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

Class 1. Sep-12 Introduction to pattern recognition. Why is vision difficult? Visual input. Natural image statistics. The retina.

Class 2. Sep-19 Lesion studies in animal models. Neurological studies of cortical visual deficits in humans.

Class 3. Sep-26 Psychophysics of visual object recognition [Joseph Olson]

Class 4. Oct-03 Introduction to the thalamus and primary visual cortex [Camille Gomez-Laberge]

Oct-10 *Columbus Day. No class.*

Class 5. Oct-17 Adventures into *terra incognita*. Neurophysiology beyond V1 [Kreiman]

Class 6. Oct-24 First steps into inferior temporal cortex [Carlos Ponce]

Class 7. Oct-31 From the highest echelons of visual processing to cognition [Leyla Isik]

Class 8. Nov-07 Correlation and causality. Electrical stimulation in visual cortex.

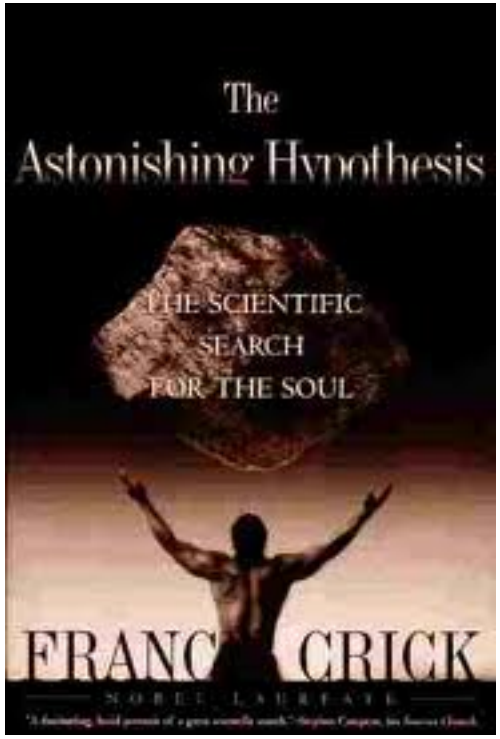
Class 9. Nov-14 Theoretical neuroscience. Computational models of neurons and neural networks. [Bill Lotter]

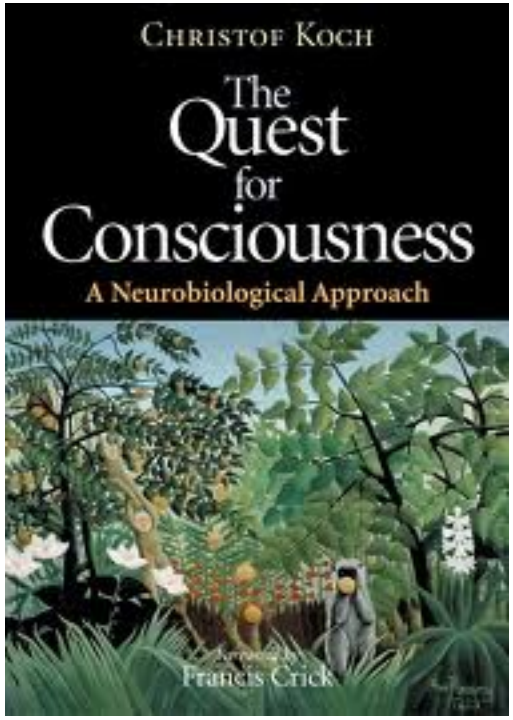
Class 10. Nov-21 Computer vision. Towards artificial intelligence systems for cognition [David Cox]

Class 11. Nov-28 Computational models of visual object recognition. [Kreiman]

Class 12. Dec-05 [Extra class] Towards understanding subjective visual perception. Visual consciousness.

Towards the neural correlates of consciousness





Mary's room

Mary is a brilliant scientist who is, for whatever reason, forced to investigate the world from a black and white room via a black and white television monitor. She specializes in the neurophysiology of vision and acquires, let us suppose, all the physical information there is to obtain about what goes on when we see ripe tomatoes, or the sky, and use terms like 'red', 'blue', and so on. She discovers, for example, just which wavelength combinations from the sky stimulate the retina, and exactly how this produces via the central nervous system the contraction of the vocal cords and expulsion of air from the lungs that results in the uttering of the sentence 'The sky is blue'. [...] What will happen when Mary is released from her black and white room or is given a color television monitor? Will she learn anything or not?

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

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)

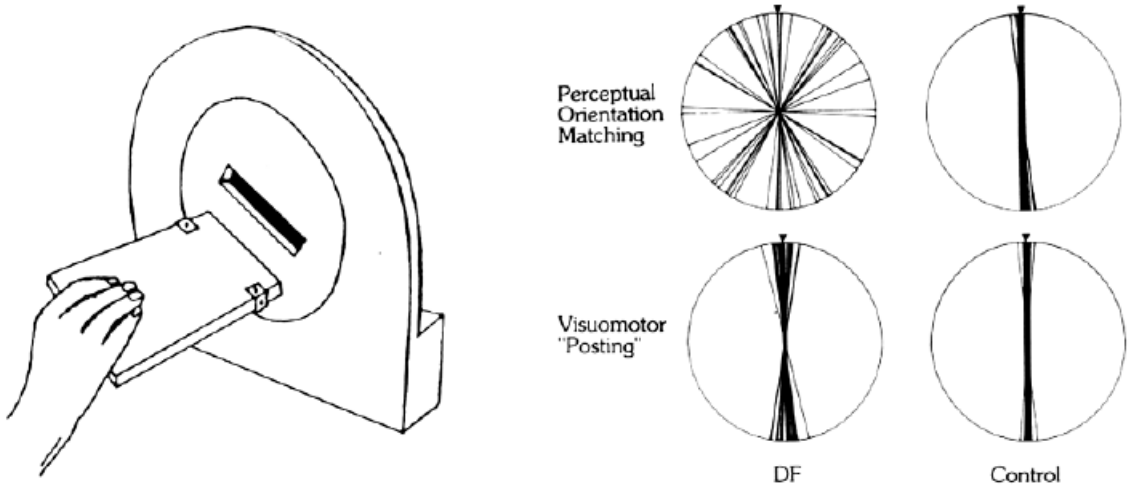
Koch. The quest for consciousness

"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

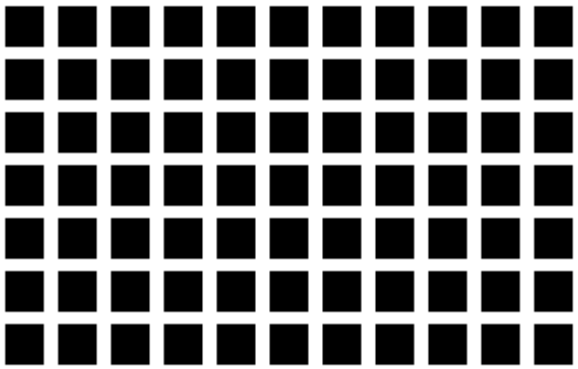


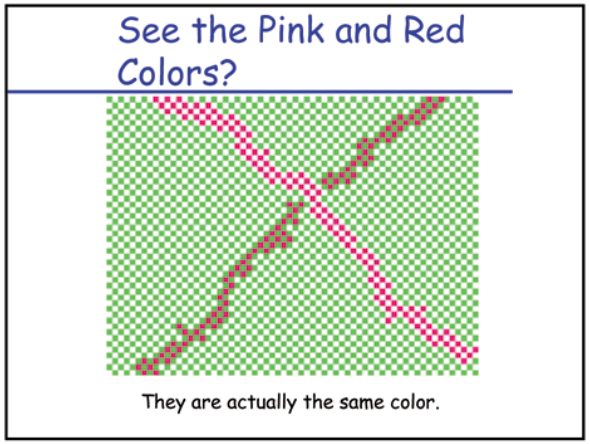
Goodale, M. and A. Milner (1992) Separate visual pathways for perception and action *Trends in Neurosciences* **15**:20-25

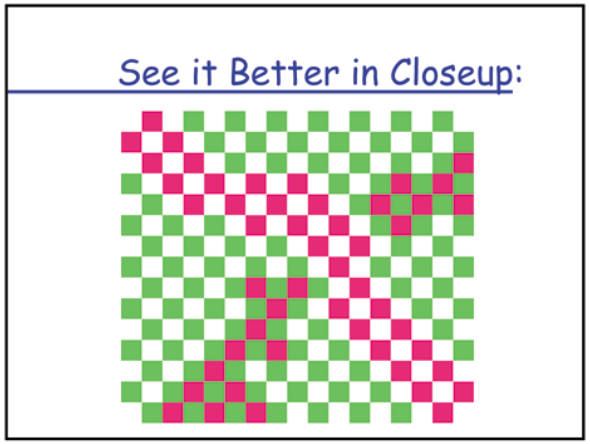
The NCC representation must be *explicit*

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*

Attention is closely related to consciousness

Attention is closely related to consciousness

Resnik et al 1997

Whether consciousness can be dissociated from attention is a matter of debate in the field (e.g. Tsuchiya and Koch)

More demos

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

Filling in
http://smc.neuralcorr

Change blindness
http://nivea.psycho.univ-paris5.fr/CBMovies/FarmsFlickerMovie.gif

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

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

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

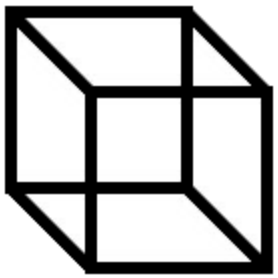
Change blindness in a movie
http://www.youtube.com/watch?v=ubNF9QNEQLA

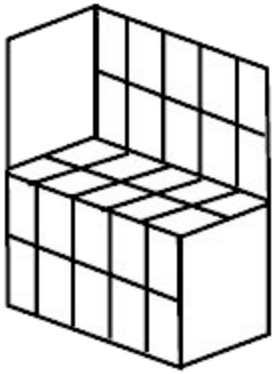
A framework to define the NCC (Crick and Koch)

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

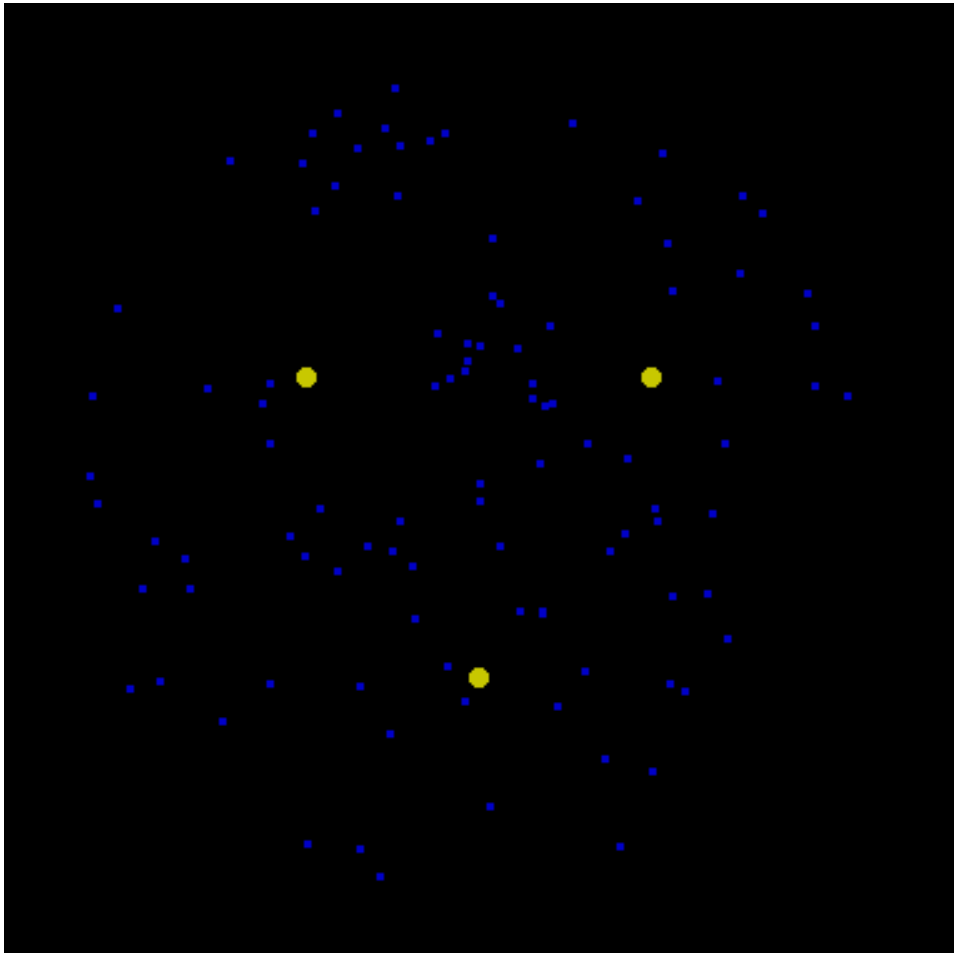
Experimental paradigms to examine the neural correlates of visual consciousness





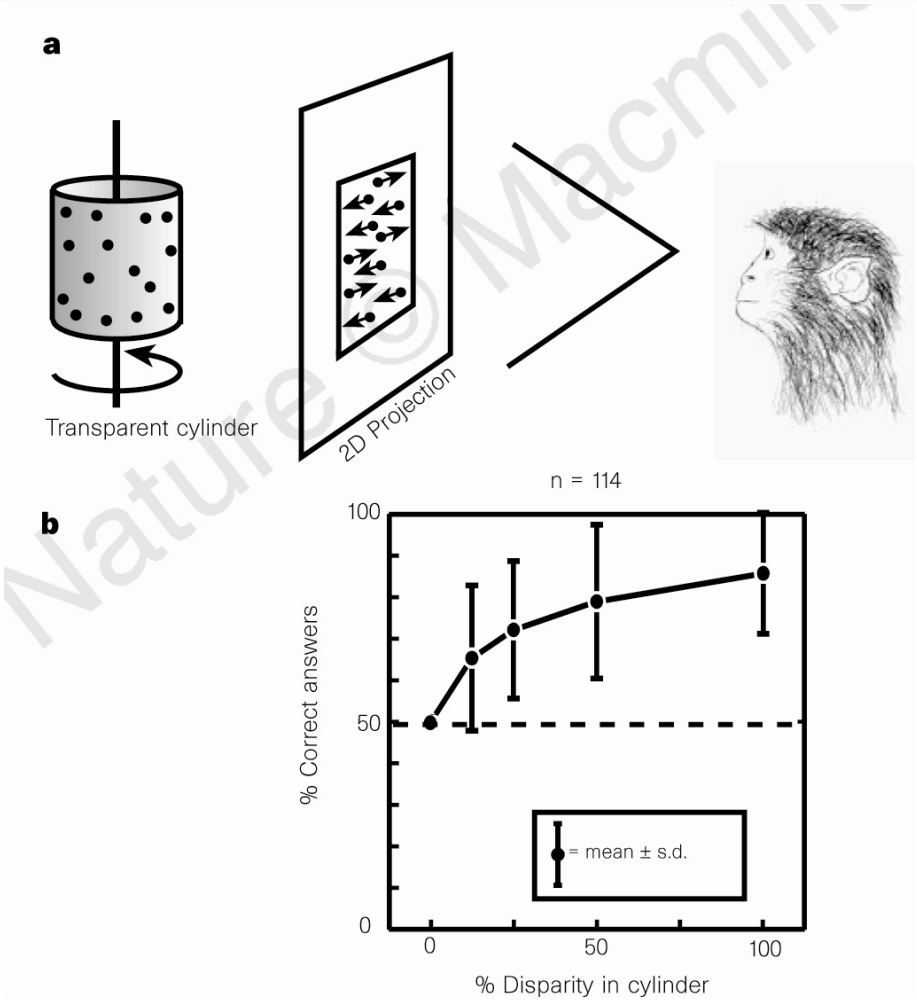
Difficulty: where/how/when to search for the neural correlates?

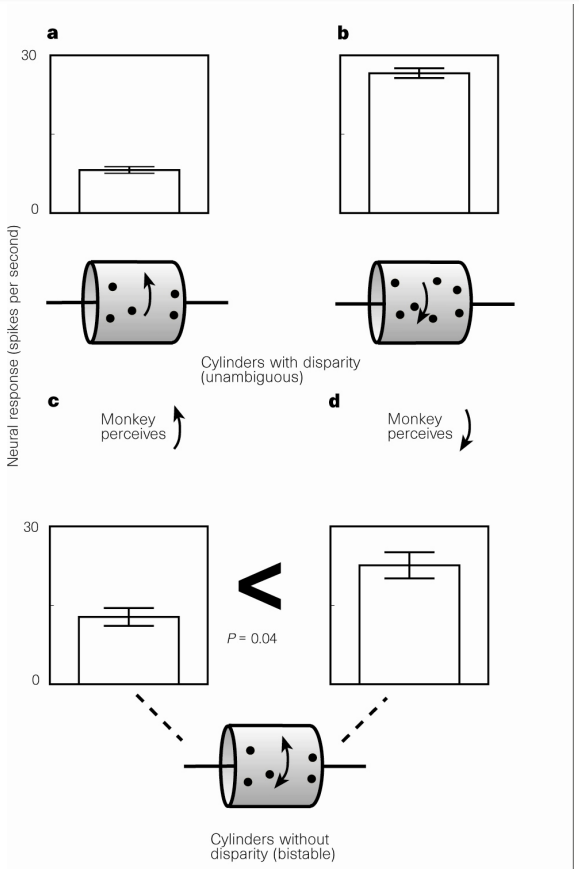
Experimental paradigms to examine the neural correlates of visual consciousness



PLAY MOVIE 1 (Bonneh)

Neurons in area MT following the percept

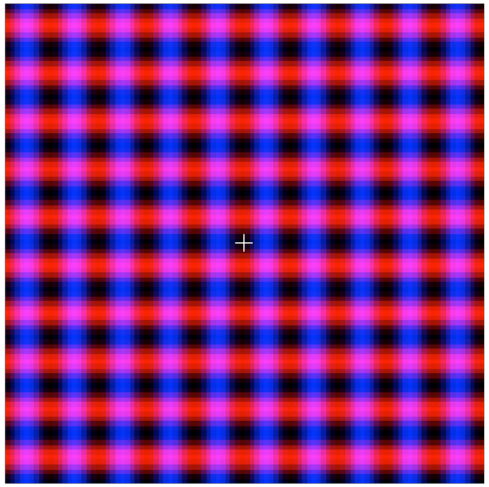


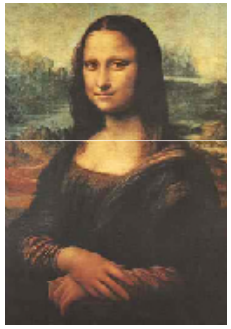


Bradley, D. C., G. C. Chang, et al. (1998). "Encoding of 3D structure from motion by primate area MT neurons." Nature **392**: 714-717.

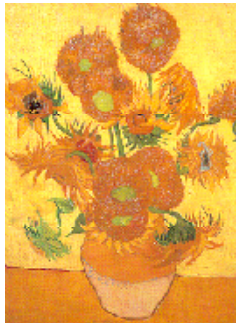
Binocular rivalry

Monocular rivalry (weaker)

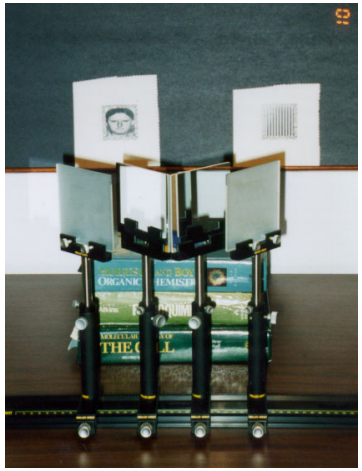




Right eye



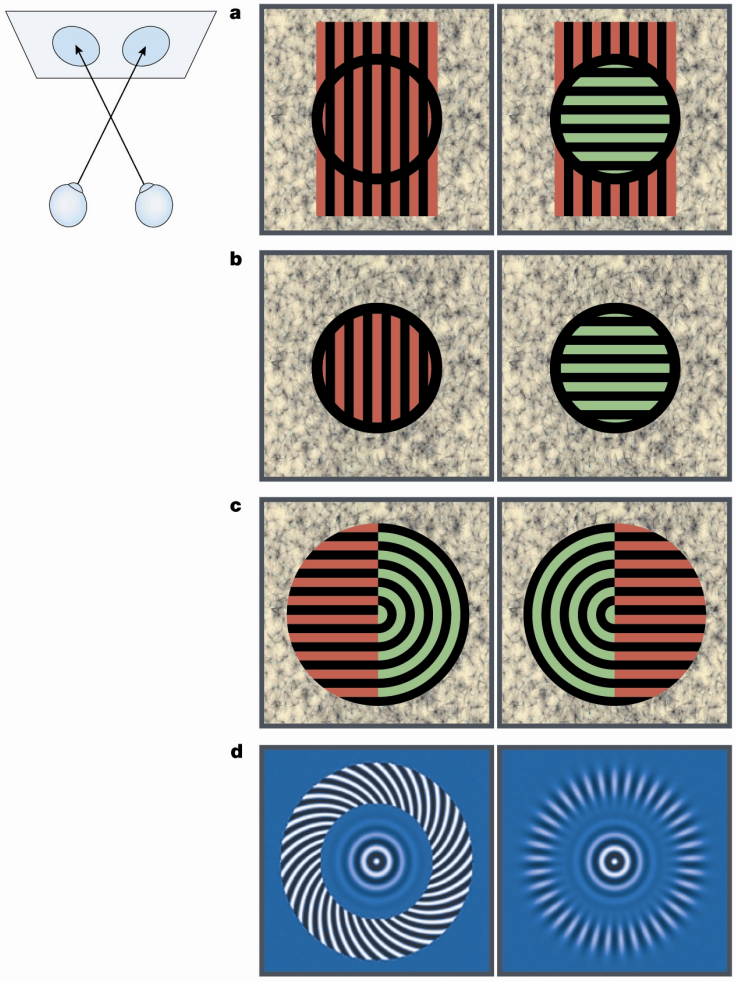
Left eye



perception

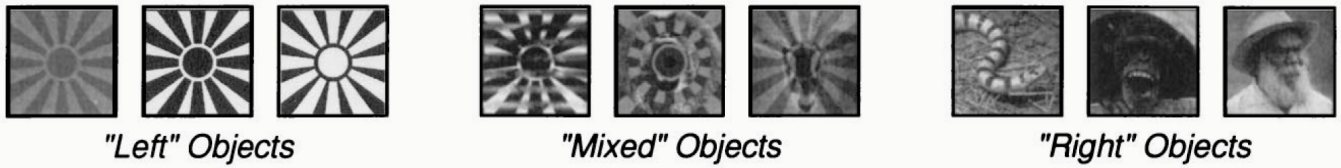
- Different stimuli are presented to the right and left eyes
- The input is constant
- Perception alternates between one percept and the other
- What are the neuronal changes responsible for the perceptual alternation?

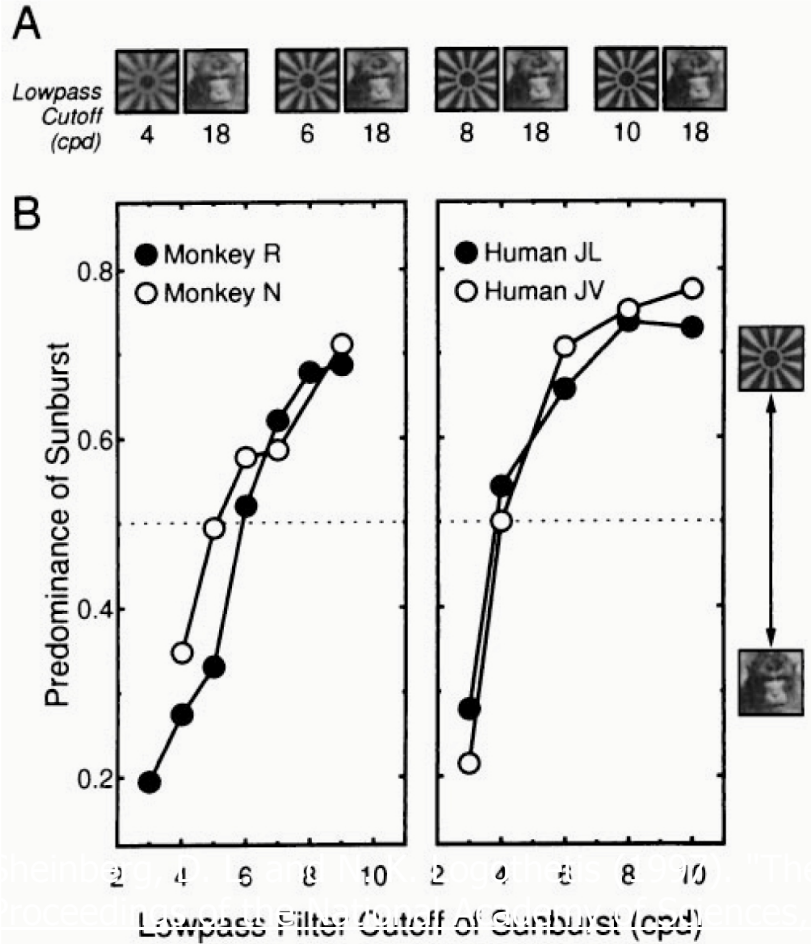
Binocular rivalry: competition between percepts (as opposed to competition between eyes)

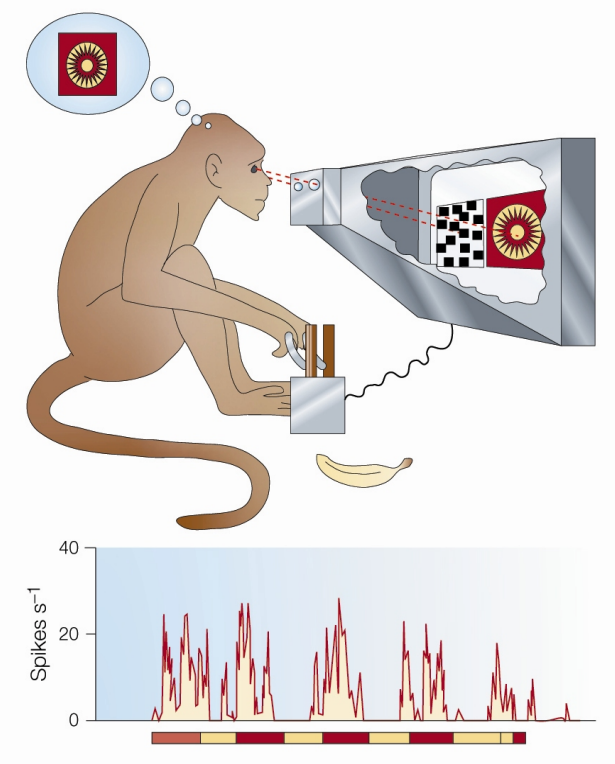


Blake, R. and N. Logothetis (2002). "Visual competition." Nature Reviews Neuroscience **3**: 13-21.

Binocular rivalry can be studied in both humans and monkeys

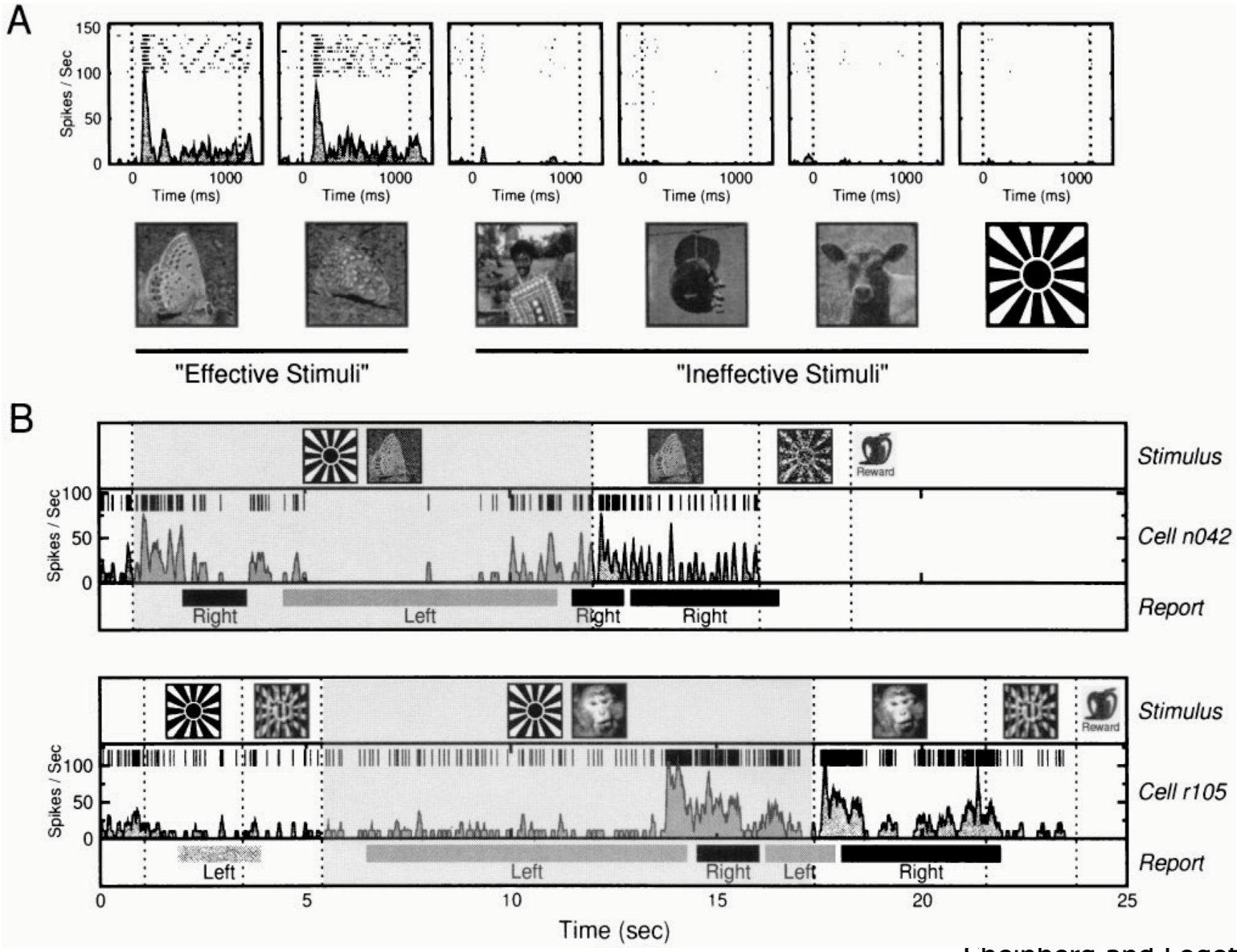






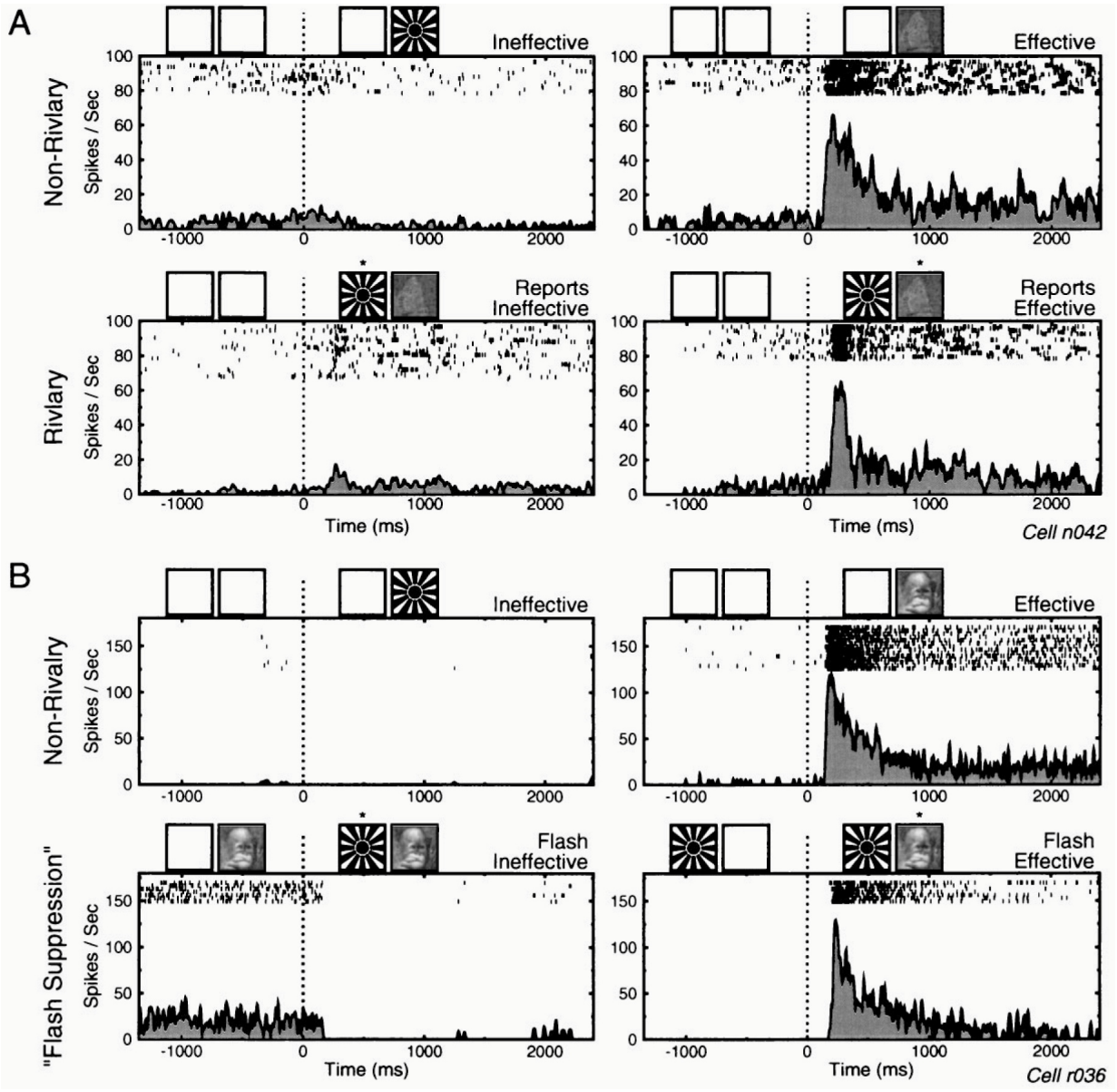
Myerson, Miezin, Allman,
Behavioral Analysis Letters, 1981. **1**: p. 149-159.

Neurons in inferior temporal cortex follow the percept



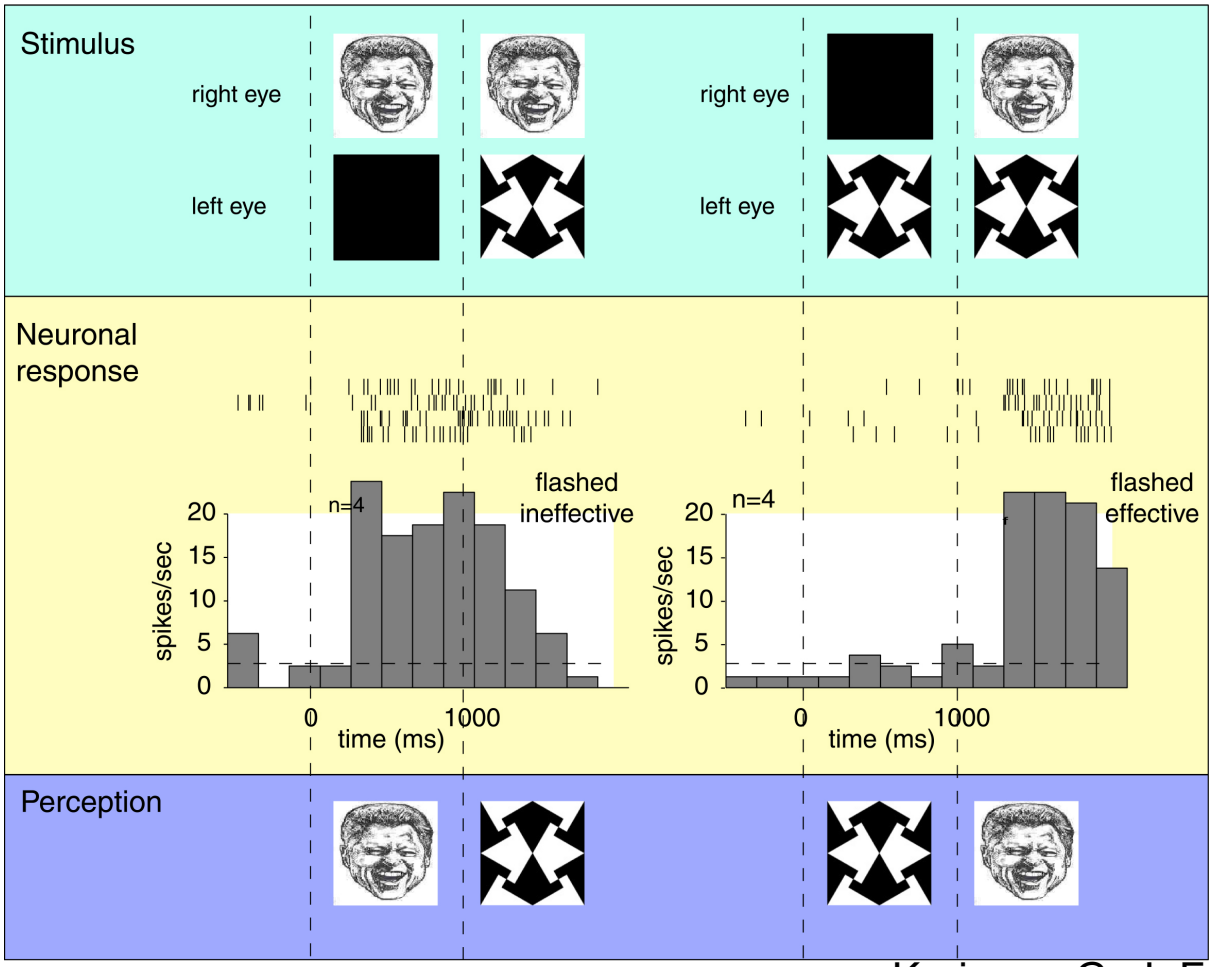
Sheinberg and Logothetis 1997
Leopold and Logothetis 1999

Neurons in inferior temporal cortex follow the percept



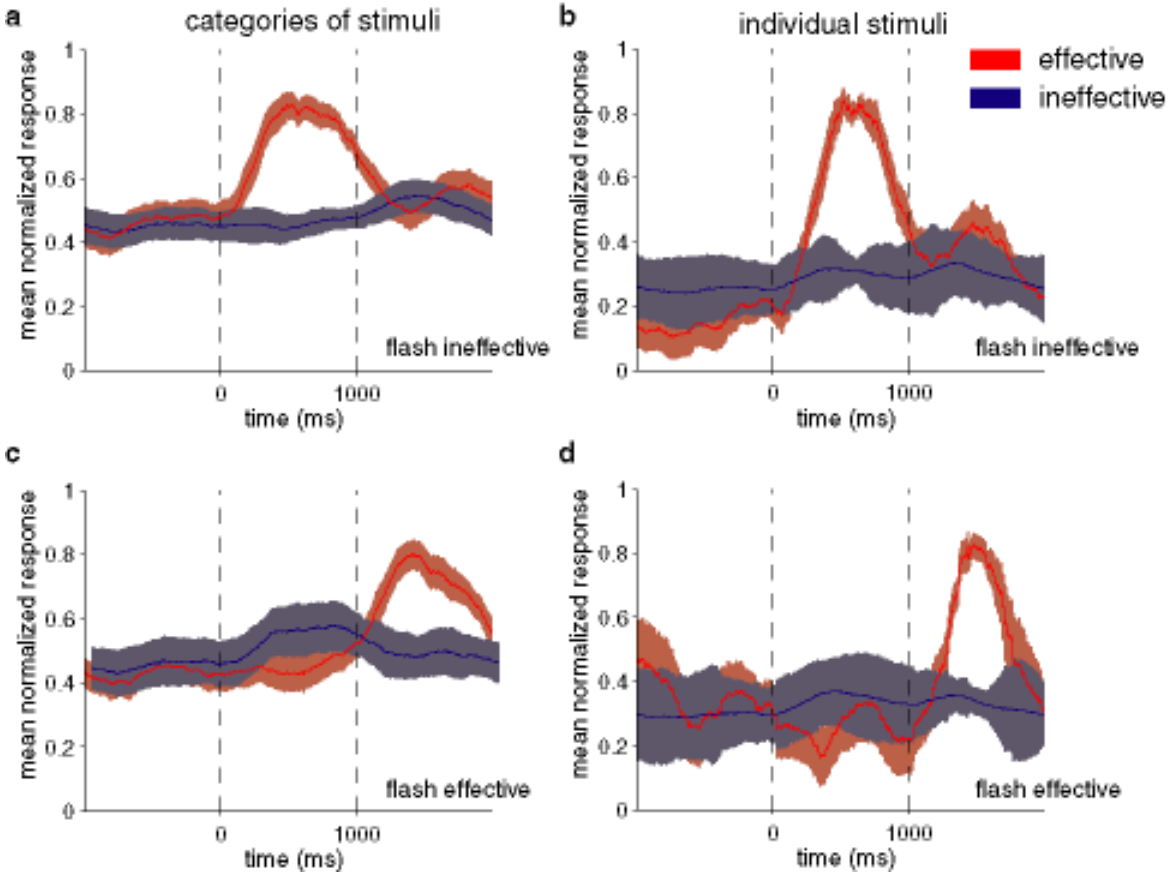
Sheinberg and Logothetis 1997
Leopold and Logothetis 1999

Neurons in the human medial temporal lobe follow the percept

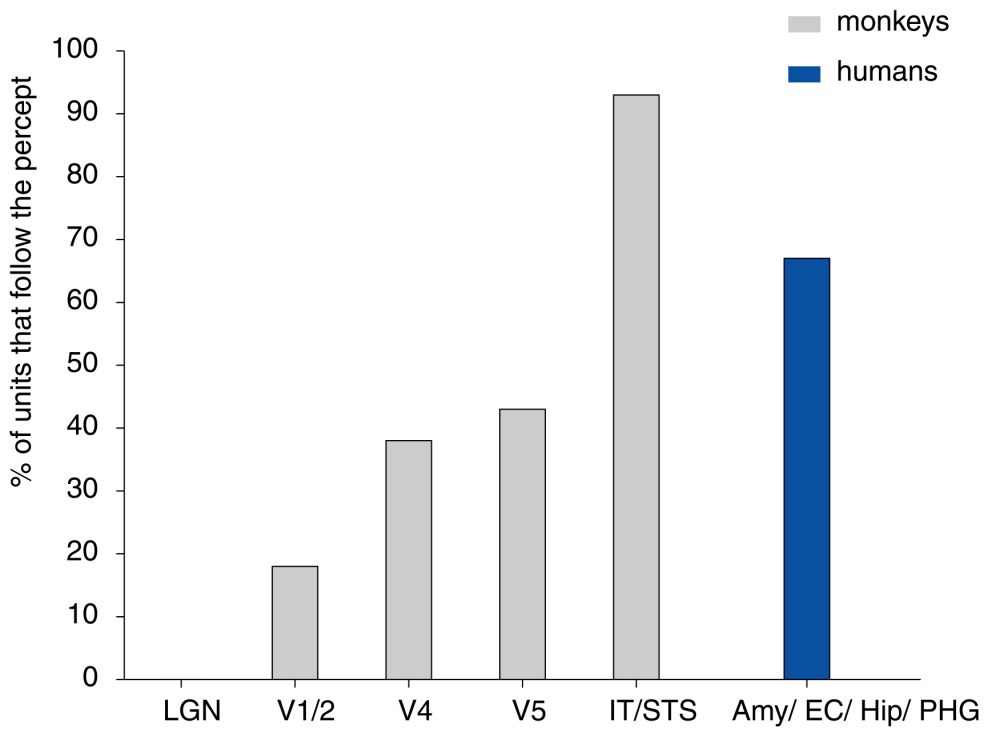


Kreiman, G., I. Fried, and C. Koch,
Single neuron correlates of subjective vision in the human medial temporal lobe.
PNAS, 2002. **99**:8378-8383.

Flash suppression in humans: summary of responses



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:

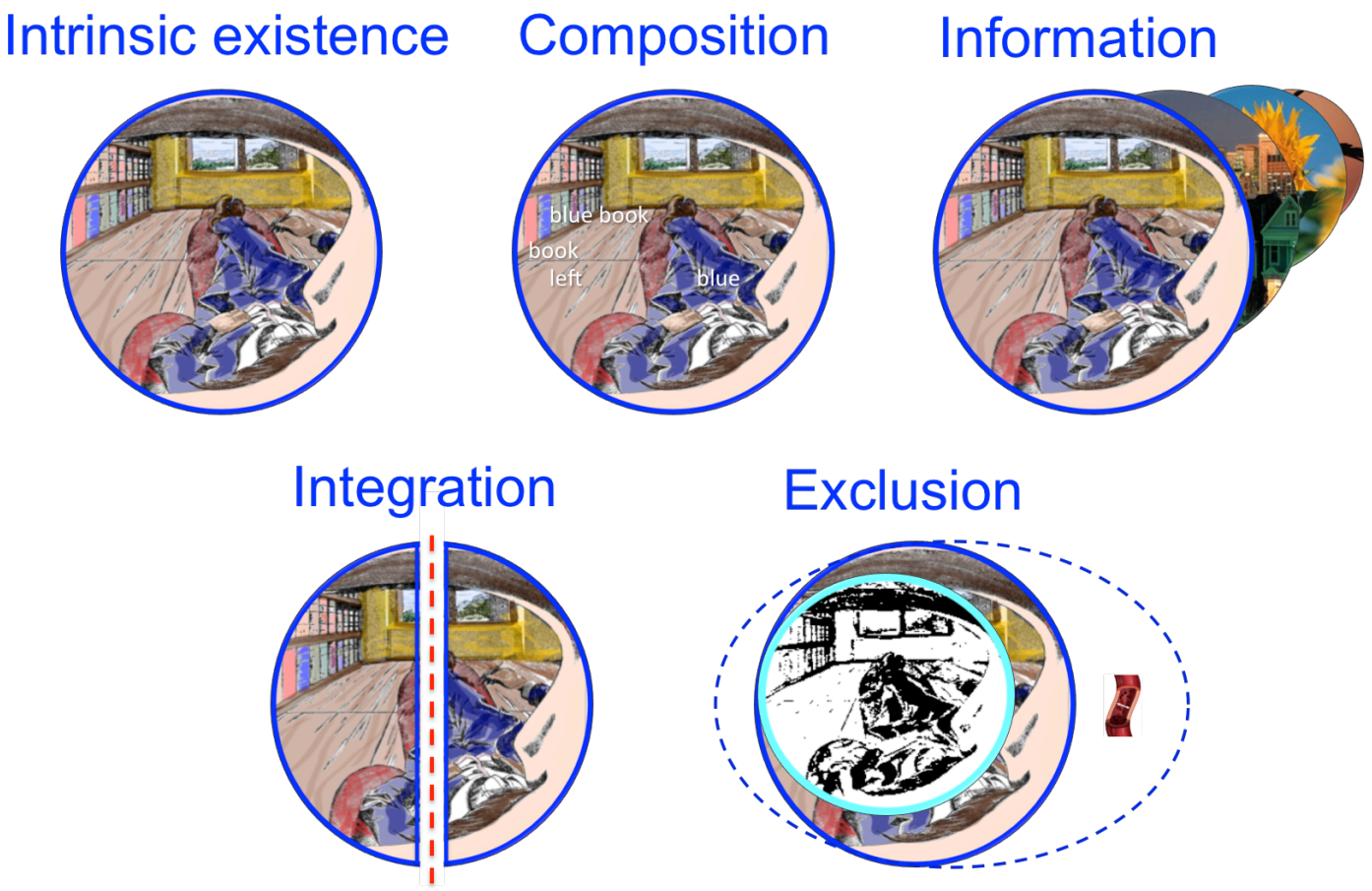
(a) Model and predict neuronal responses given a perceptual state

(b) Accurately predict perceptual state given neuronal activity

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

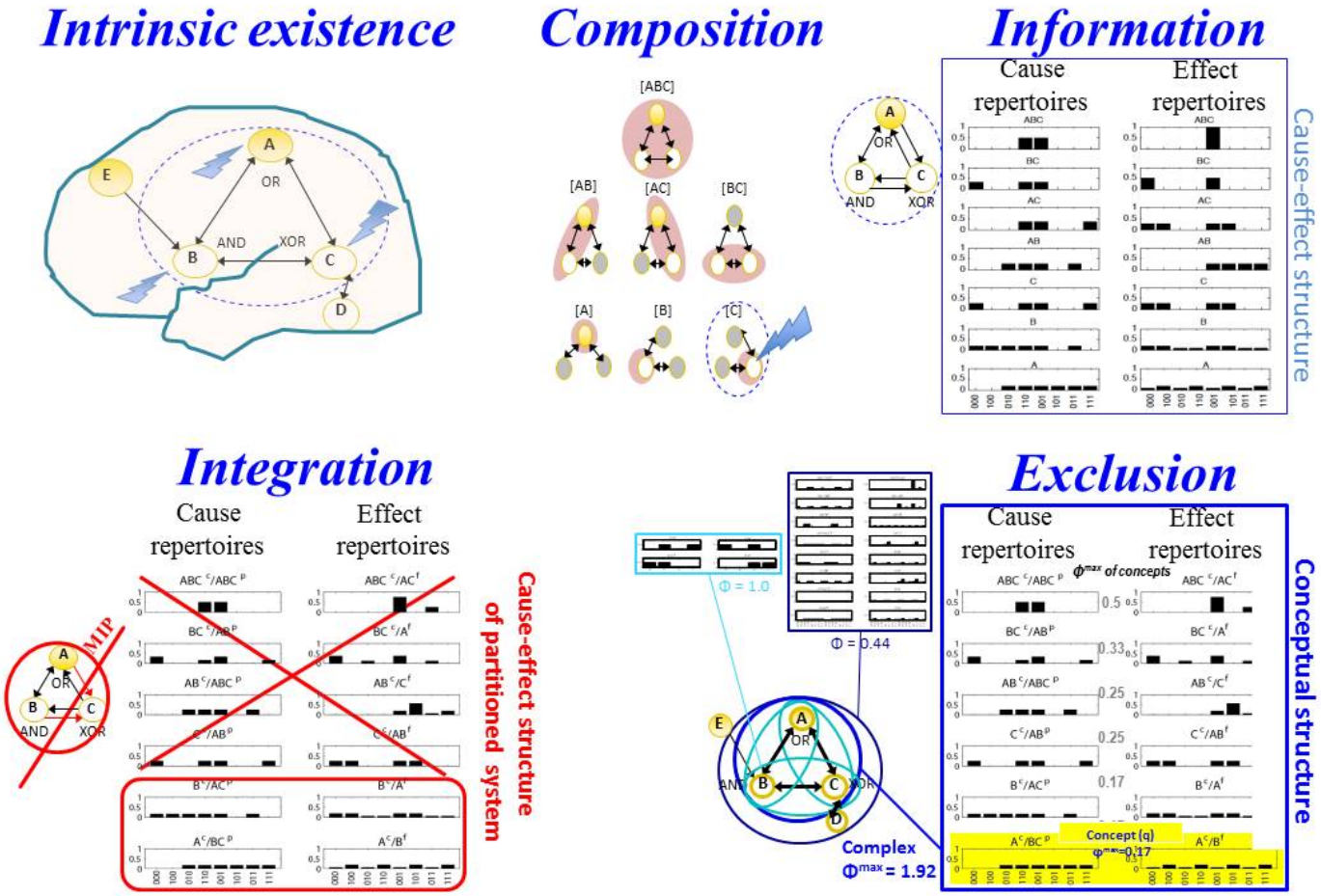
(d) Inactivate or repress a perceptual state

Integrated Information Theory -- Axioms



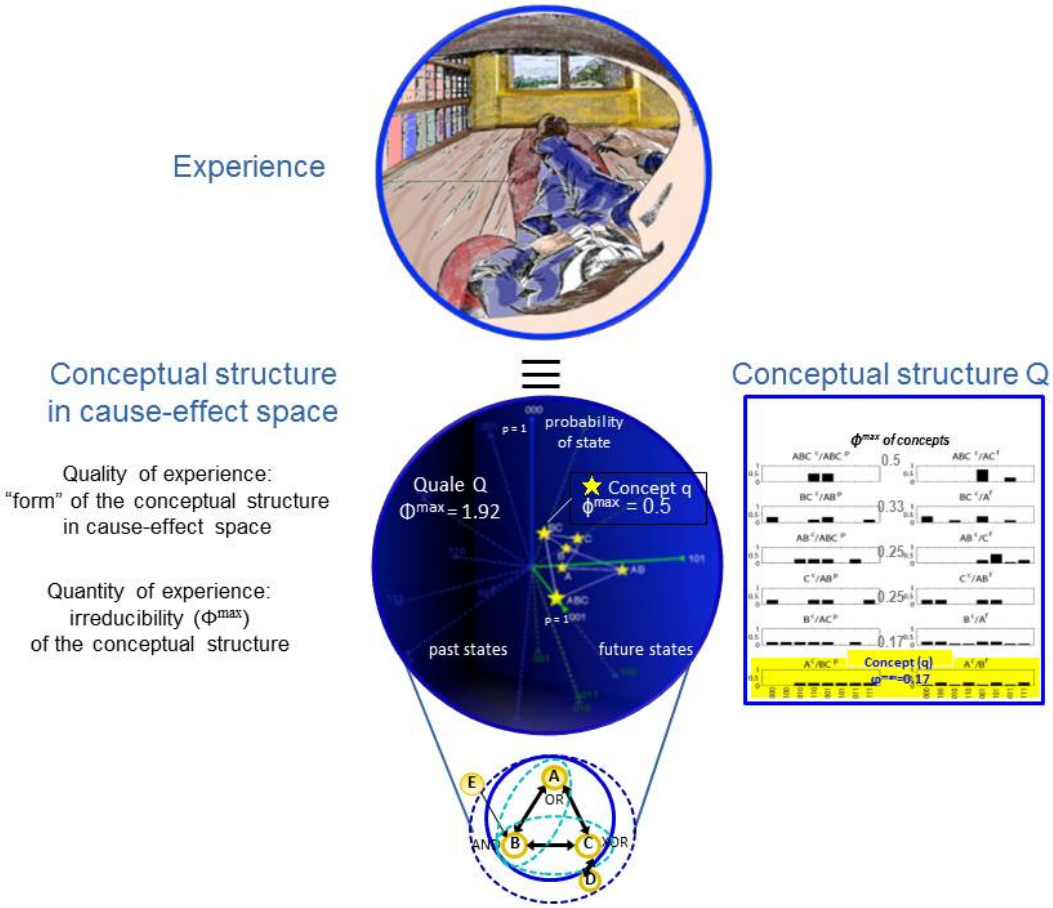
Giulio Tononi (2015), Scholarpedia, 10(1):4164.

Integrated Information Theory – Postulates illusration



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

Central identity: an experience as a maximally irreducible conceptual structure



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

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.

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