, Miezin, Allman,
Behavioral Analysis Letters, 1981. **1**: p. 149-159.

Neurons in inferior temporal cortex follow the percept



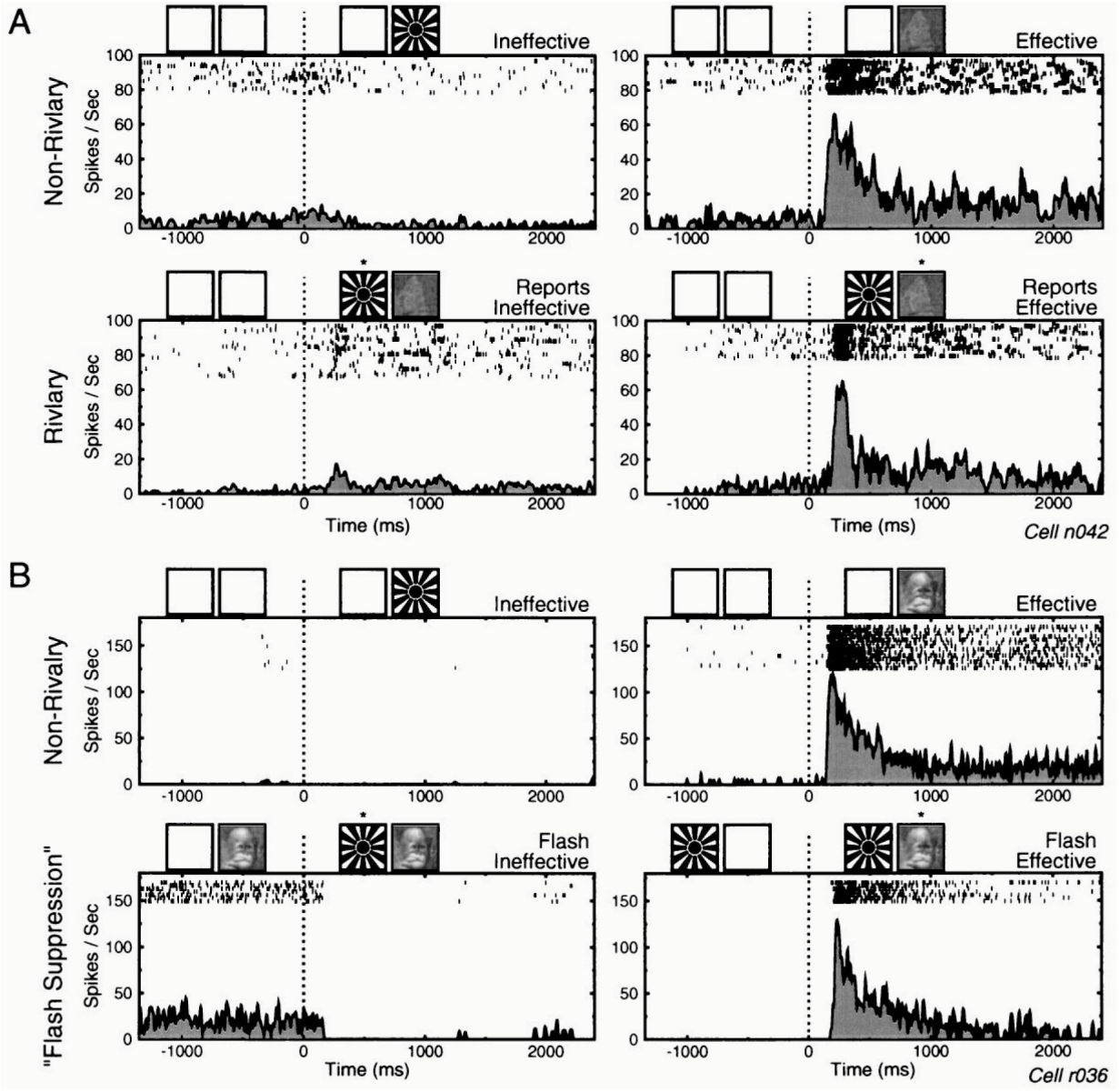
A visually selective neuron in inferior temporal cortex

Neuronal responses correlate with subjective reports

Another example

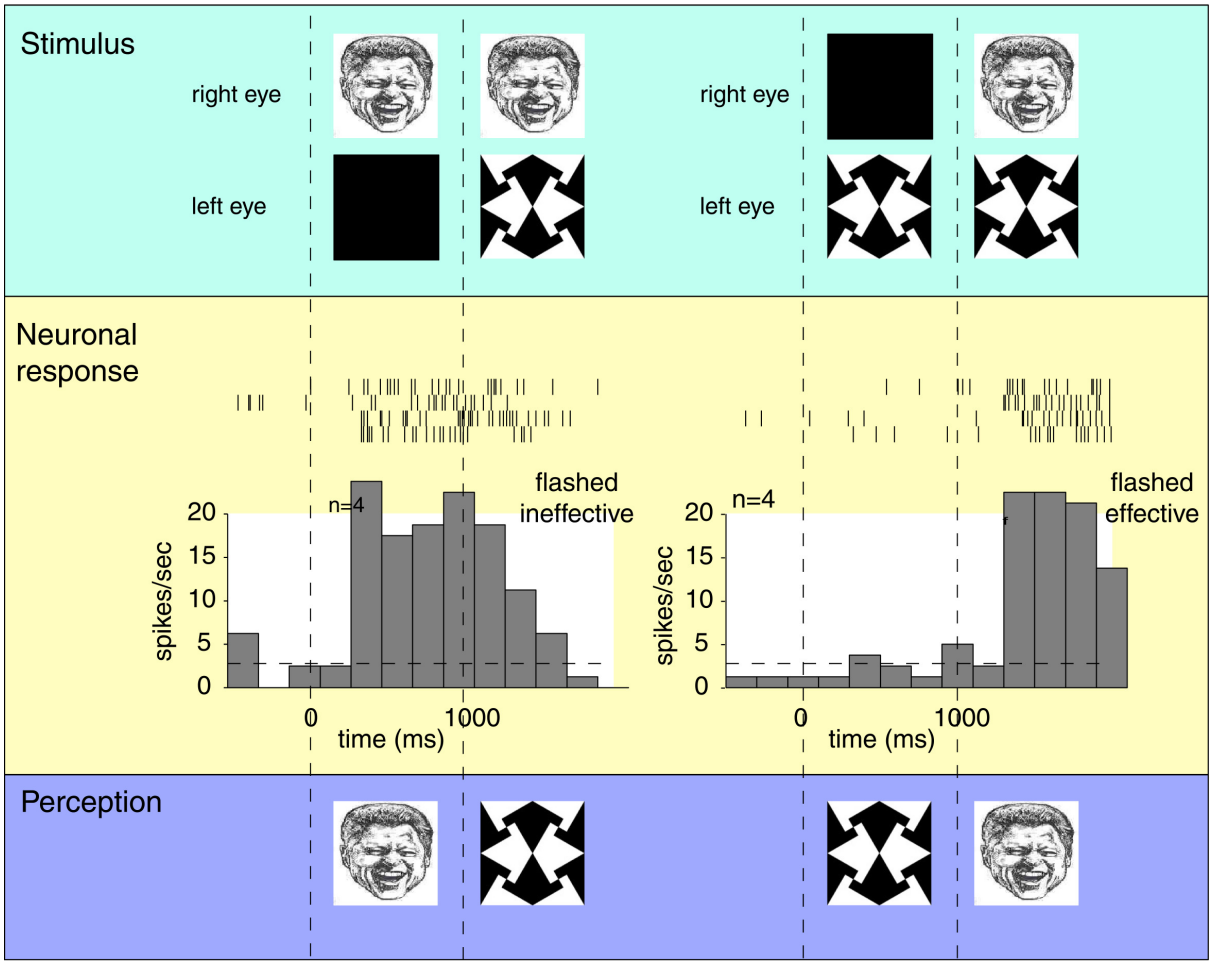
Sheinberg and Logothetis 1997; Leopold and Logothetis 1999

Neurons in inferior temporal cortex follow the percept



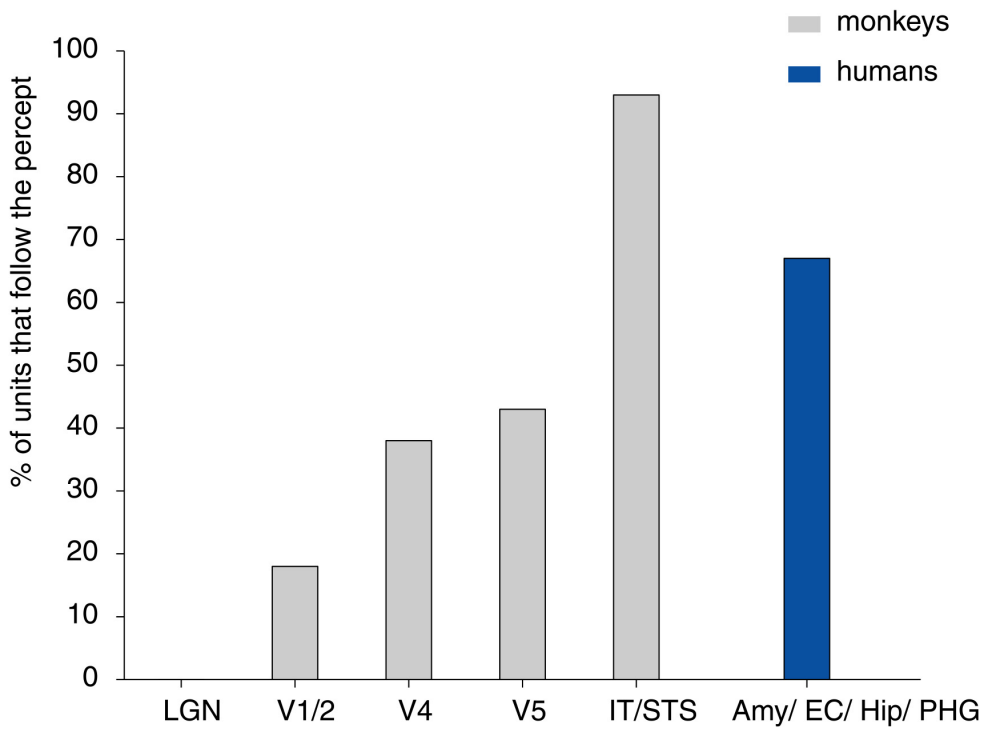
Sheinberg and Logothetis 1997
Leopold and Logothetis 1999

Neurons in the human medial temporal lobe follow the percept



Kreiman, G., I. Fried, and C. Koch. *Single neuron correlates of subjective vision in the human medial temporal lobe.* PNAS, 2002. **99**:8378-8383.

There is an increase along the visual hierarchy in the proportion of neurons that correlate with the subjective percept



- Binocular Rivalry/Flash Suppression – "one-to-many" between stimulus and percept. Allow us to manipulate the percept
- Neuronal evidence from monkeys shows that neurons in early areas (LGN, V1) show little or no percept effect
- Neurons in later areas (IT, MTL) predominantly follow the percept
- Candidates for the NCC?
- These studies showed correlations. What we will need in the future is causation.

What would constitute evidence that we understand the NCC?

The possibility to:

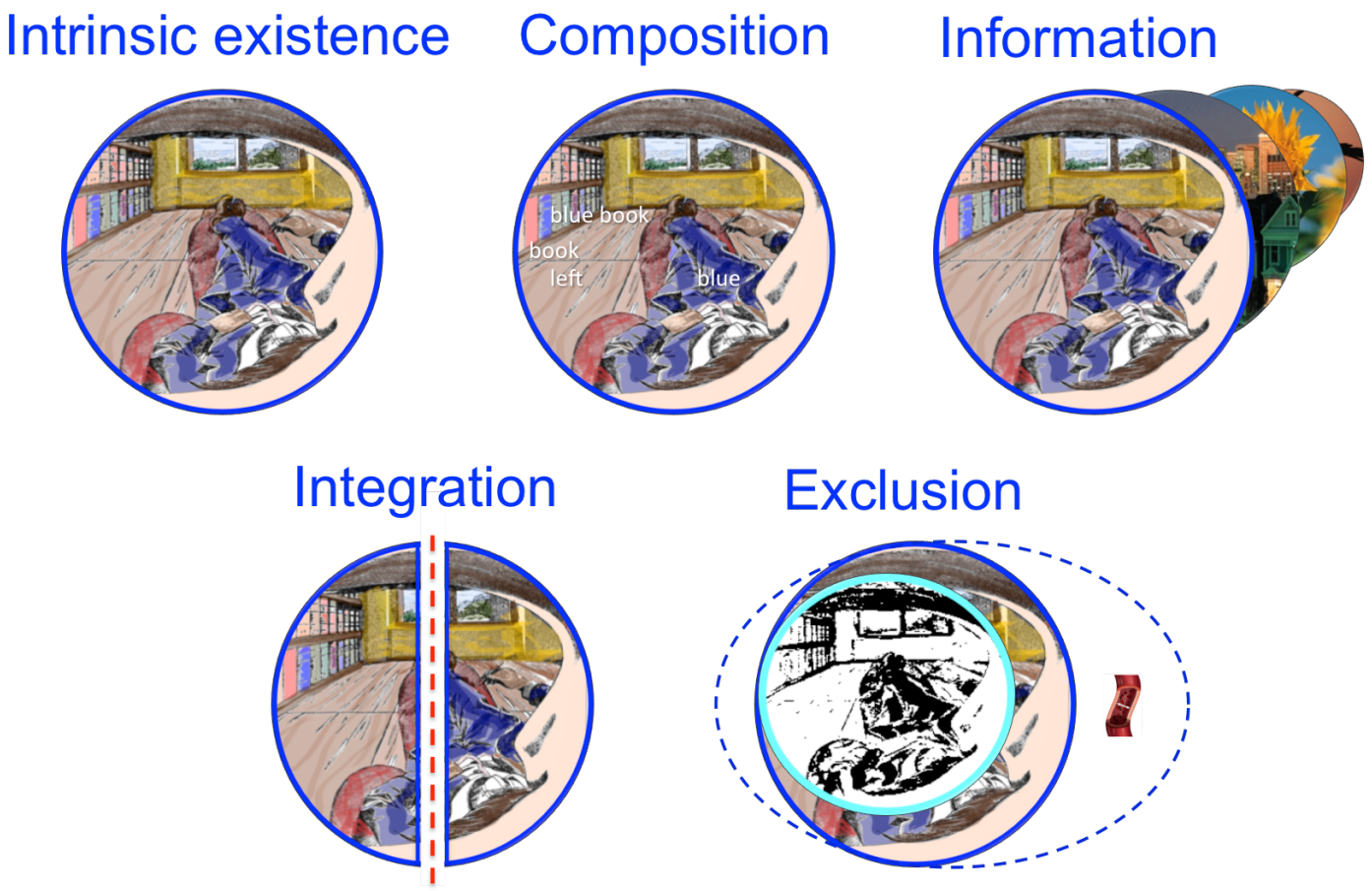
(a) Model and predict neuronal responses given a perceptual state

(b) Accurately predict perceptual state given neuronal activity

(c) Induce a specific perceptual state by selective electrical stimulation

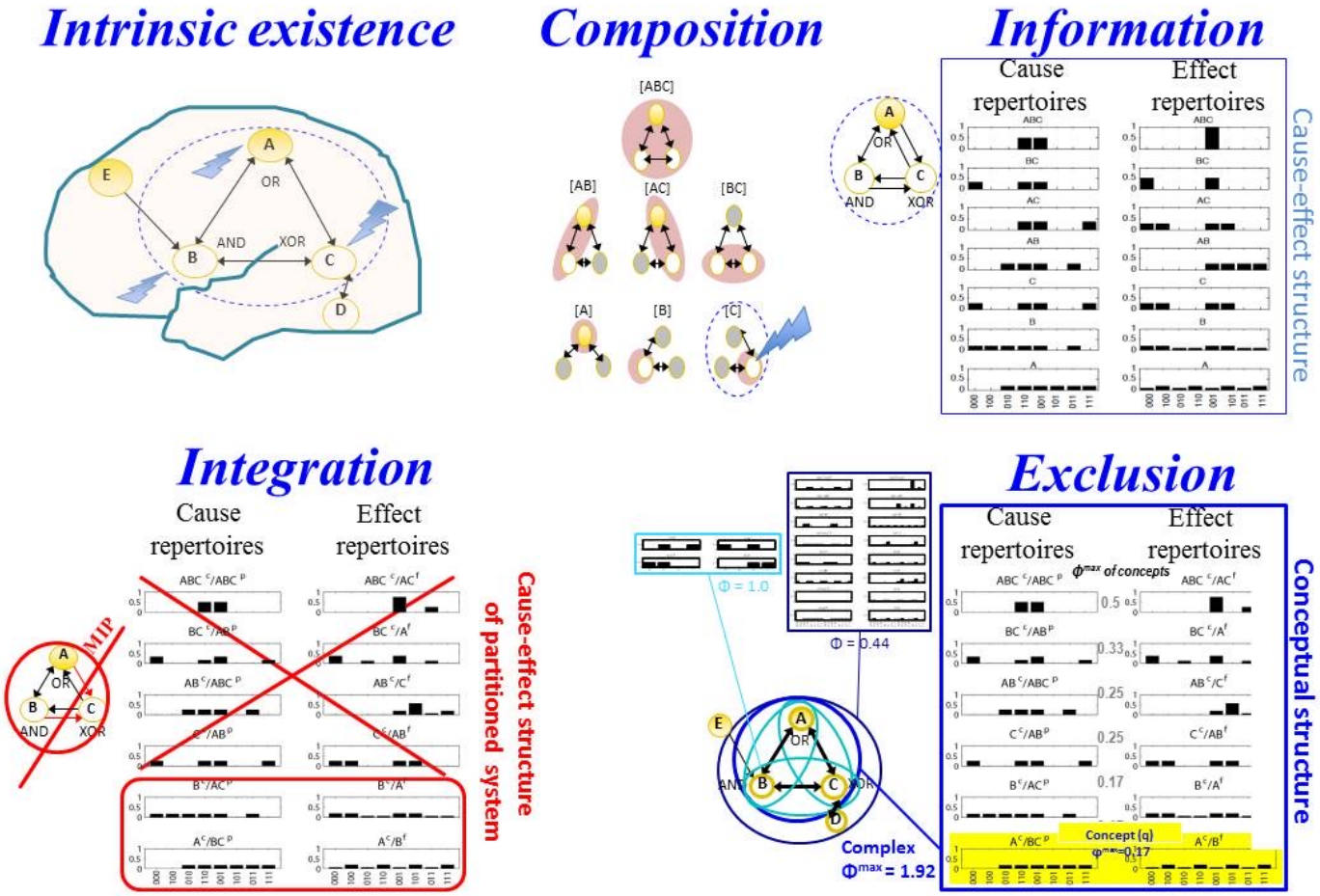
(d) Inactivate or repress a perceptual state

Integrated Information Theory -- Axioms



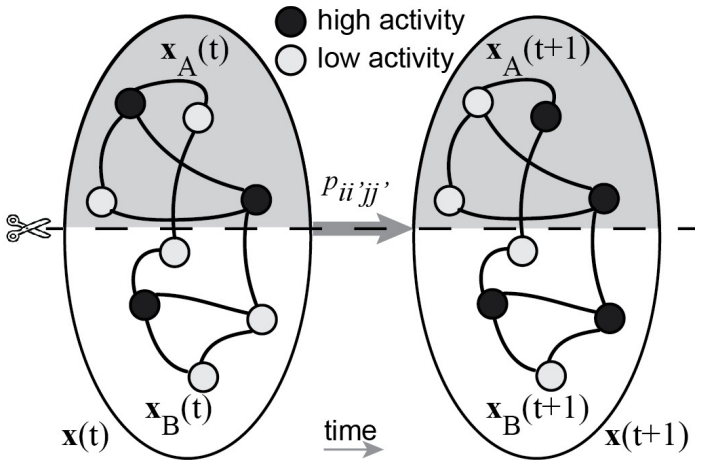
Giulio Tononi (2015), Scholarpedia, 10(1):4164.

Integrated Information Theory – Postulates illusration



Giulio Tononi (2015), Scholarpedia, 10(1):4164.

Central identity: an experience as a maximally irreducible conceptual structure

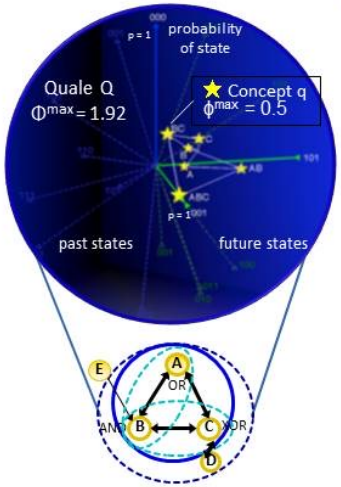


Experience

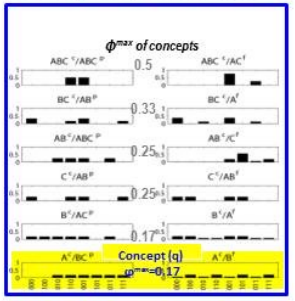
Conceptual structure in cause-effect space

Quality of experience: "form" of the conceptual structure in cause-effect space

Quantity of experience: irreducibility (Φ^{max}) of the conceptual structure



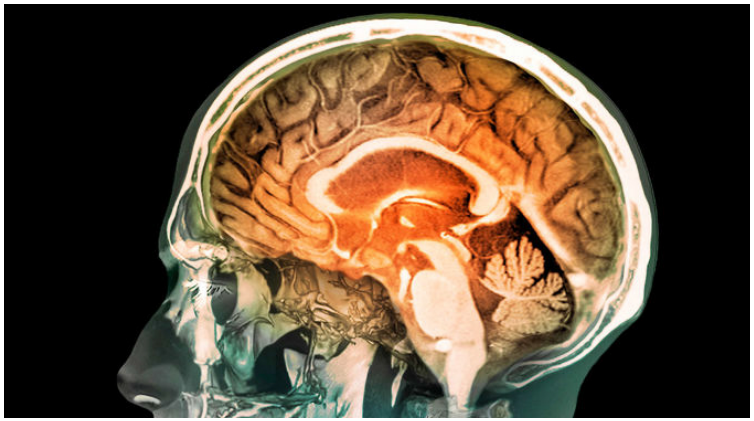
Conceptual structure Q



Giulio Tononi (2015), Scholarpedia, 10(1):4164.

Outlandish competition seeks the brain sources of consciousness

http://klab.tch.harvard.edu/press/2019/Outlandish%20competition%20seeks%20the%20brain%E2%80%99s%20source%20of%20consciousness%20_%20Science%20_%20AAAS.pdf



Adversarial collaboration

Preregistered experiments

Data sharing

Summary

- Consciousness has been discussed for millennia. Now, it is a central scientific question in Neuroscience.
- Experimental efforts have focused on searching for minimal and jointly sufficient neuronal correlates of consciousness, the NCC.
- During binocular rivalry, neuronal responses in the highest parts of visual cortex correlate with the dynamical changes in the contents of consciousness.
- A full description of the NCC would require a quantitative computational model that can predict neuronal responses given the perceptual state, and that can also predict the perceptual state given the neuronal responses. Activating or suppressing the NCC should elicit or silence specific perceptual states.
- Integrated information theory (IIT) is the first quantitative theoretical framework that aims to explain how consciousness emerges from a dynamical system with interconnected parts.

Further reading

Further reading

Crick, F. (1994). The astonishing hypothesis (New York: Simon & Schuster).

Koch, C. (2005). The quest for consciousness, 1st edn (Los Angeles: Roberts & Company Publishers).

Original articles cited in class

Resnik, R.A., O'Regan, J.K., and Clark, J.J. (1997). To see or not to see: the need for attention to perceive changes in scenes. Psychological Science 8, 368-373.

Crick, F., and Koch, C. (2003). A framework for consciousness. Nat Neurosci 6, 119-126.

Goodale, M., and Milner, A. (1992). Separate visual pathways for perception and action. Trends in Neurosciences 15, 20-25.

Blake, R., and Logothetis, N. (2002). Visual competition. Nature Reviews Neuroscience 3, 13-21.

Myerson, Miezin, Allman, Behavioral Analysis Letters, 1981. 1: p. 149-159.

Bonneh, Y., Cooperman, A., and Sagi, D. (2001). Motion-induced blindness in normal observers. Nature 411, 798-801.

Bradley, D. C., G. C. Chang, et al. (1998). "Encoding of 3D structure from motion by primate area MT neurons." Nature 392: 714-717.

Kreiman, G., Fried, I., and Koch, C. (2002). Single neuron correlates of subjective vision in the human medial temporal lobe. PNAS 99, 8378-8383.

Jackson, Frank (1982). Epiphenomenal Qualia. Philosophical Quarterly. 32: 127–136. doi:10.2307/2960077

Giulio Tononi (2015), Integrated information theory. Scholarpedia, 10(1):4164.

Sheinberg and Logothetis 1997

Leopold and Logothetis 1999

Tsuchiya and Koch

Jackson, Frank (1982). "Epiphenomenal Qualia". Philosophical Quarterly. 32: 127–136. doi:10.2307/2960077

Desimone and Duncan (1995). *Annual Review of Neuroscience*

Li et al. (2002) *Proc Natl Acad Sci USA*