Donders Institute
for Brain, Cognition and Behaviour

Brain Reading (MKI43)

Lecture 10: Bayesian brain/Course conclusions

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Bayesian statistics provides principled analysis of brain data:

- Dynamic causal modelling
- Bayesian connectomics

Bayesian statistics also provides a theoretical framework for understanding brain function!

Bayesian brain hypothesis

Bayesian brain is a term that is used to refer to the ability of the nervous system to operate in situations of uncertainty in a fashion that is close to the optimal prescribed by Bayesian statistics. This term is used in behavioural sciences and neuroscience and studies associated with this term often strive to explain the brain's cognitive abilities based on statistical principles. It is frequently assumed that the nervous system maintains internal probabilistic models that are updated by neural processing of sensory information using methods approximating those of Bayesian probability.

Source: Wikipedia

Bayesian brain hypothesis

A wide range of approaches exist that link Bayesian ideas to the function of the brain.

- **Psychophysics**: Many aspects of human perceptual or motor behavior are modeled with Bayesian statistics (e.g. Knill, Wolpert).
- **Neural coding**: Many theoretical studies ask how the nervous system could implement Bayesian algorithms (e.g. Pouget).
- **Electrophysiology**: A number of recent electrophysiological studies focus on the representation of probabilities in the nervous system (e.g. Shadlen).
- **Predictive Coding**: A neurobiologically plausible scheme for inferring the causes of sensory input based on minimizing prediction error (e.g. Mumford).
- **Free-energy hypothesis:** Bayesian brain emerging from the general principle of free-energy minimisation (e.g. Friston).
- **Bayesian cognitive science**: Bayesian models as explanatory models for human behaviour (e.g. Tenenbaum).

Perception as inference

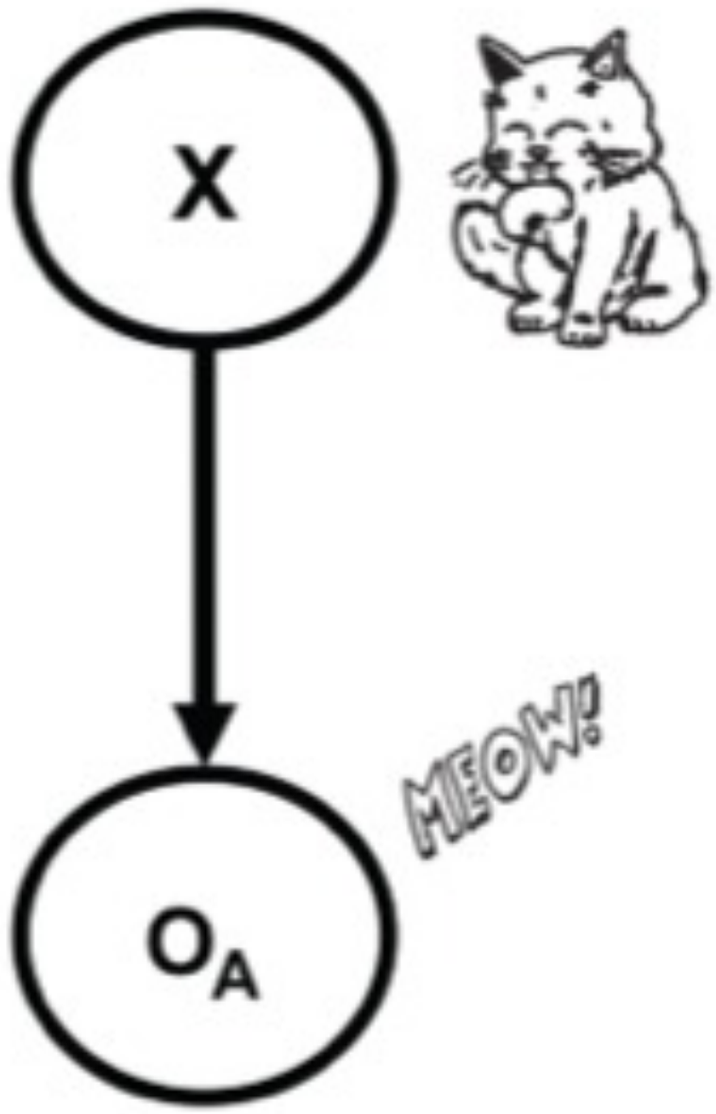
Perception depends on "inference and judgment" that has become habitual, rapid, and unnoticed (Alhazen)

Perception as unconscious inductive inference (Helmholtz)
recover the most likely objects in the world based on ambiguous evidence

Combining observed data with prior knowledge

Vilares and Kording, Ann N Y Acad Sci, 2011

Combining observed data with prior knowledge

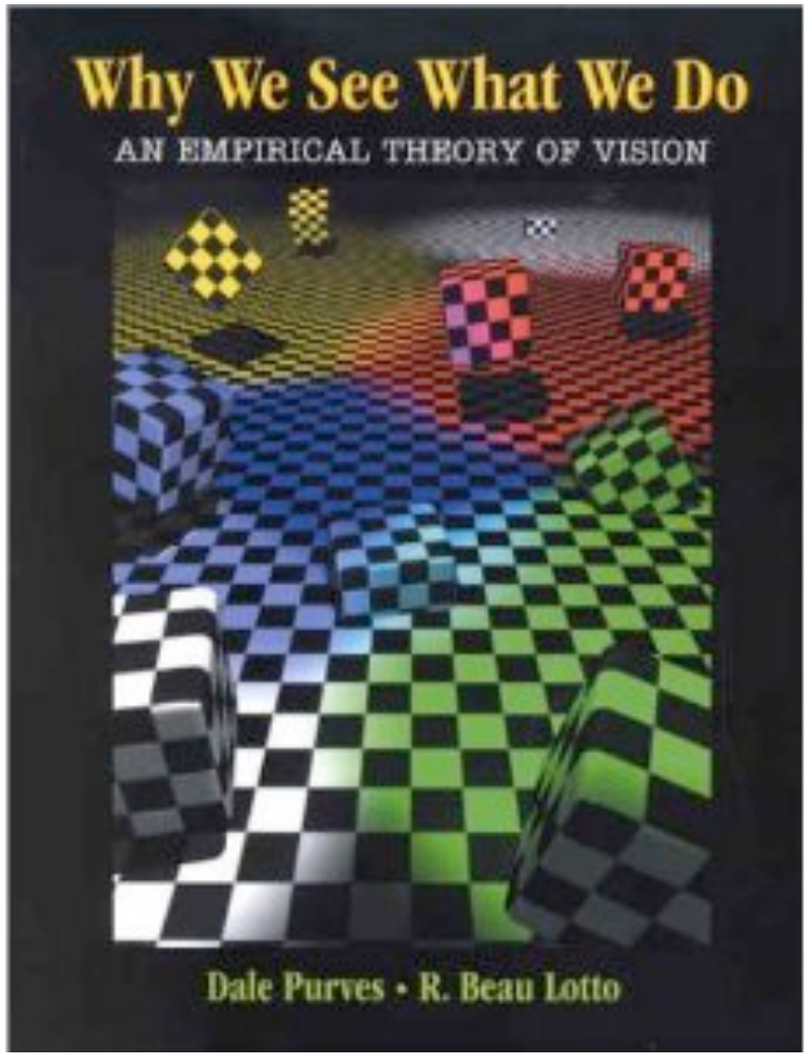


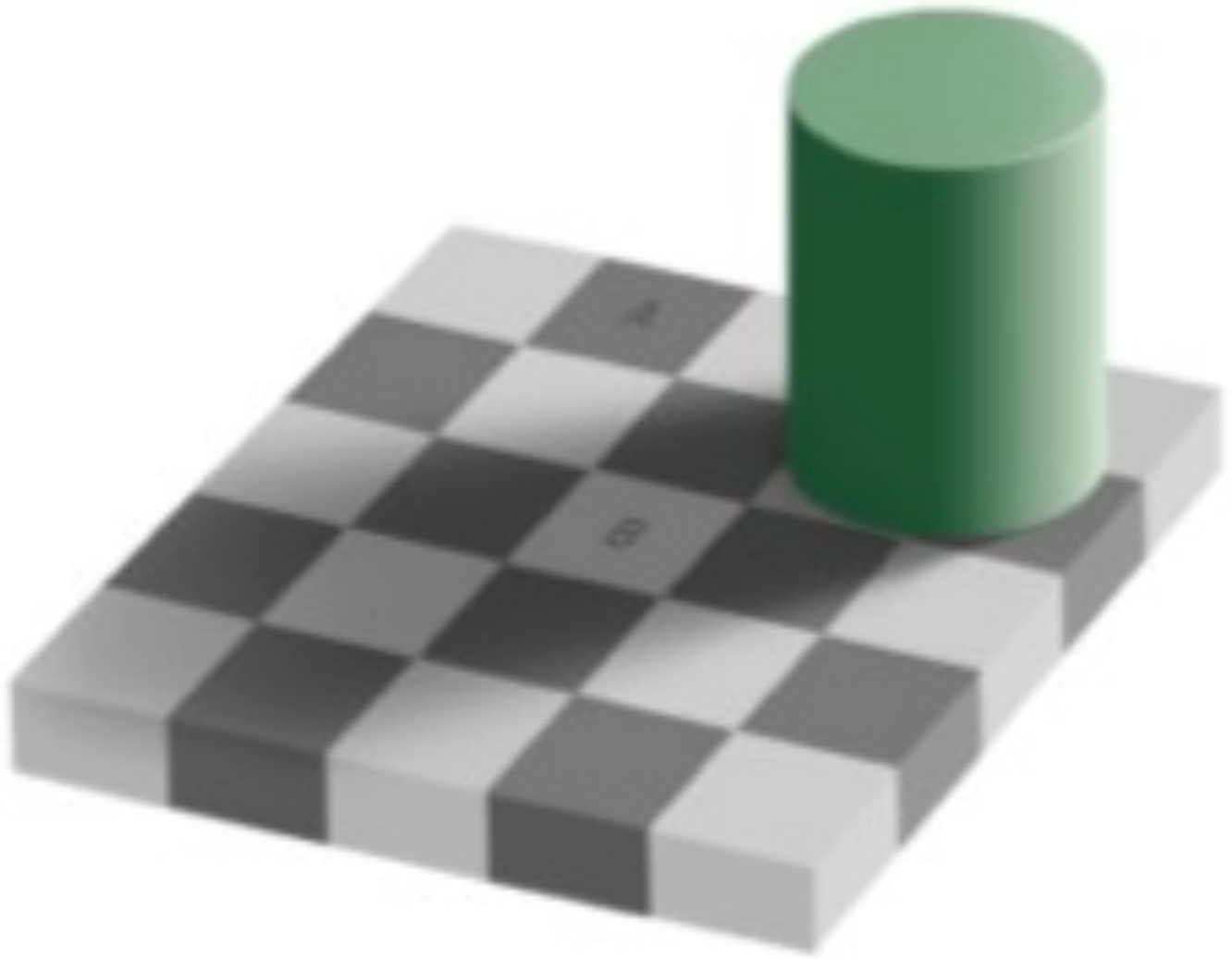
$$P(\text{position}, \text{audition}) = P(\text{position})P(\text{audition} \mid \text{position})$$

Vilares and Kording, Ann N Y Acad Sci, 2011

Prior knowledge

Prior knowledge

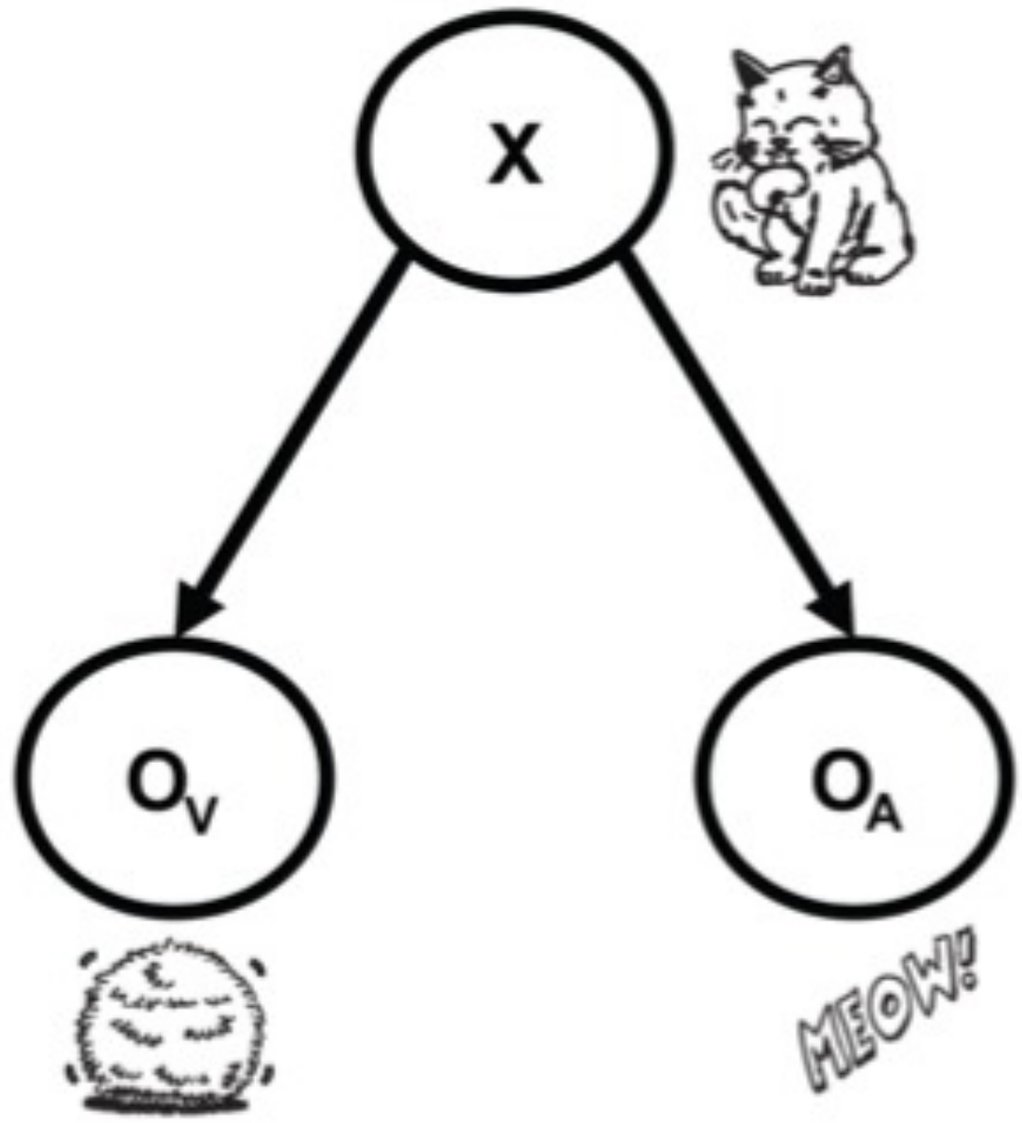




Cue integration

Vilares and Kording, Ann N Y Acad Sci, 2011

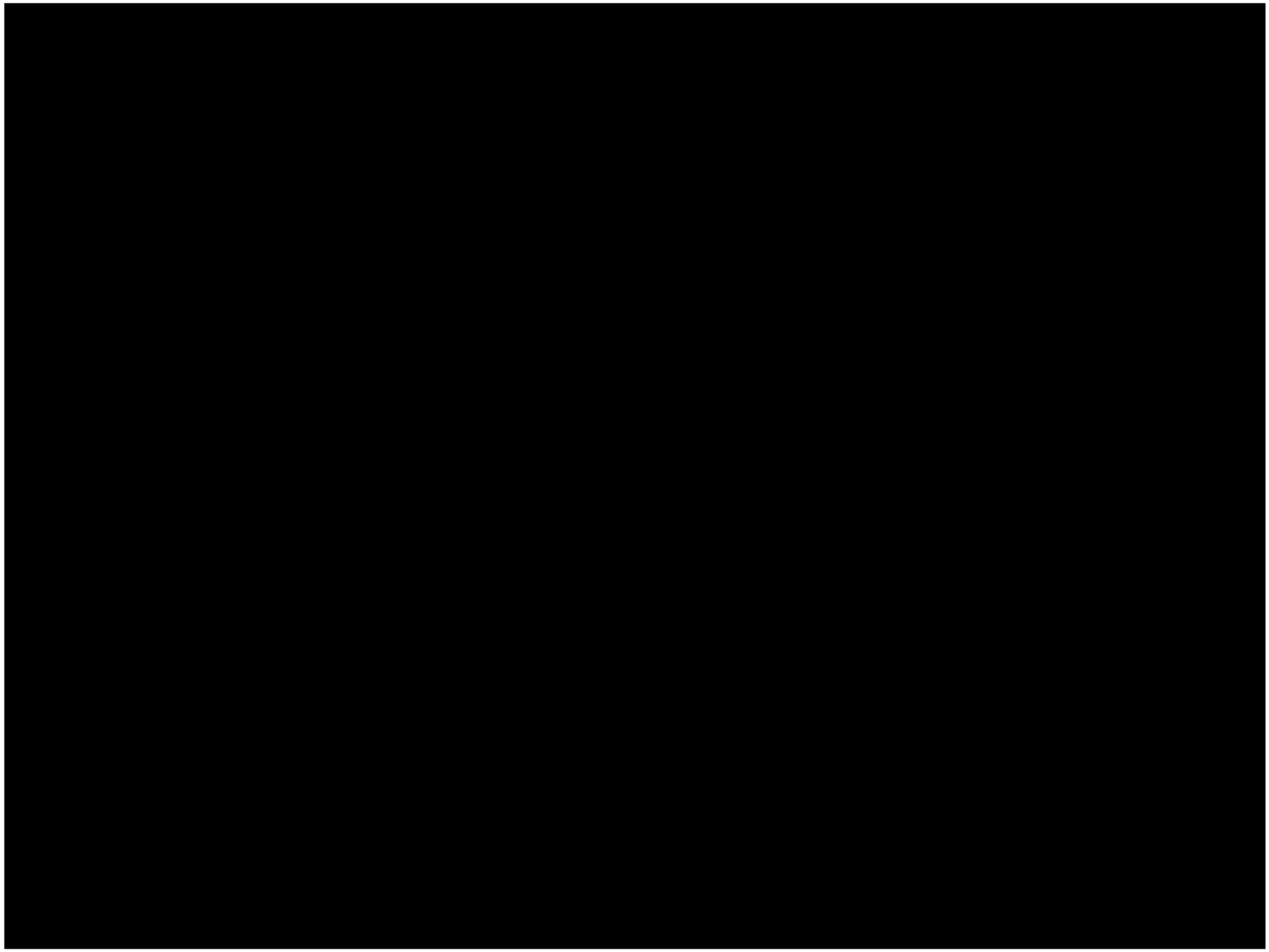
Cue integration



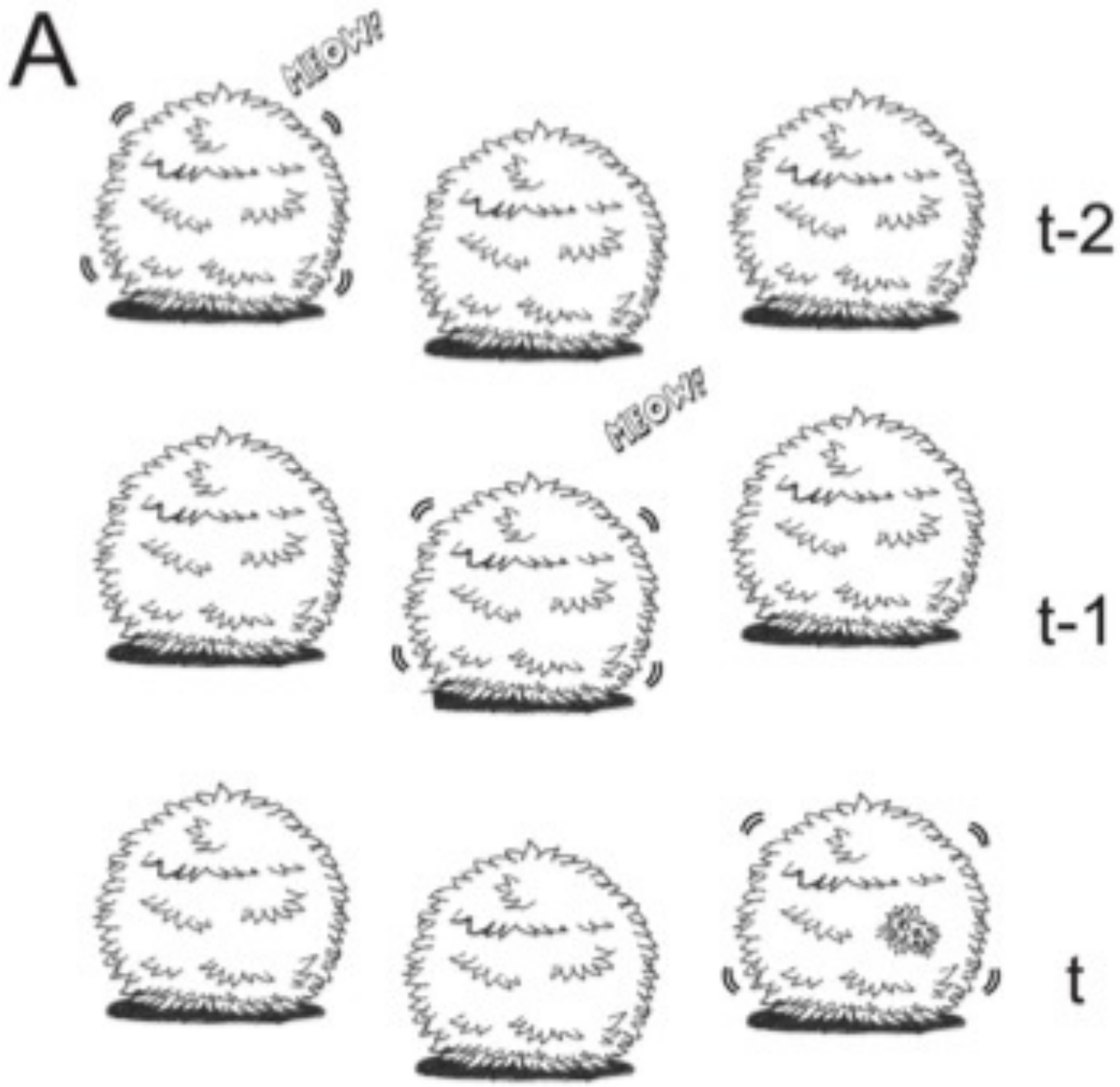
$$P(\text{position}, \text{vision}, \text{audition}) = P(\text{position})P(\text{audition} \mid \text{position})P(\text{vision} \mid \text{position})$$

Vilares and Kording, Ann N Y Acad Sci, 2011

McGurk effect

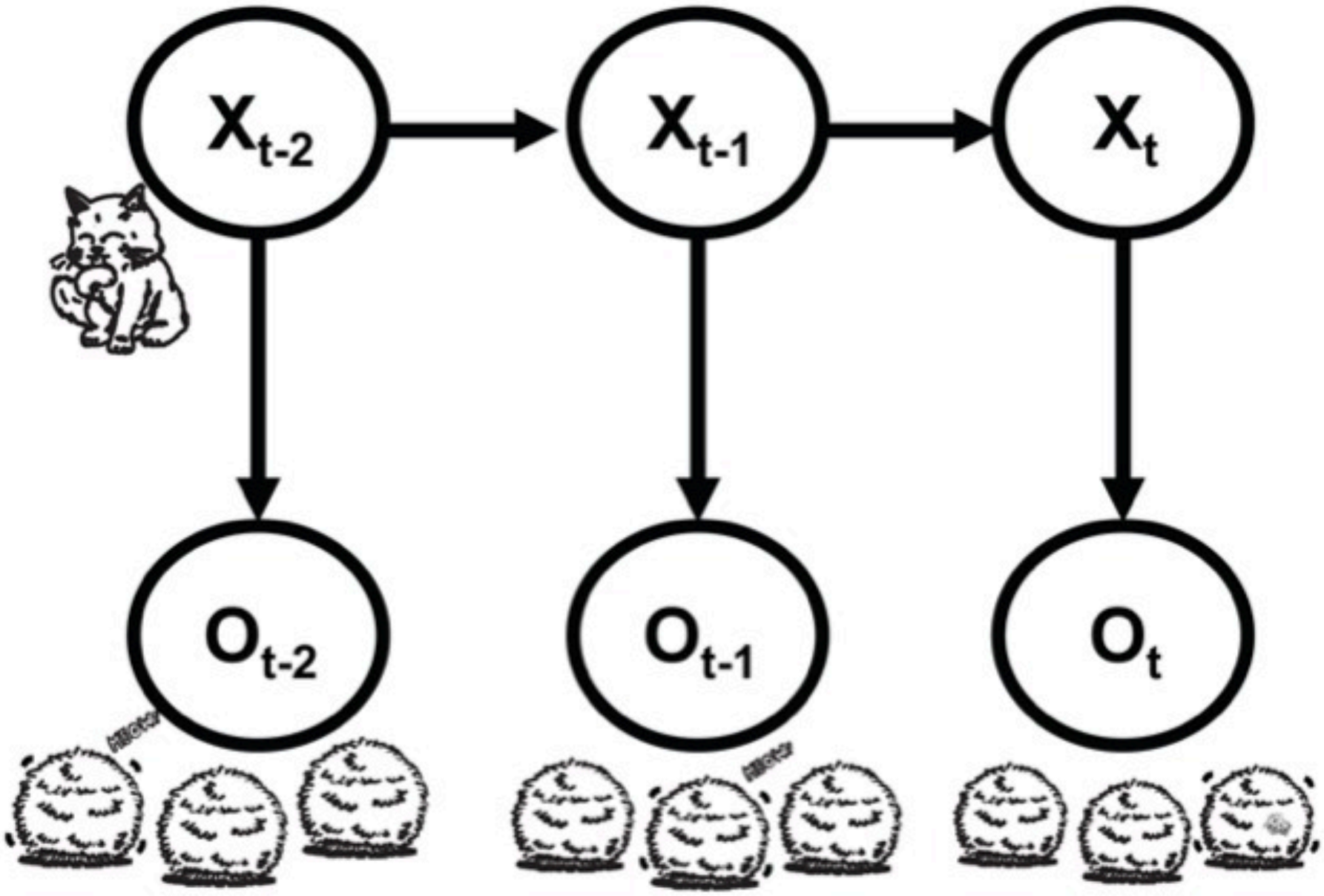


Temporal structure



Vilares and Kording, Ann N Y Acad Sci, 2011

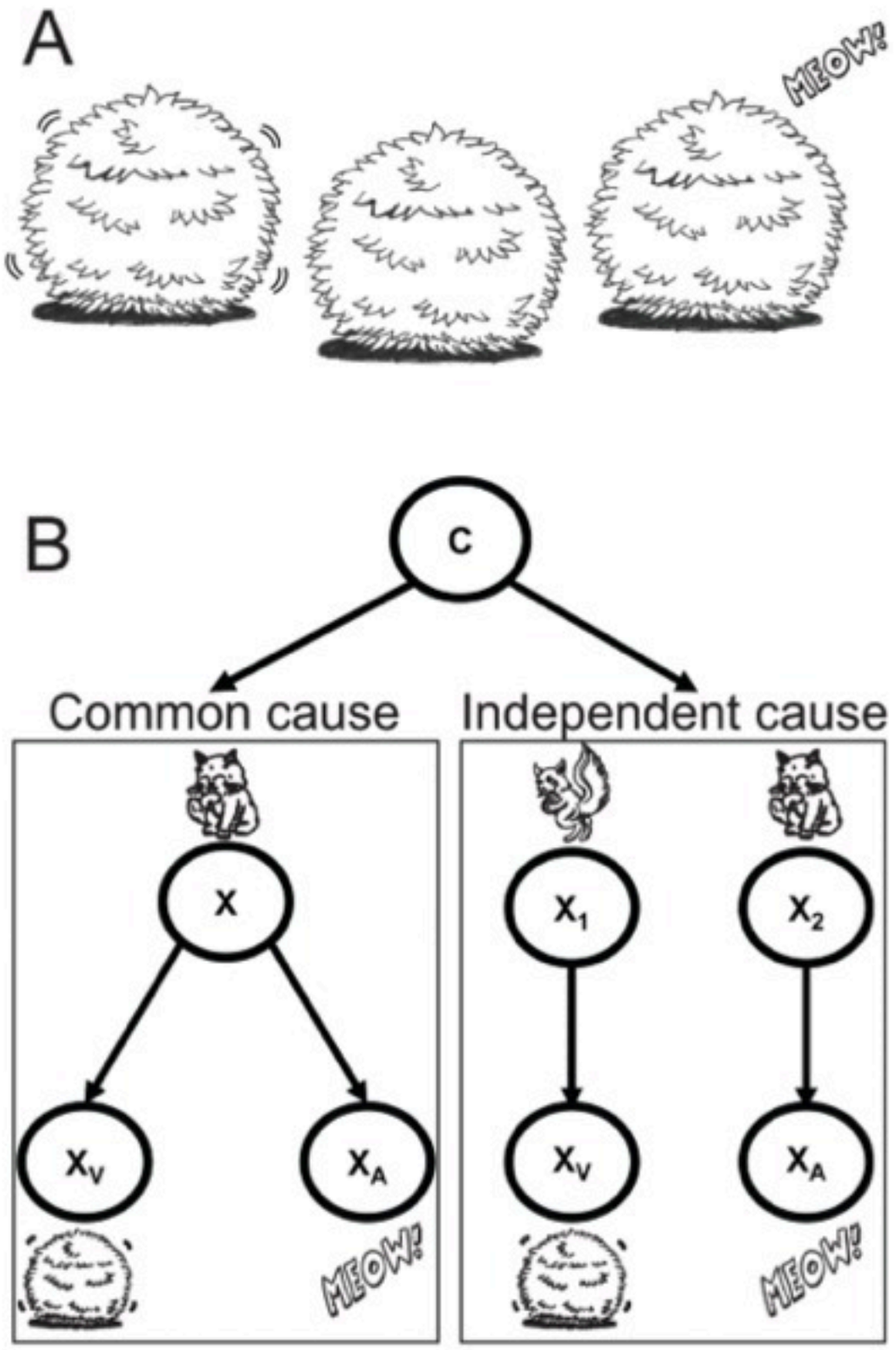
Temporal structure



hidden Markov models

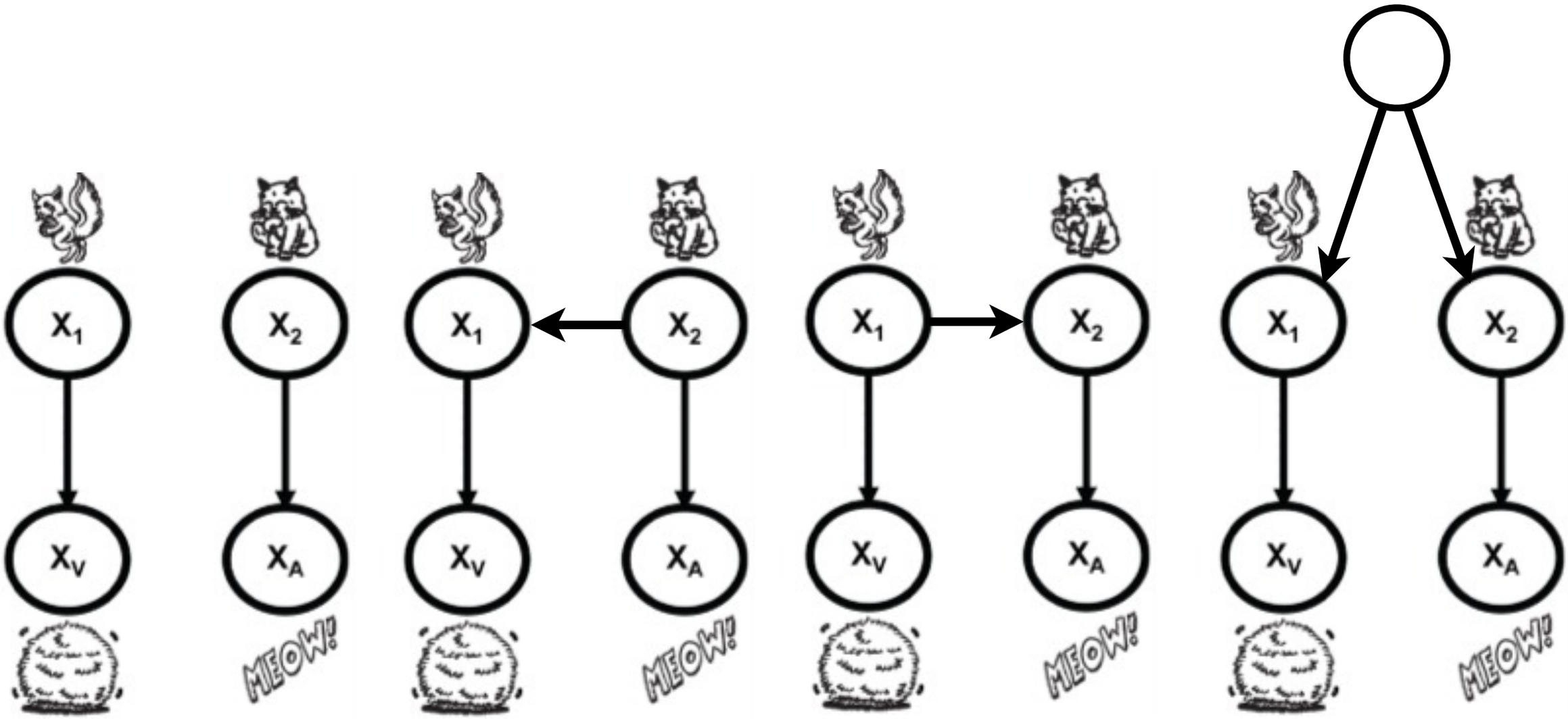
Vilares and Kording, Ann N Y Acad Sci, 2011

Inferring causal structure: how many latent causes?



Vilares and Kording, Ann N Y Acad Sci, 2011

Inferring causal structure: interactions between latent causes



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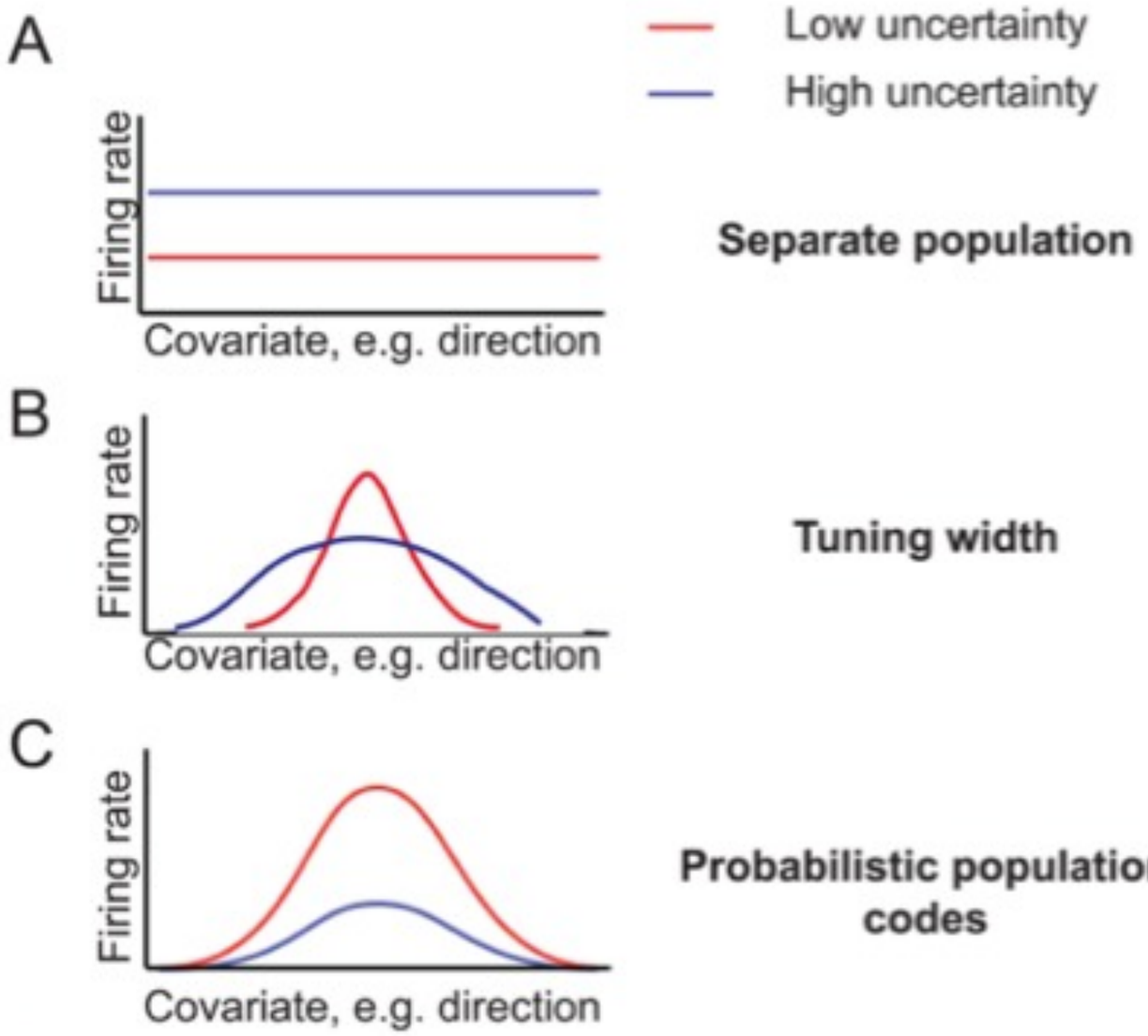
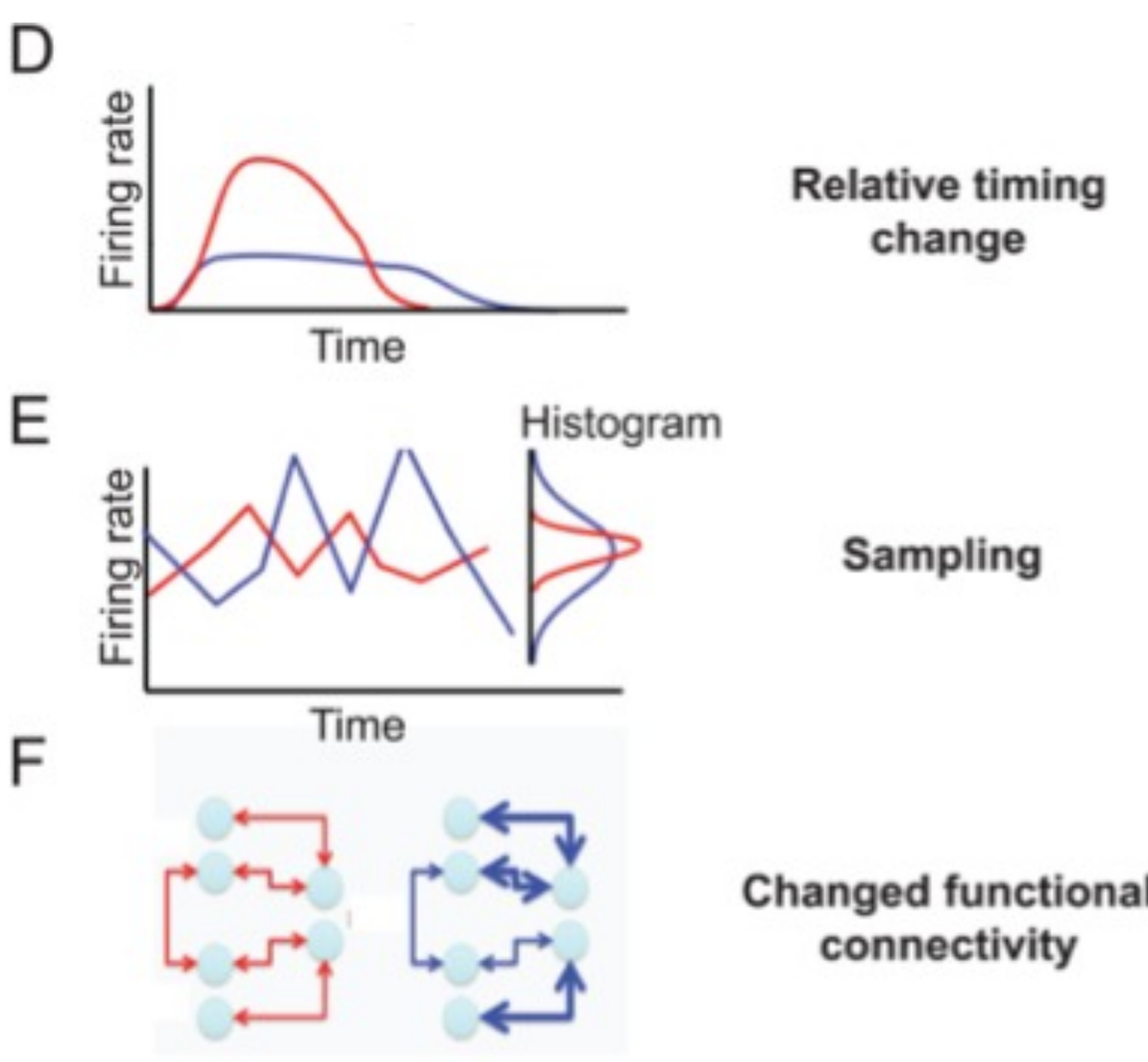
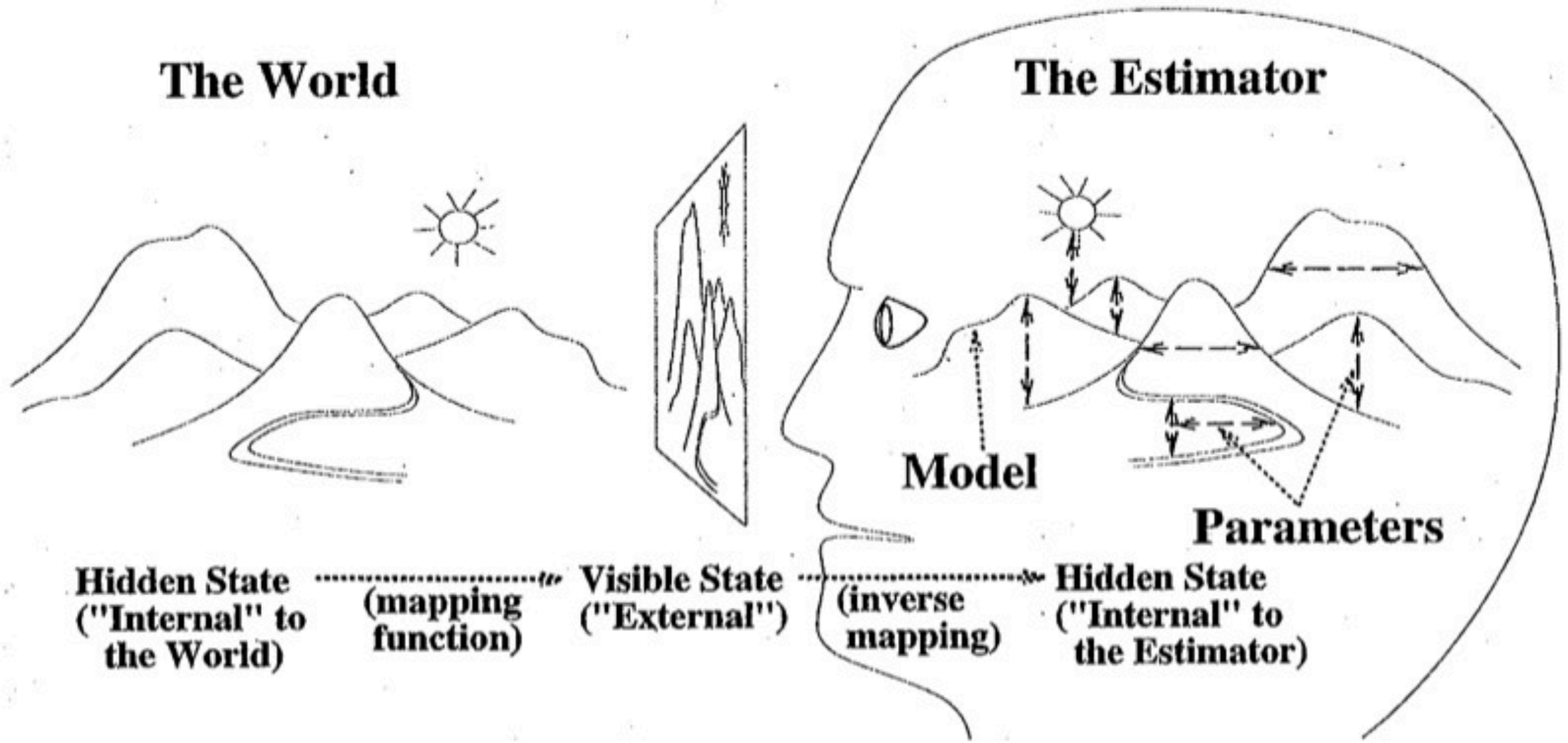
Representation of uncertainty in the brain



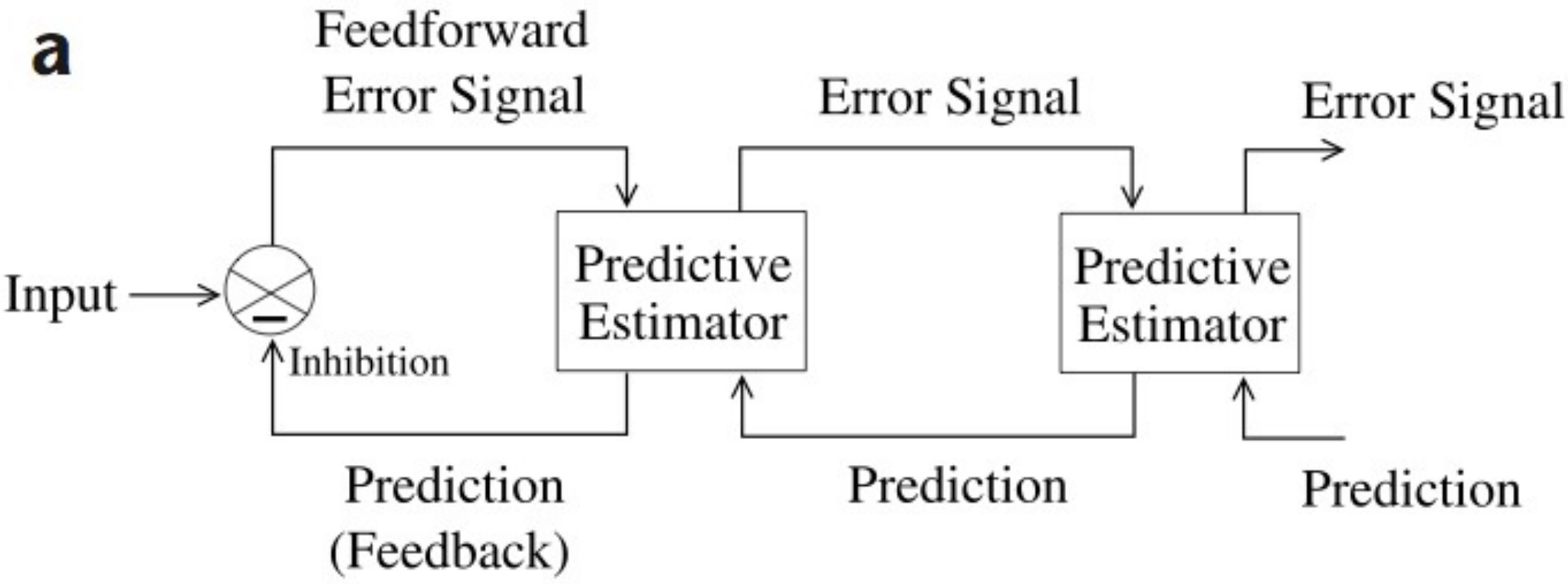


Predictive coding



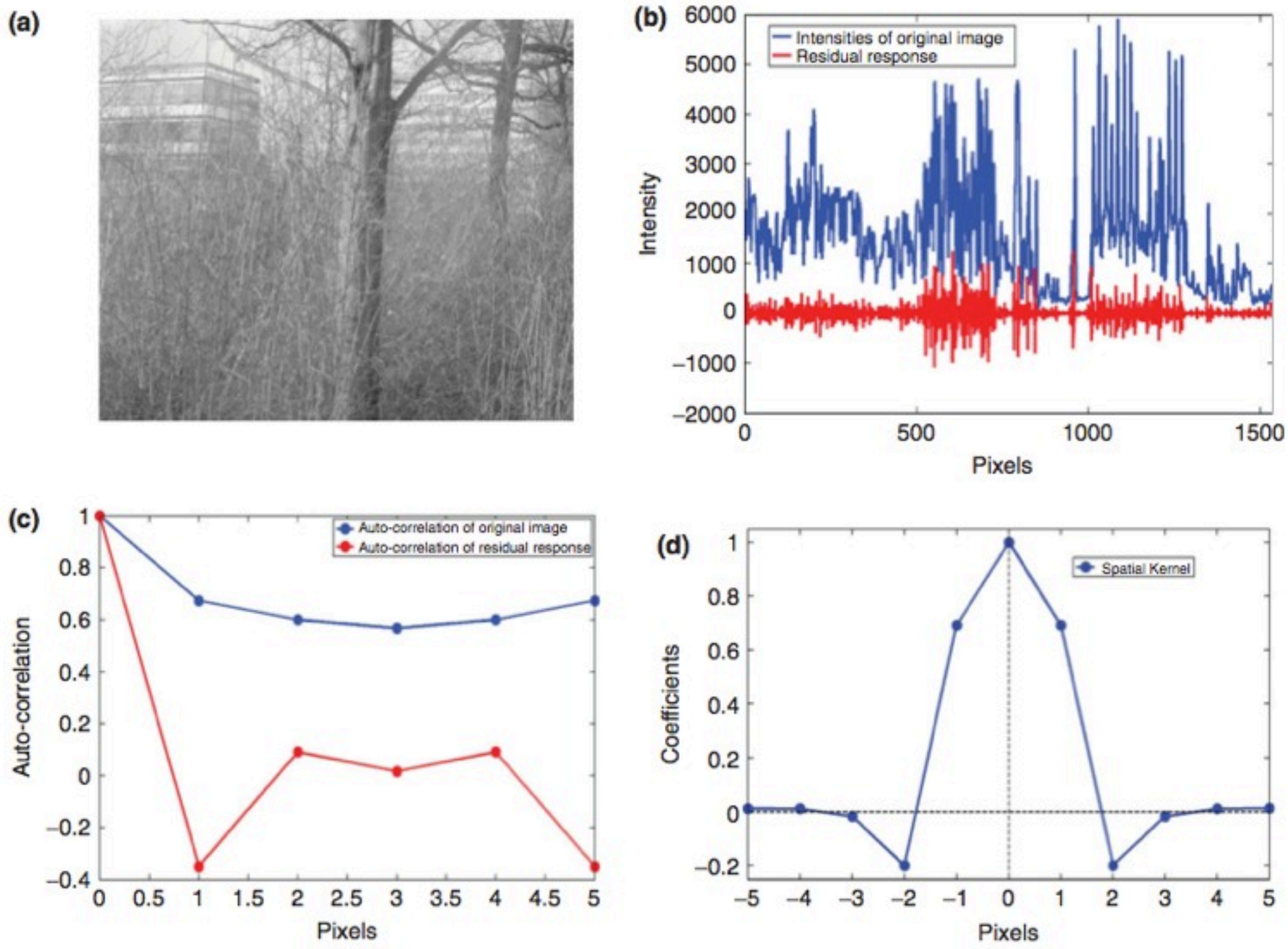
Rao RPN, Sejnowski TJ, Rao RPN, Olshausen BA, Lewicki MS. Predictive coding, cortical feedback, and spike-timing dependent plasticity. In: Probabilistic Models of the Brain. 2002

Predictive coding



Rao RP, Ballard DH. Predictive coding in the visual cortex: a functional interpretation of some extra-classical receptive-field effects. Nat. Neurosci. 1999 Jan;2(1):79–87.

Predictive coding in retina



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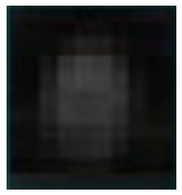

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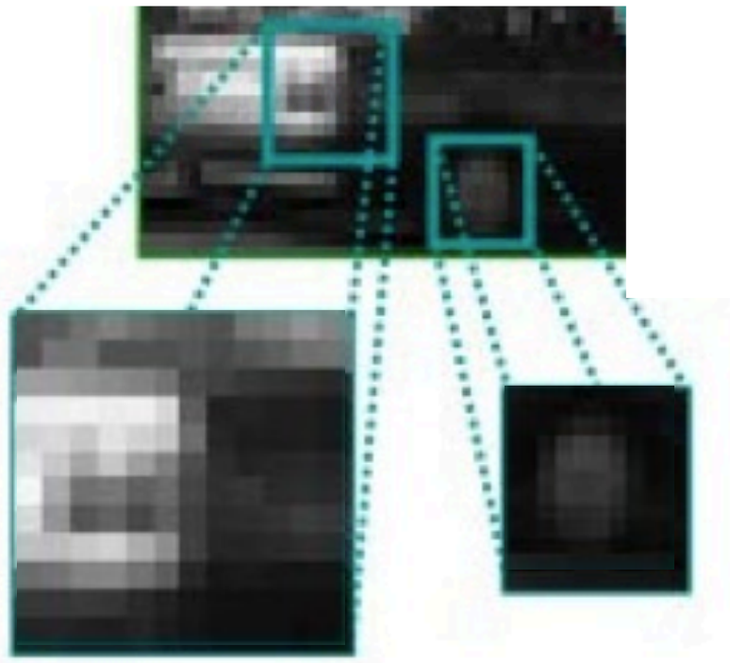

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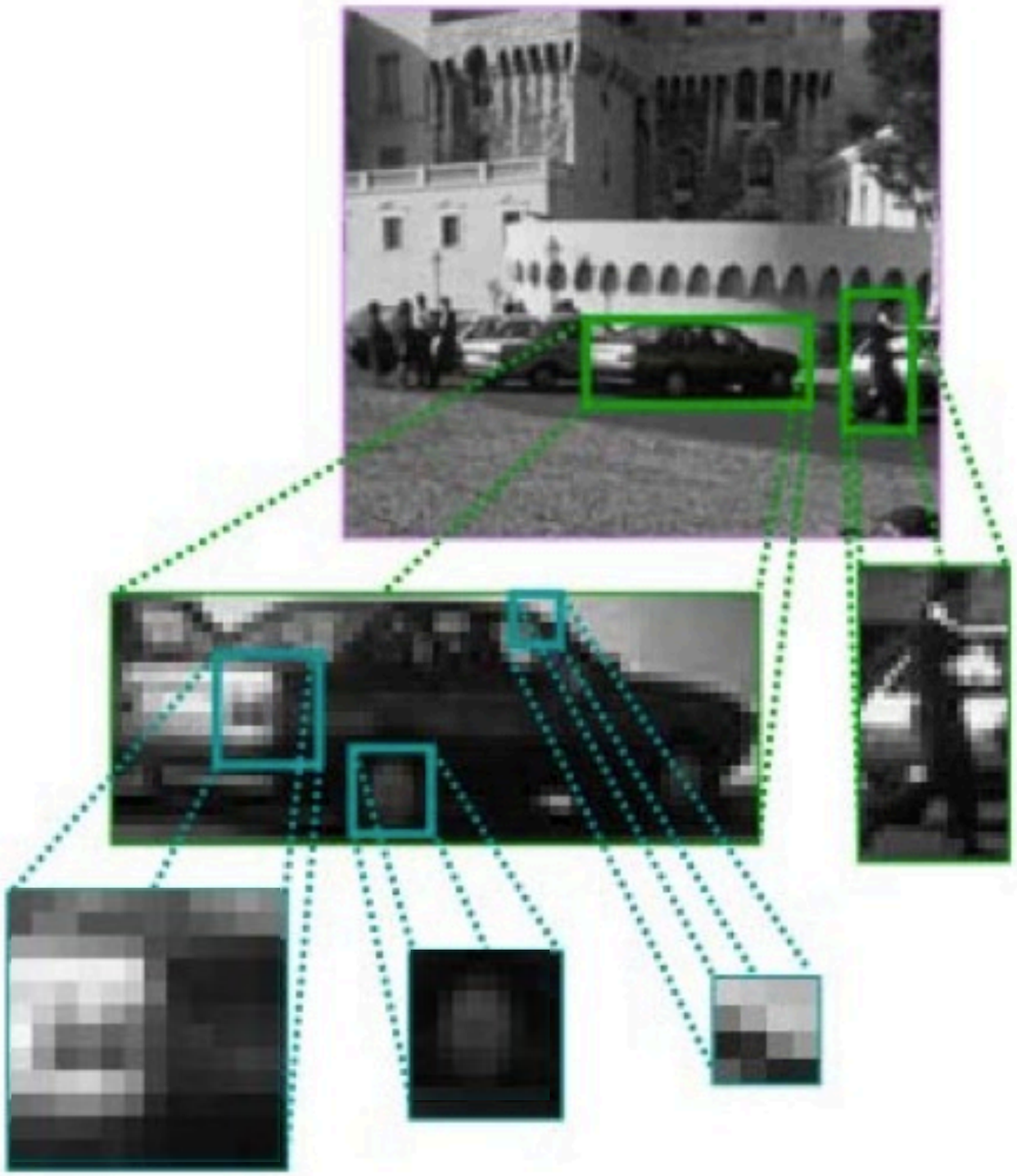
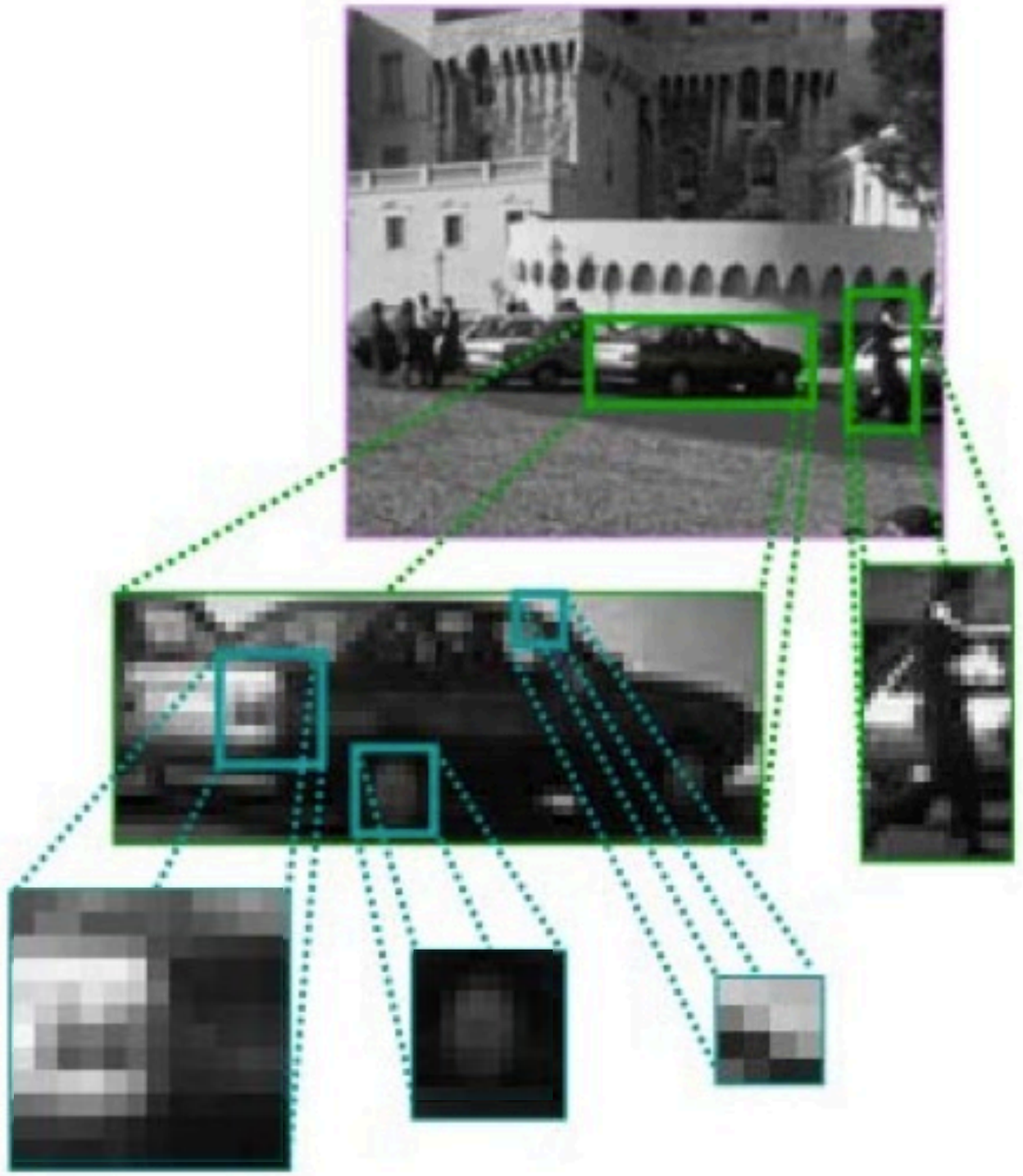
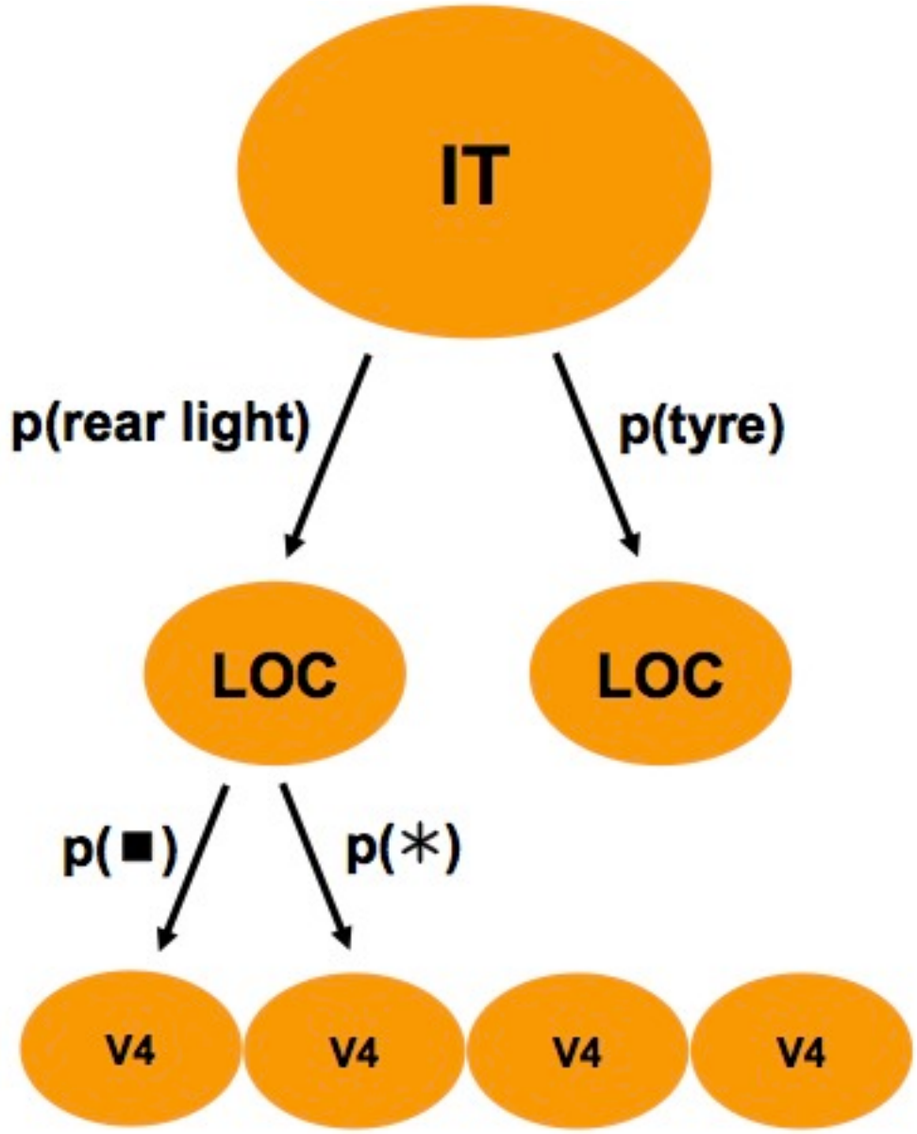
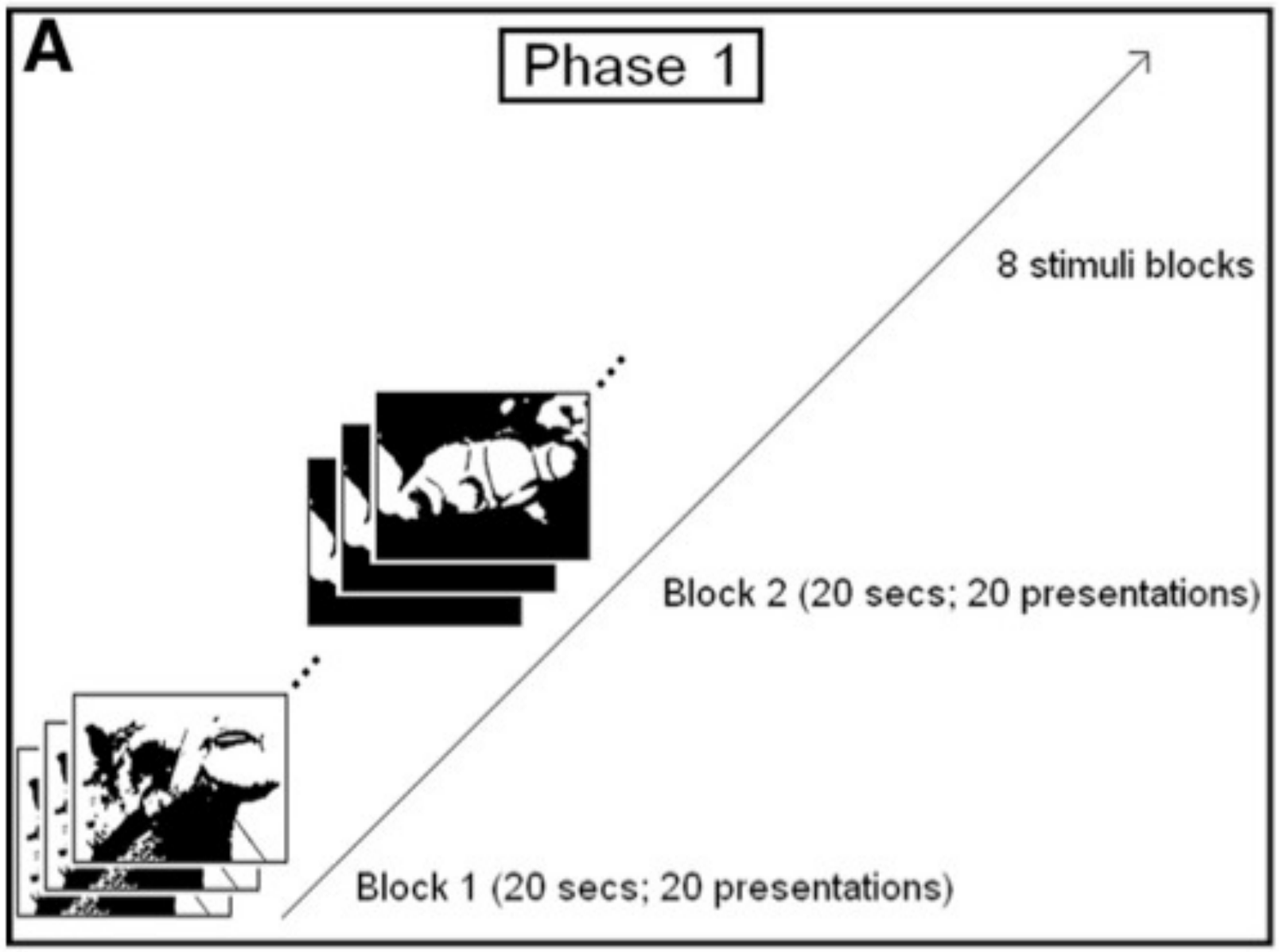


Hierarchical Bayesian inference





Recognition changes early responses



Hsieh P-J, Vul E, Kanwisher N. Recognition alters the spatial pattern of FMRI activation in early retinotopic cortex. J Neurophysiol. 2010 Mar; 103(3):1501–7.

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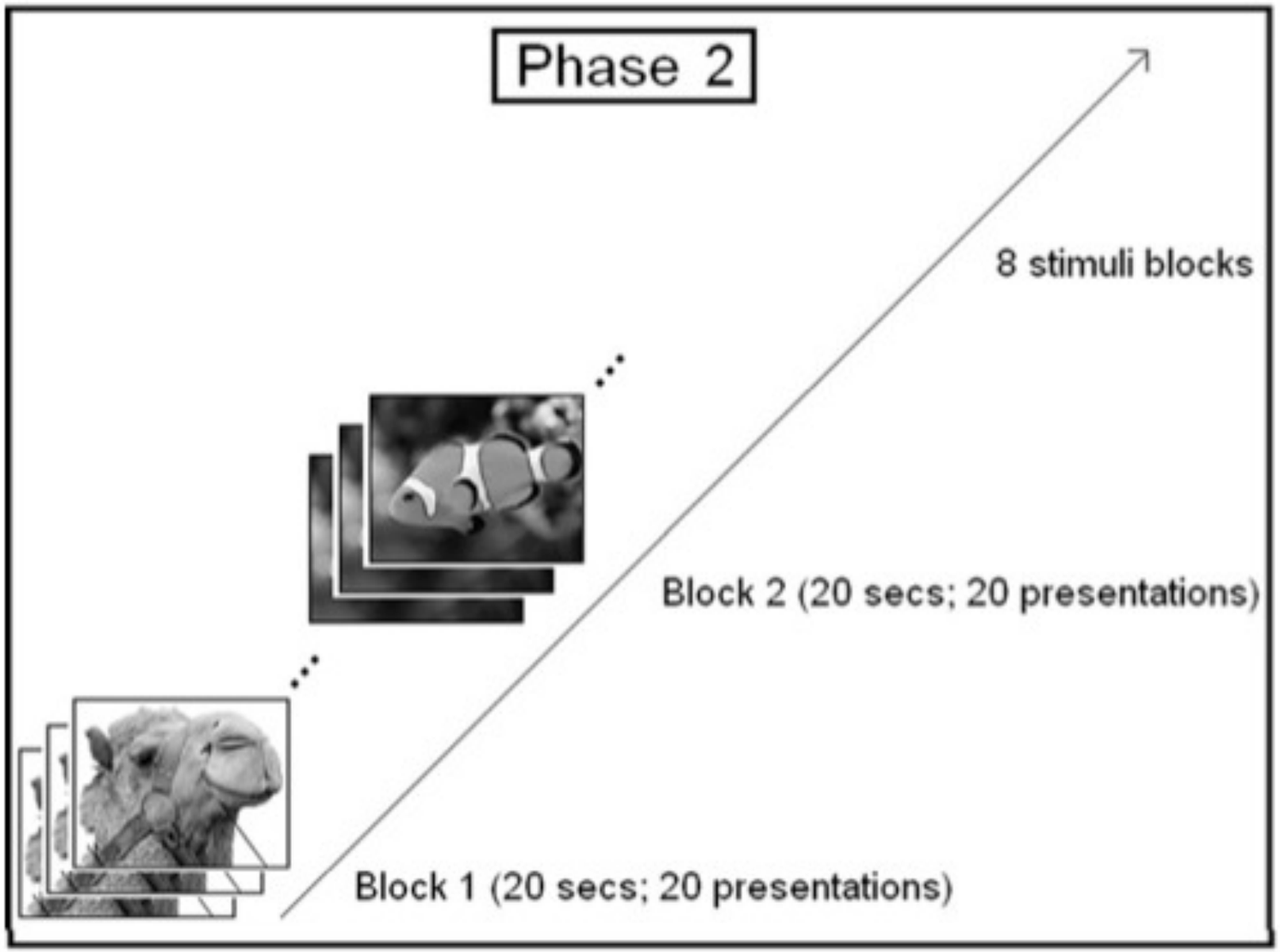

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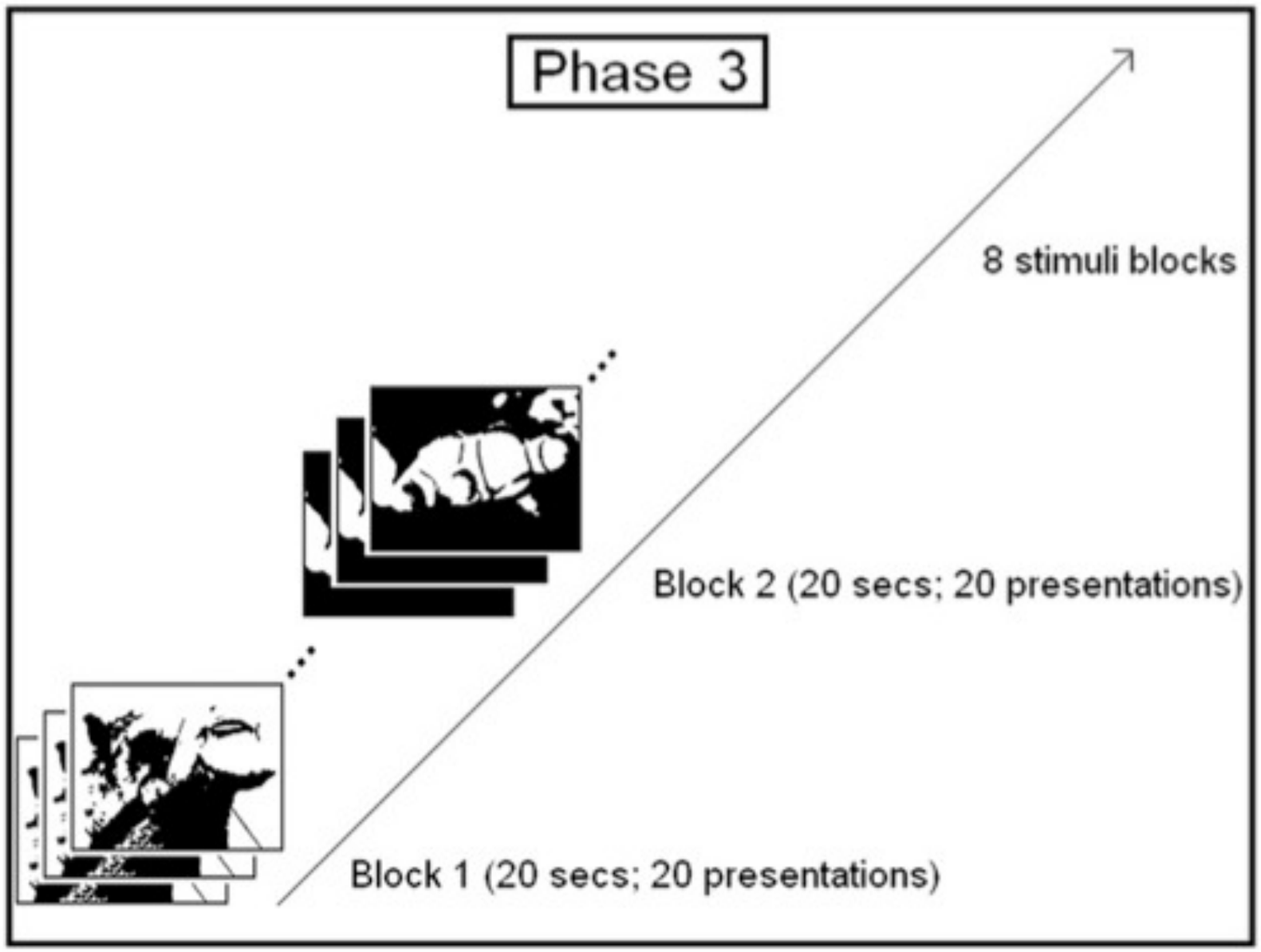

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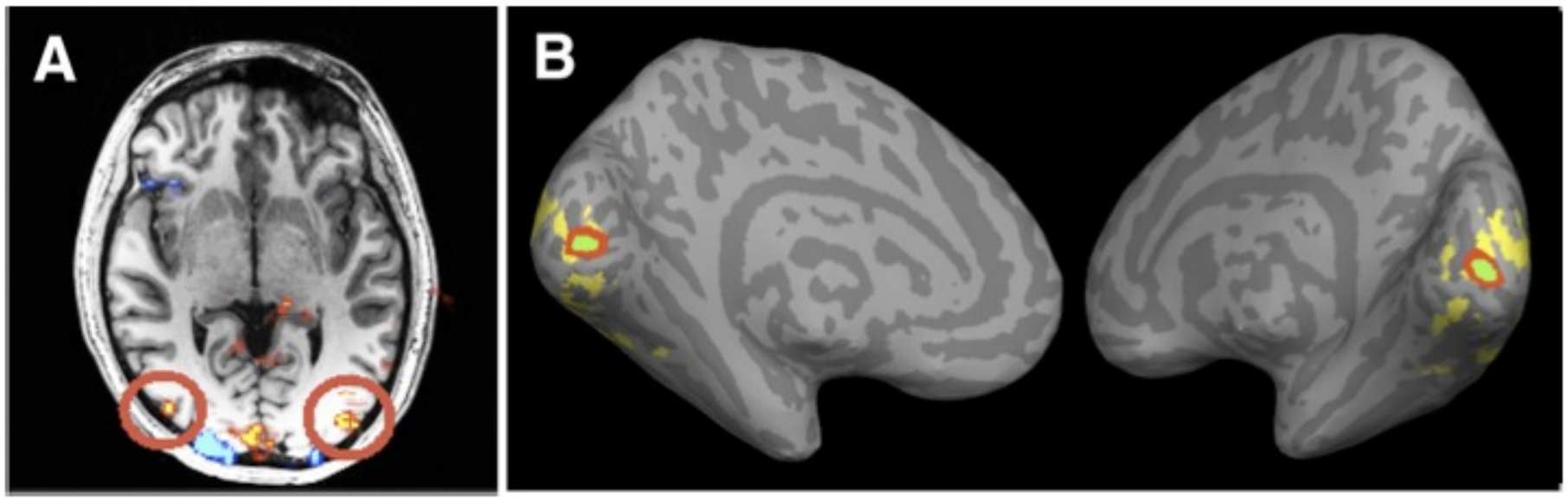

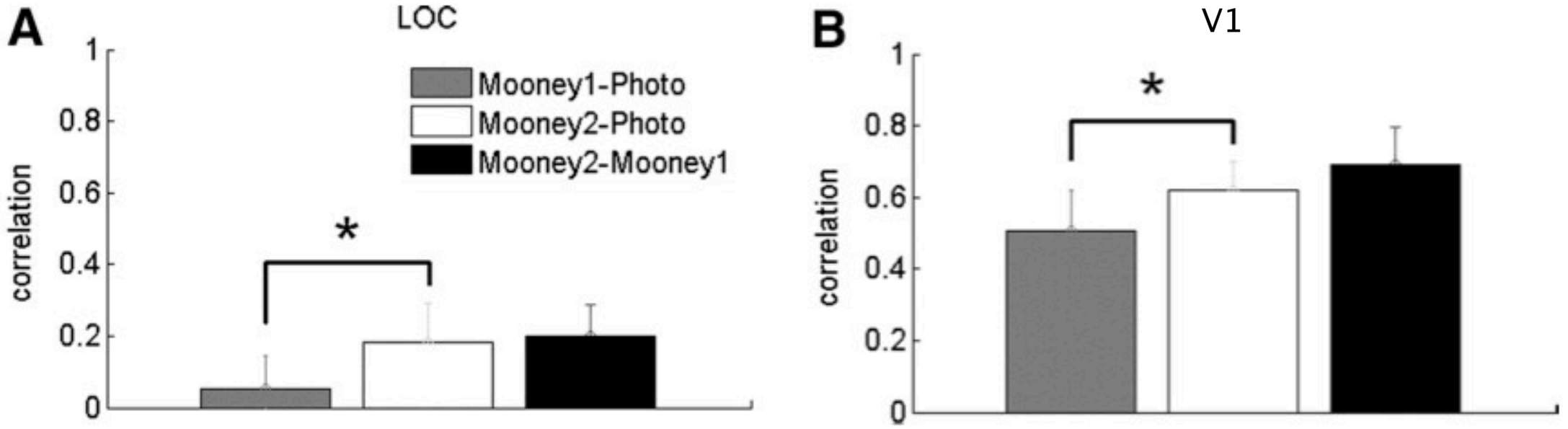

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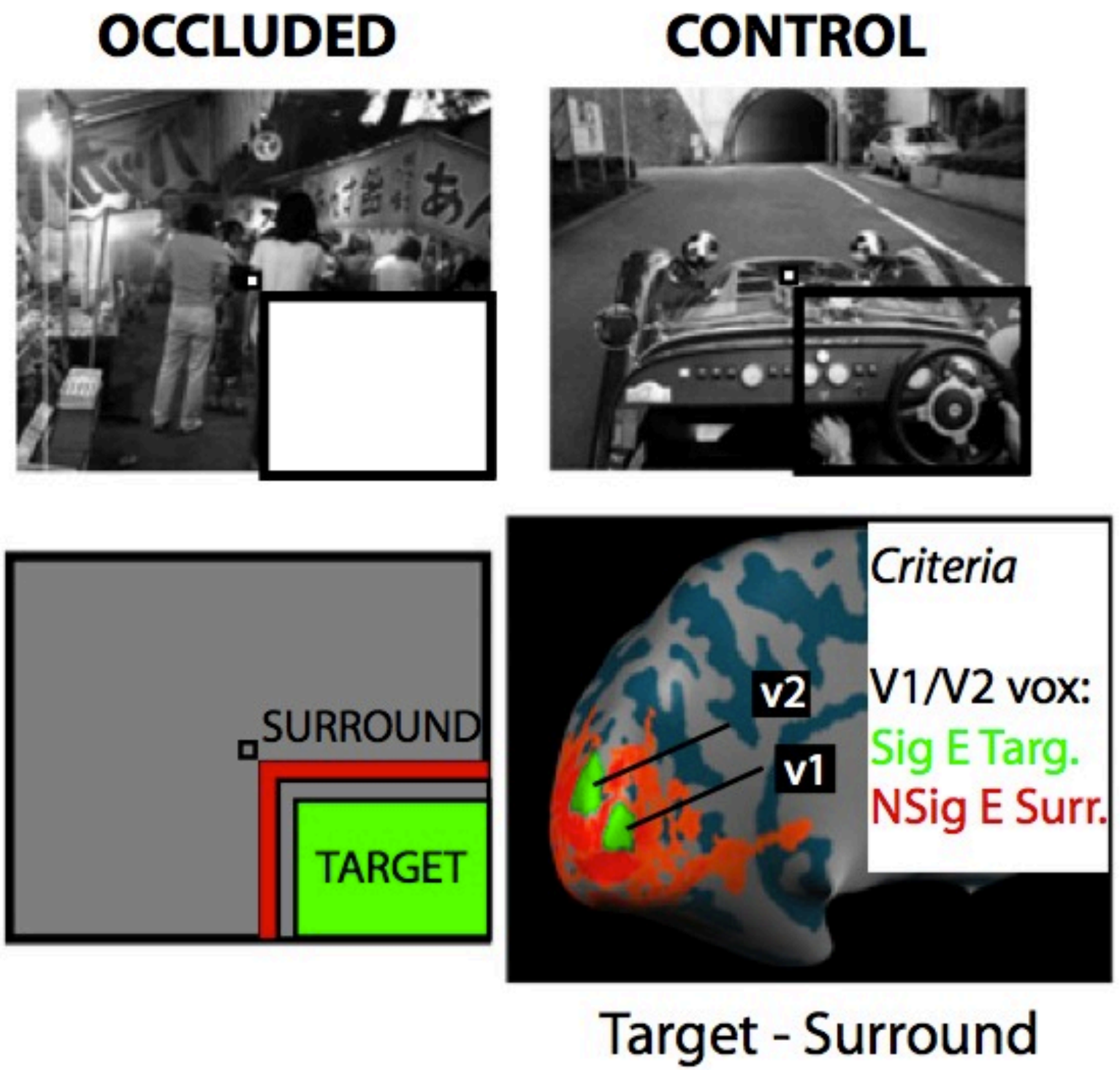
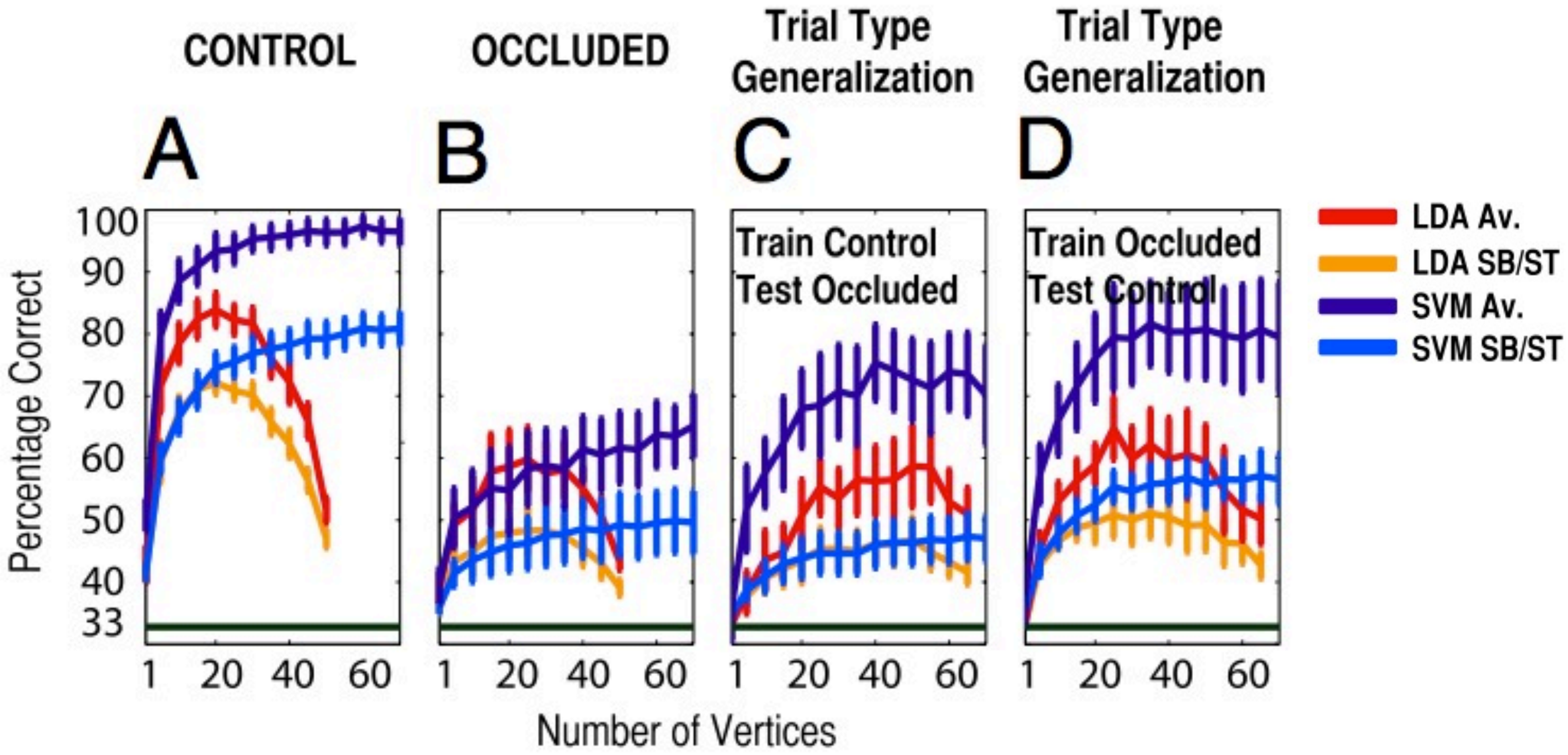
Context changes early responses



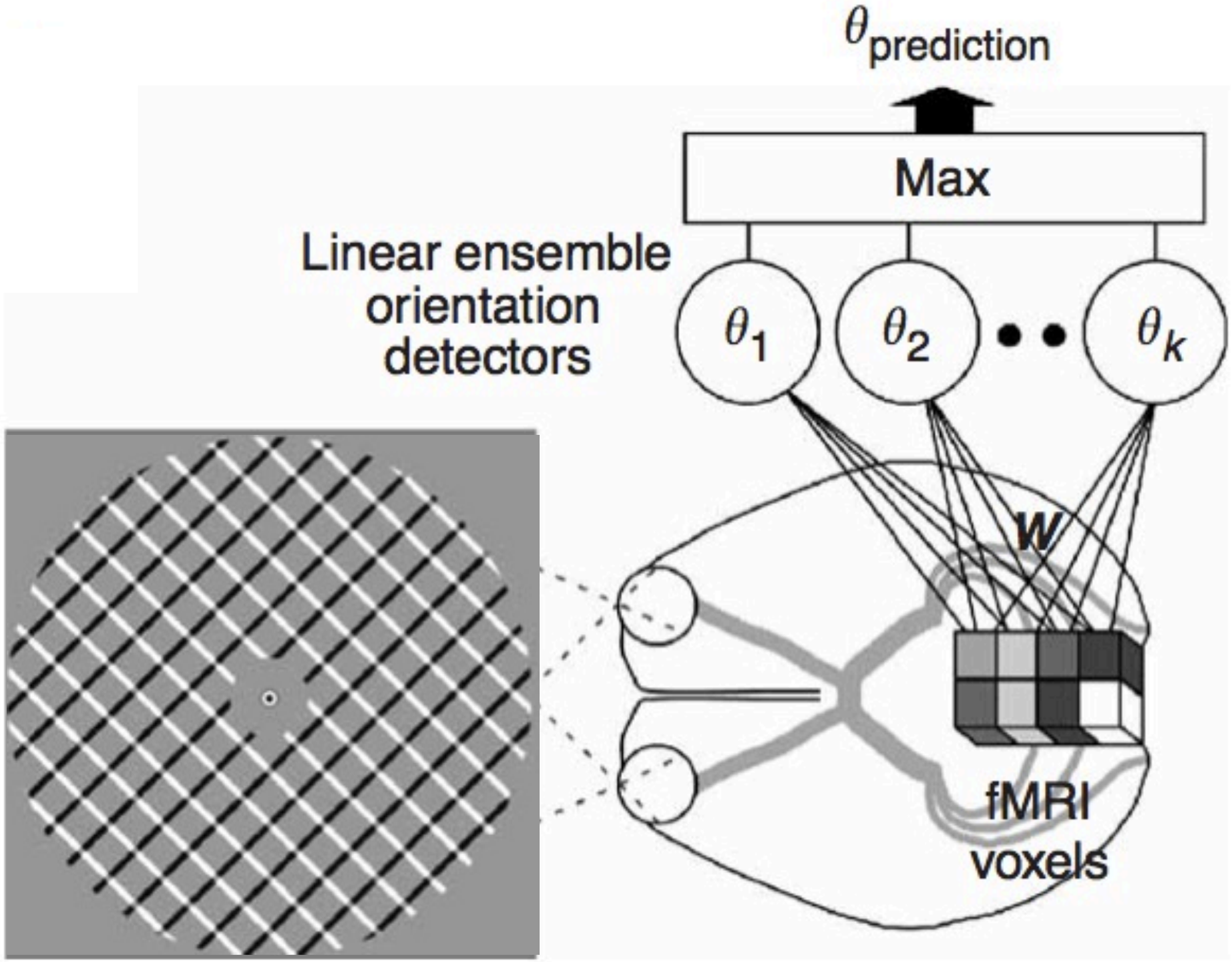
Smith FW, Muckli L. Nonstimulated early visual areas carry information about surrounding context. PNAS. 2010 Nov 16;107(46):20099–103.

Context changes early responses



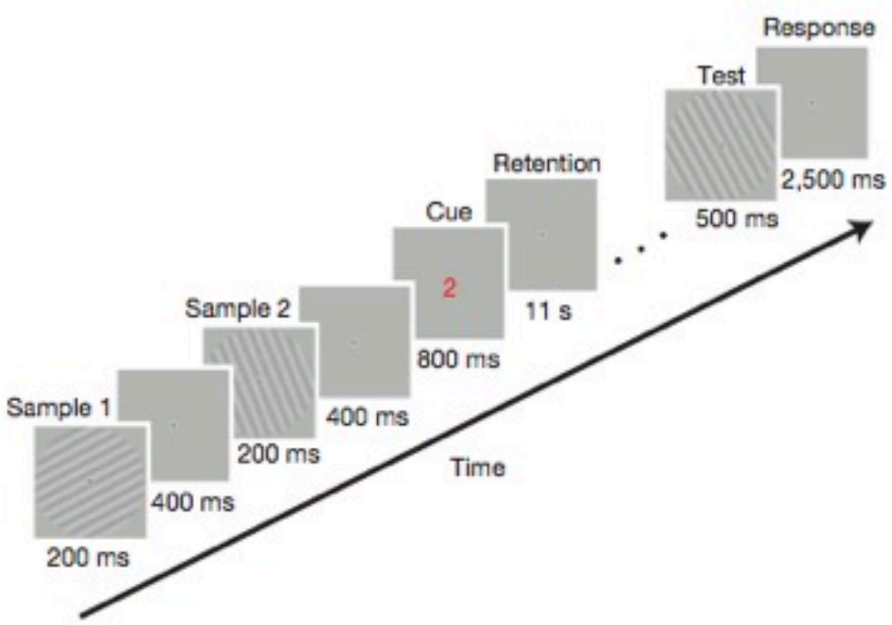
Smith FW, Muckli L. Nonstimulated early visual areas carry information about surrounding context. PNAS. 2010 Nov 16;107(46):20099–103.

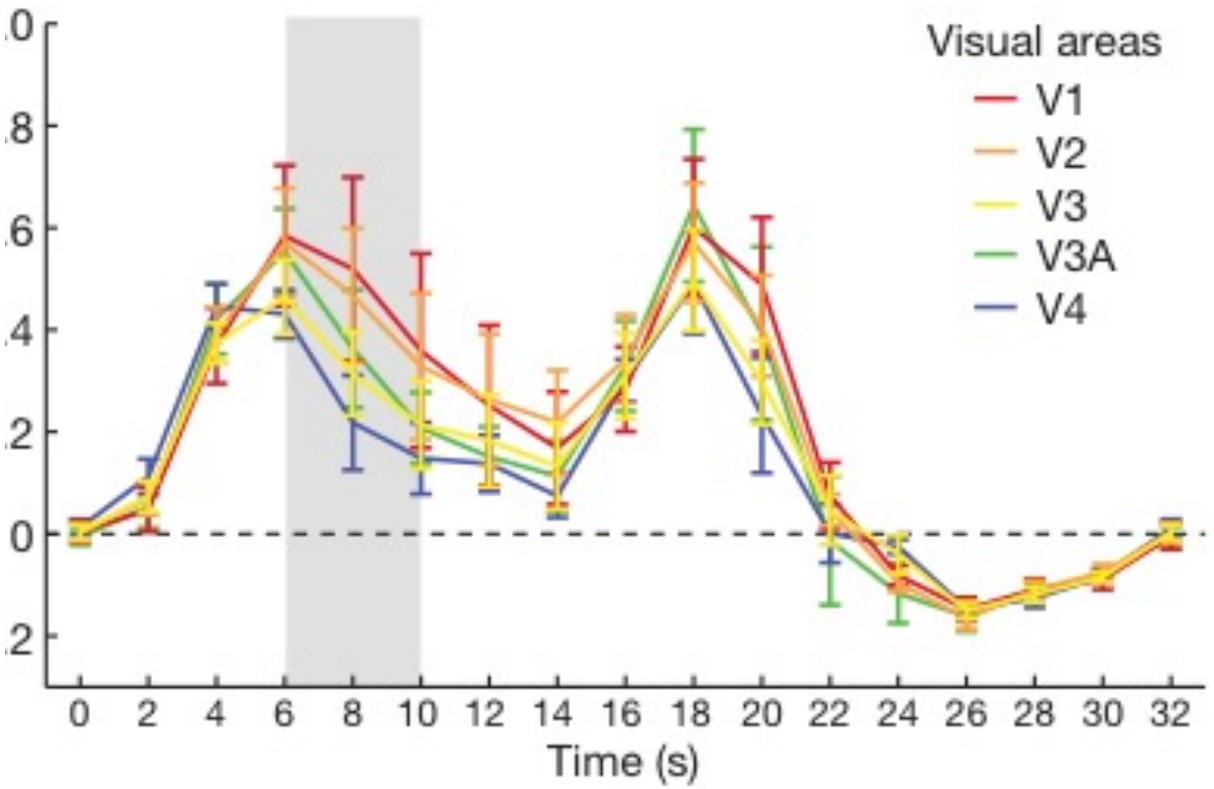
Attention changes early responses

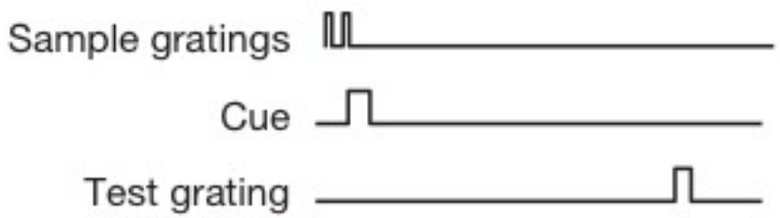


Kamitani and Tong, Nature Neuroscience, 2005

Working memory changes early responses

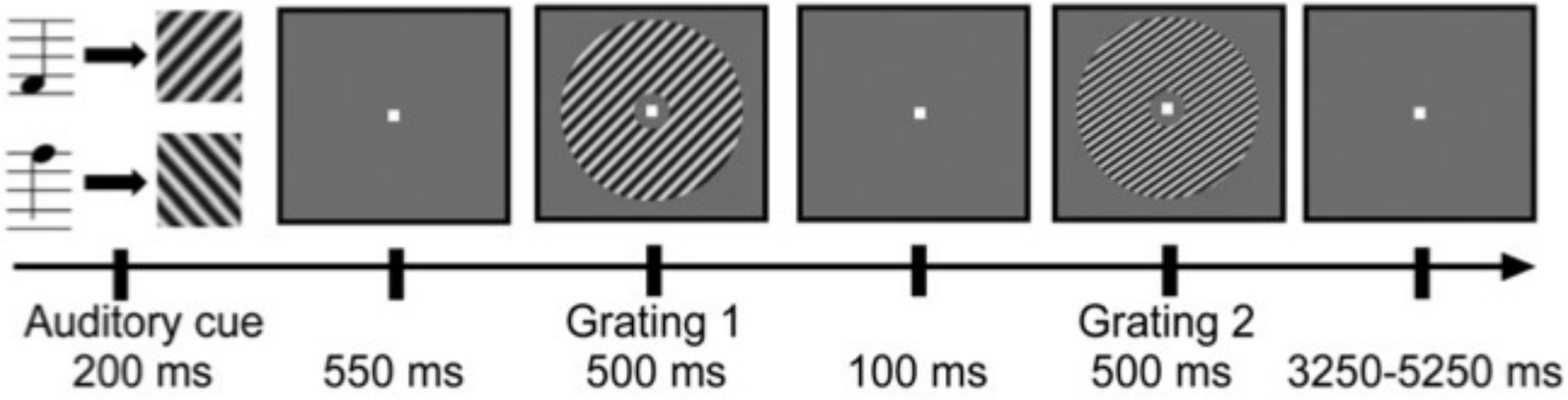


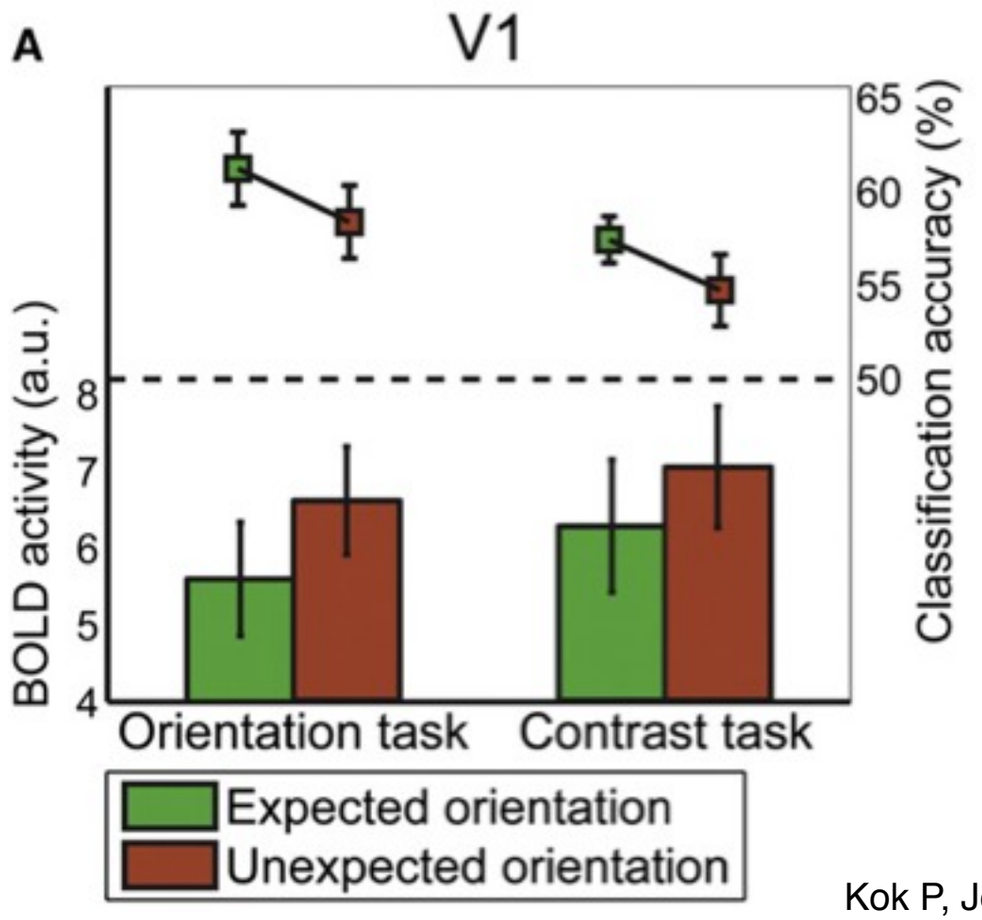




S. A. Harrison and F. Tong. Decoding reveals the contents of visual working memory in early visual areas. *Nature*, 458:632–635, 2009.

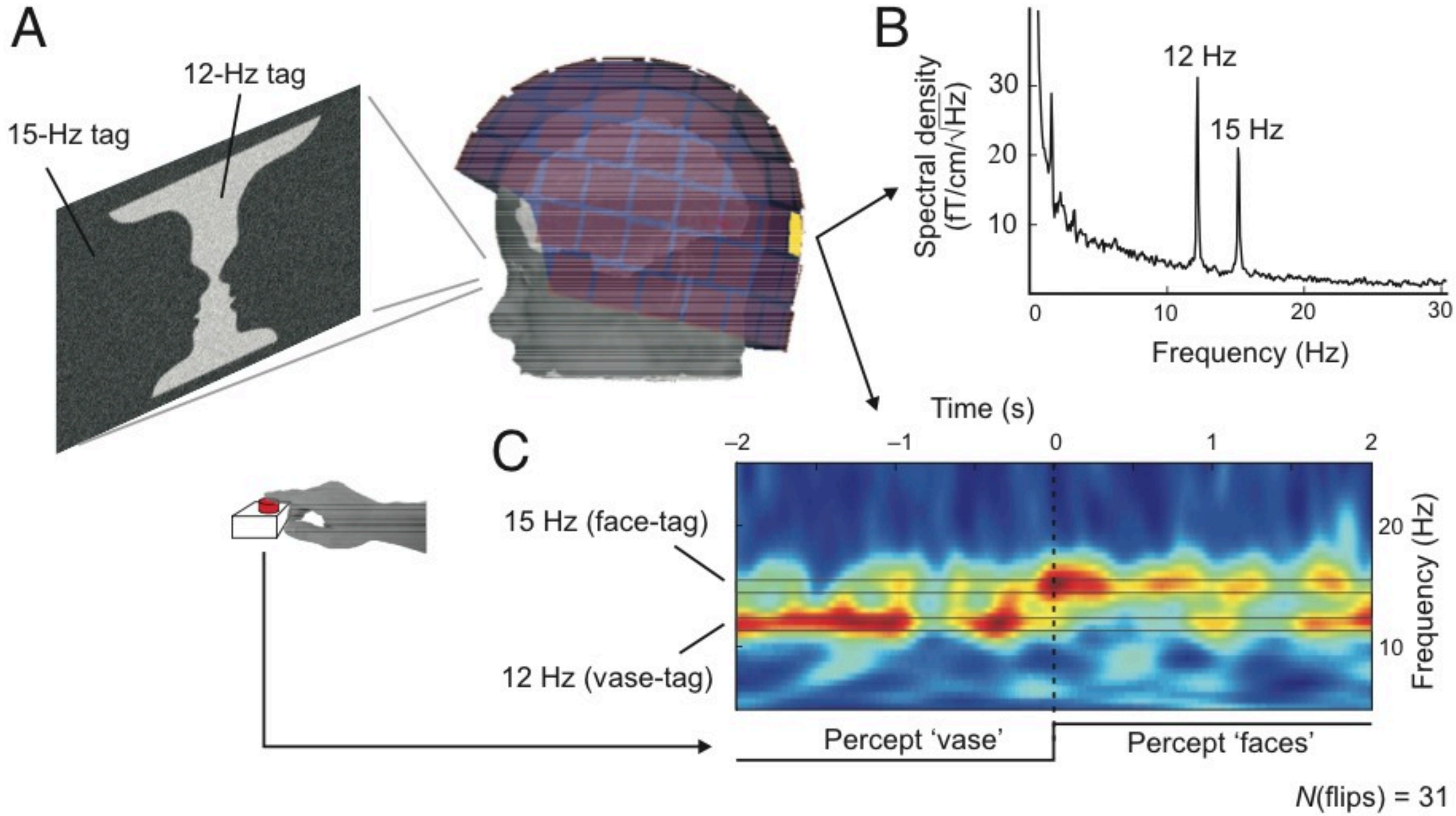
Expectation sharpens representations in primary visual cortex





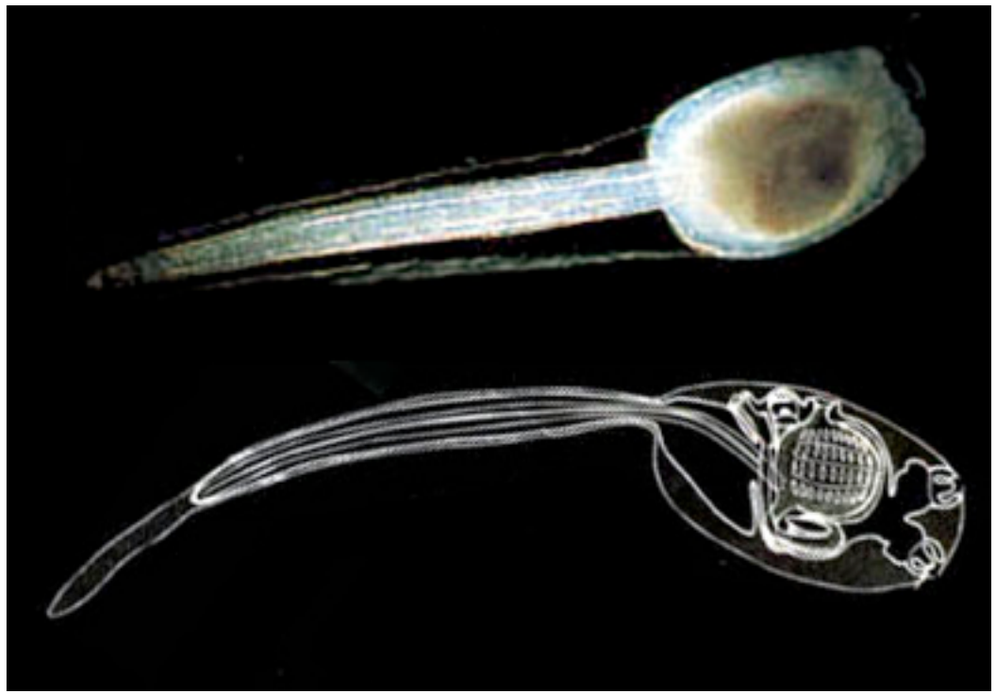
Kok P, Jehee JFM, de Lange FP. Less is more: expectation sharpens representations in the primary visual cortex. Neuron. 2012 Jul 26;75(2):265–70.

Rubin face-vase illusion



Parkkonen L, Andersson J, Hämäläinen M, Hari R. Early visual brain areas reflect the percept of an ambiguous scene. PNAS. 2008 Dec. 23;105(51):20500–20504.

- The brain only exists by virtue of being able to produce behaviour

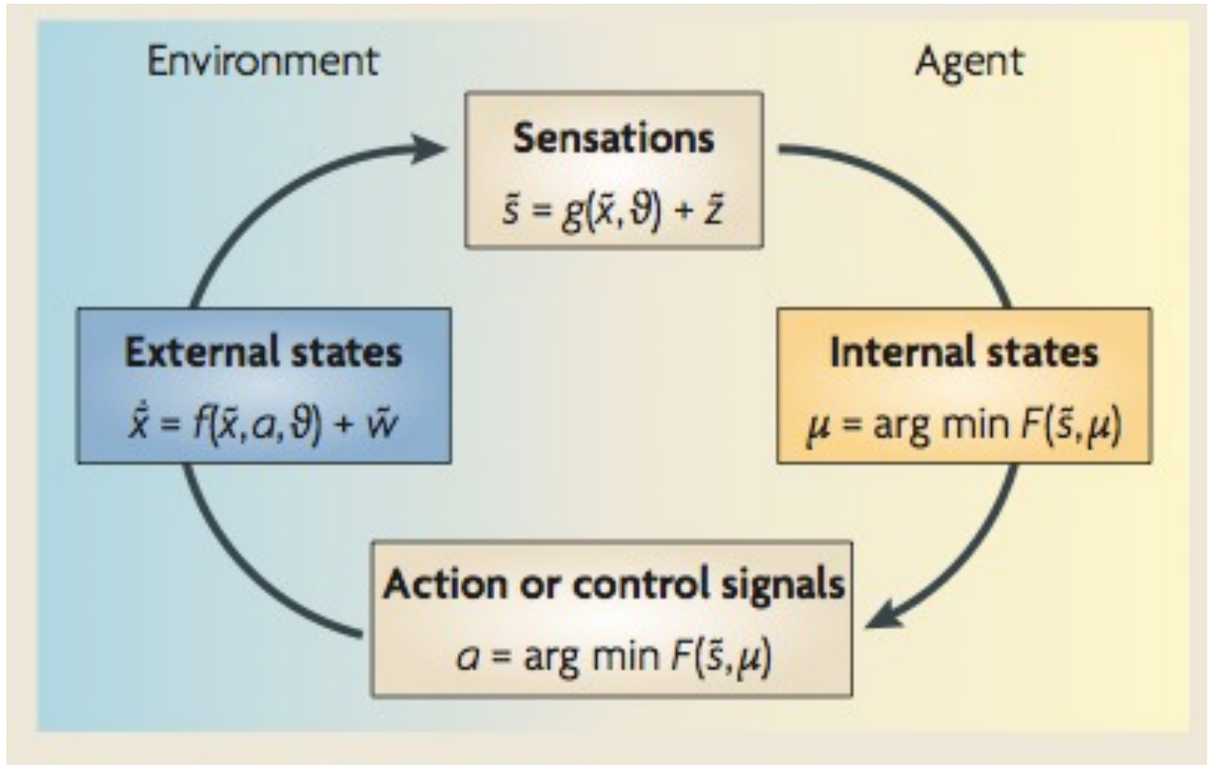


- Probability estimates must ultimately drive action

- Can be accommodated for by combining probability theory with decision theory

- Decision theory states that actions are chosen to maximize expected utility

The free-energy principle



- Free-energy minimisation: mathematical implementation of reduction of surprise

- Can be achieved by:

1. updating our internal model or

2. changing our sensory input (think of feeling your way in the dark)

- Subsumes the Bayesian brain hypothesis and predictive coding

- Very rich and general framework for understanding brain function

Friston KJ. The free-energy principle: a unified brain theory? Nat. Rev. Neurosci. 2010 Feb;11(2):127–38.

- Bayesian statistics not only as a data analysis approach but also as a general framework for understanding brain function

- People act according to Bayesian principles
- Predictive coding as an implementation of this approach
- Free-energy principle as a framework to link perception and action

Course conclusion

- Hand in practical assignments

- Hand in essay

- Study course slides, papers, lecture notes

- Supply course evaluation