The proactive brain:

Using analogies and associations to generate predictions

Moshe Bar

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Supported by NINDS RO1 #NS44319, #NS50615, and by the McDonnell Foundation - 21st Century Science Award.

Visual Cognition

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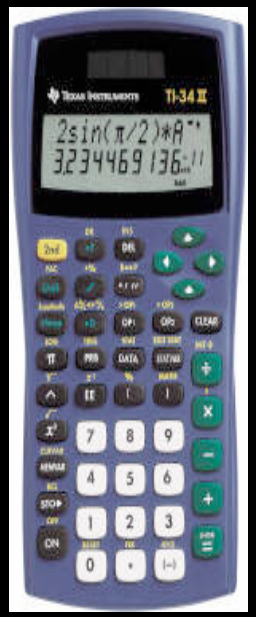
Visual Cognition



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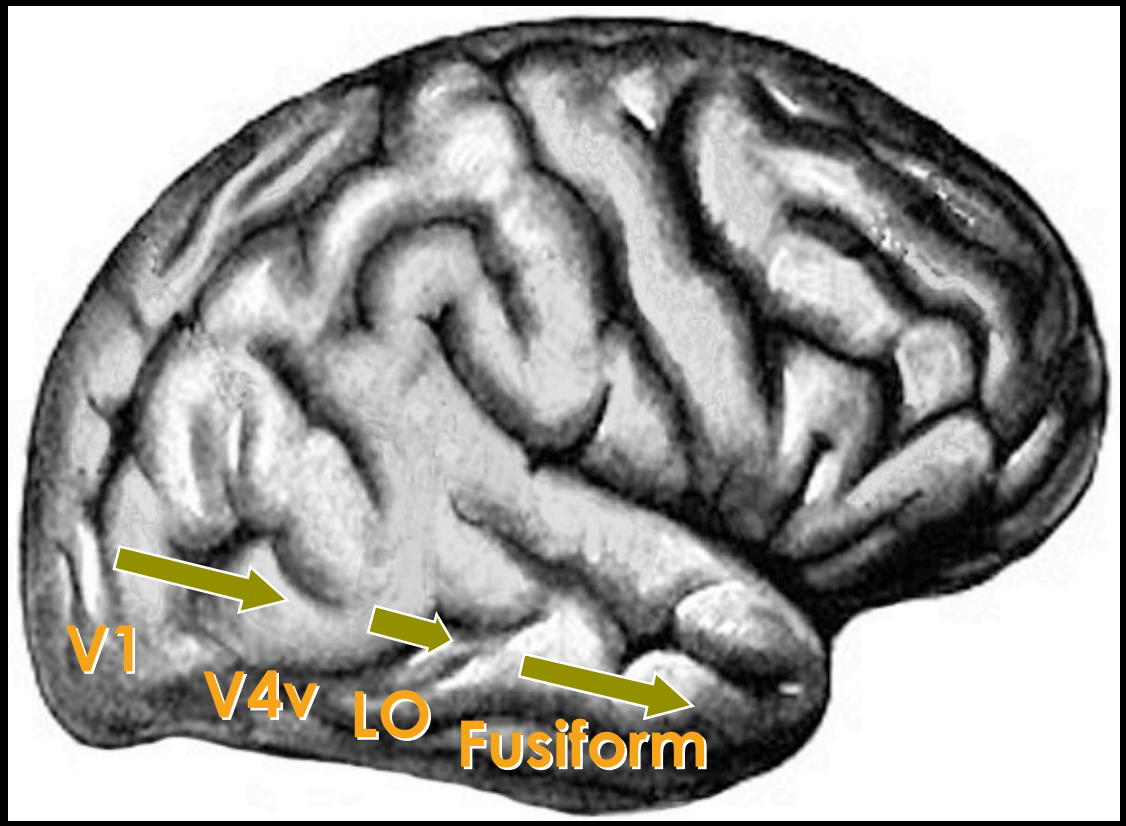
Visual Cognition

Cortical Processing in Object Recognition



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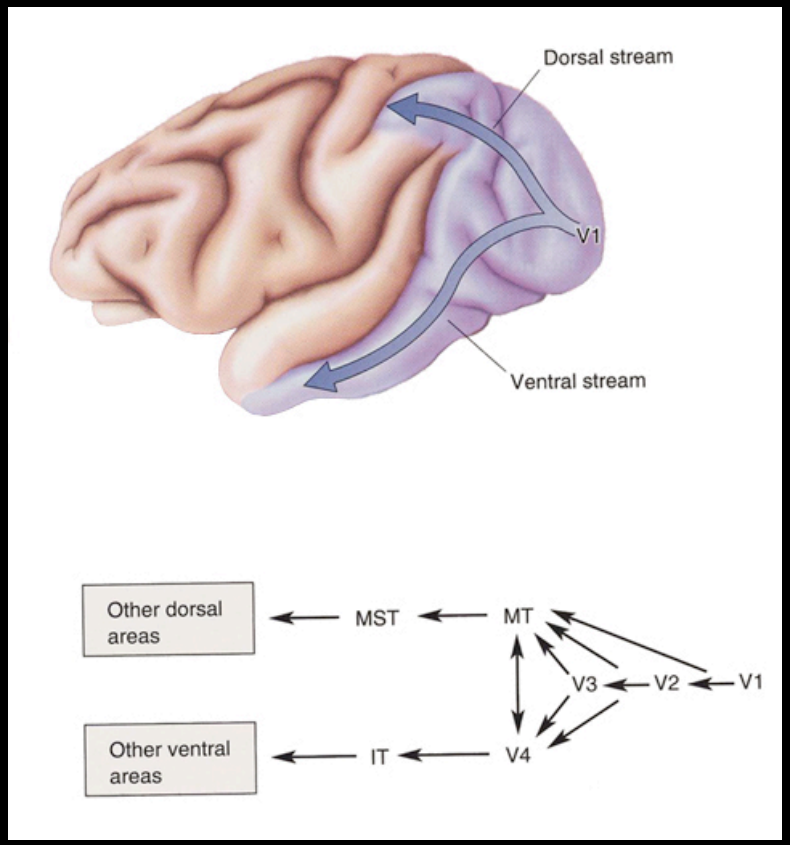
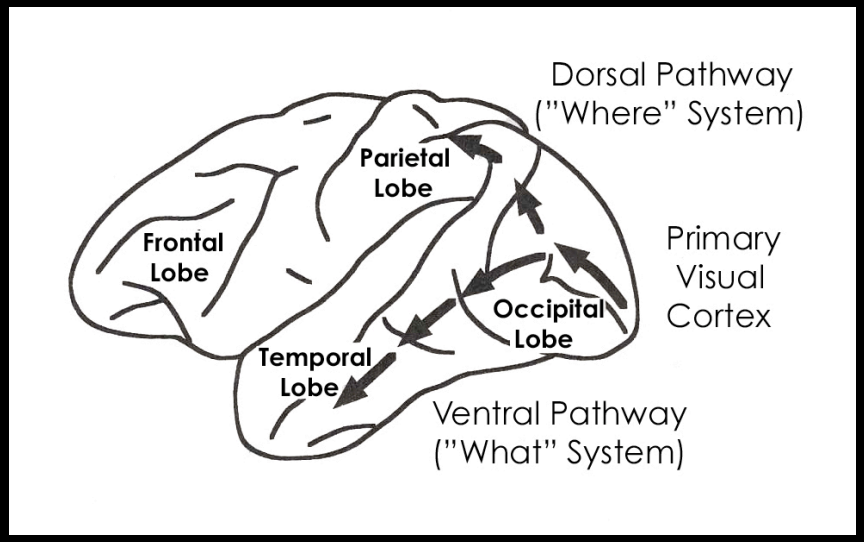
Two textbook "myths"

- The brain is a reactive organ





Massive reciprocal connections

Two textbook "myths"

- The brain is a responsive organ
- Recognition, or classification, is the goal

What is this?

What is this **like**? **analogies**

Visual recognition as analogical mapping

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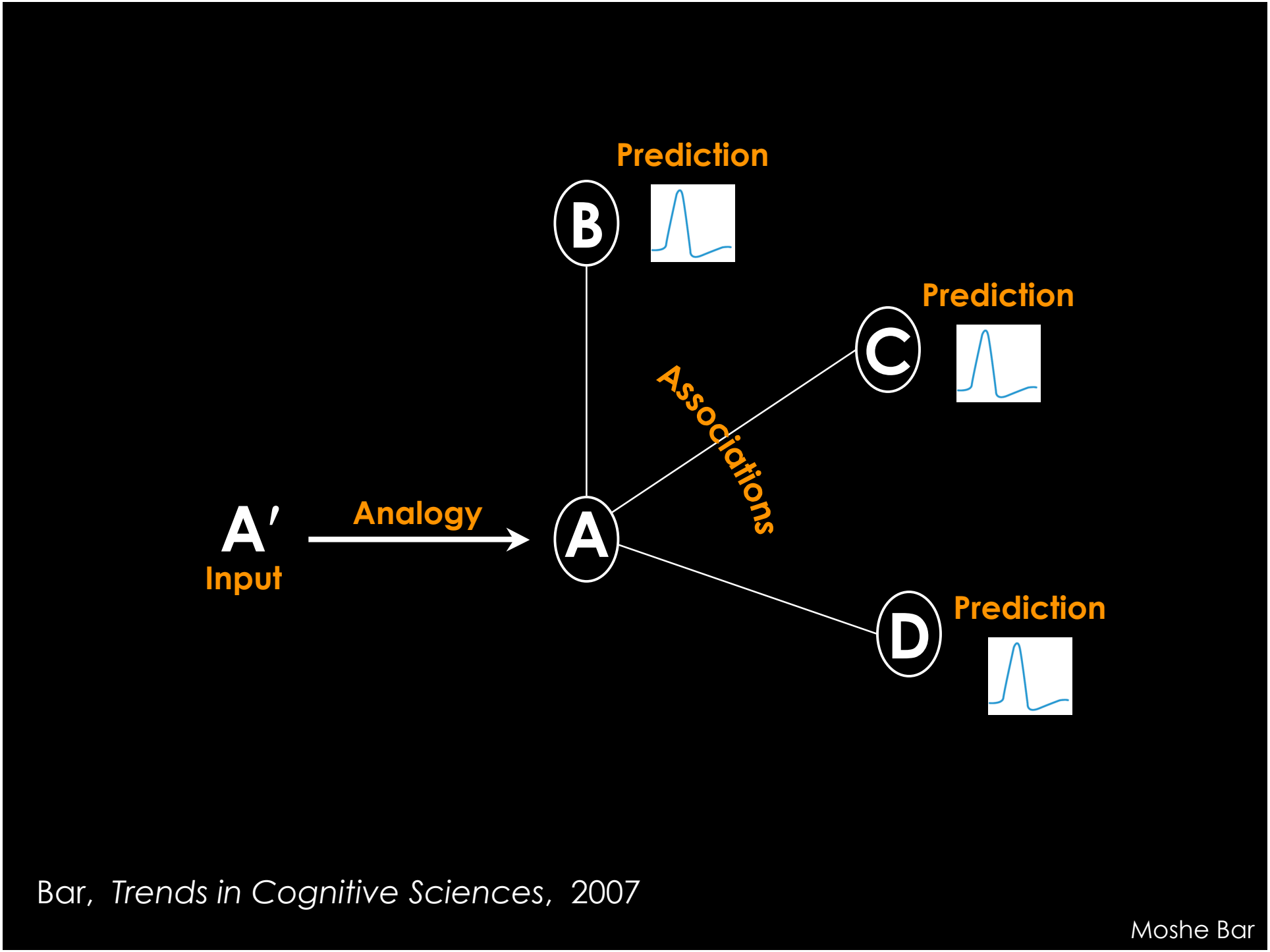
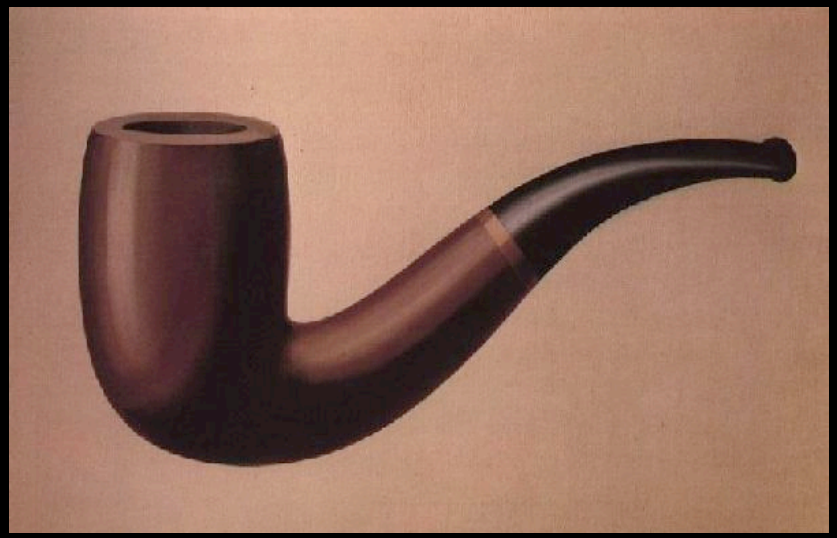
- facilitate recognition
  (auto-predictions)

- connect to associations
  (predictions)



Bar, *Trends in Cognitive Sciences*, 2007

Predictions in object recognition



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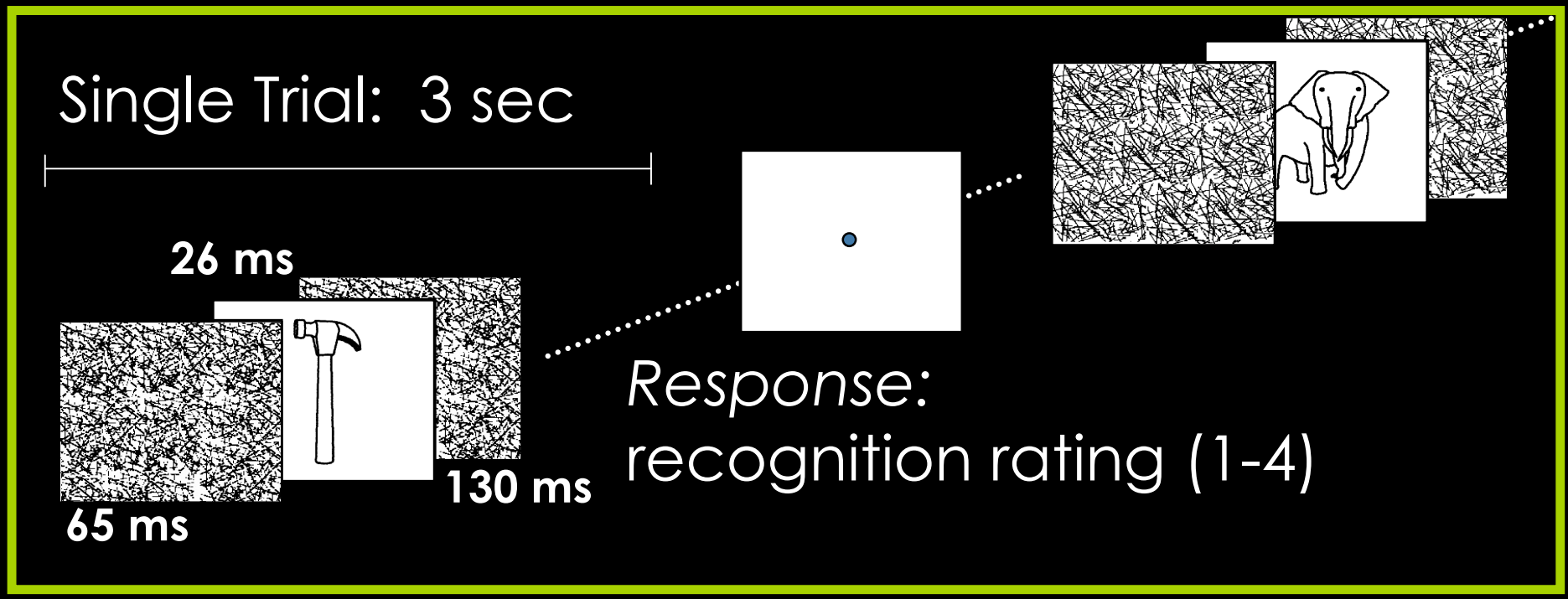
the cortical mechanism specific to conscious object recognition



(Bar et al., Neuron 2001)

- Event-related design
- Five, randomly intermixed repetitions
- Subliminal Visual Priming (Bar & Biederman,1998)

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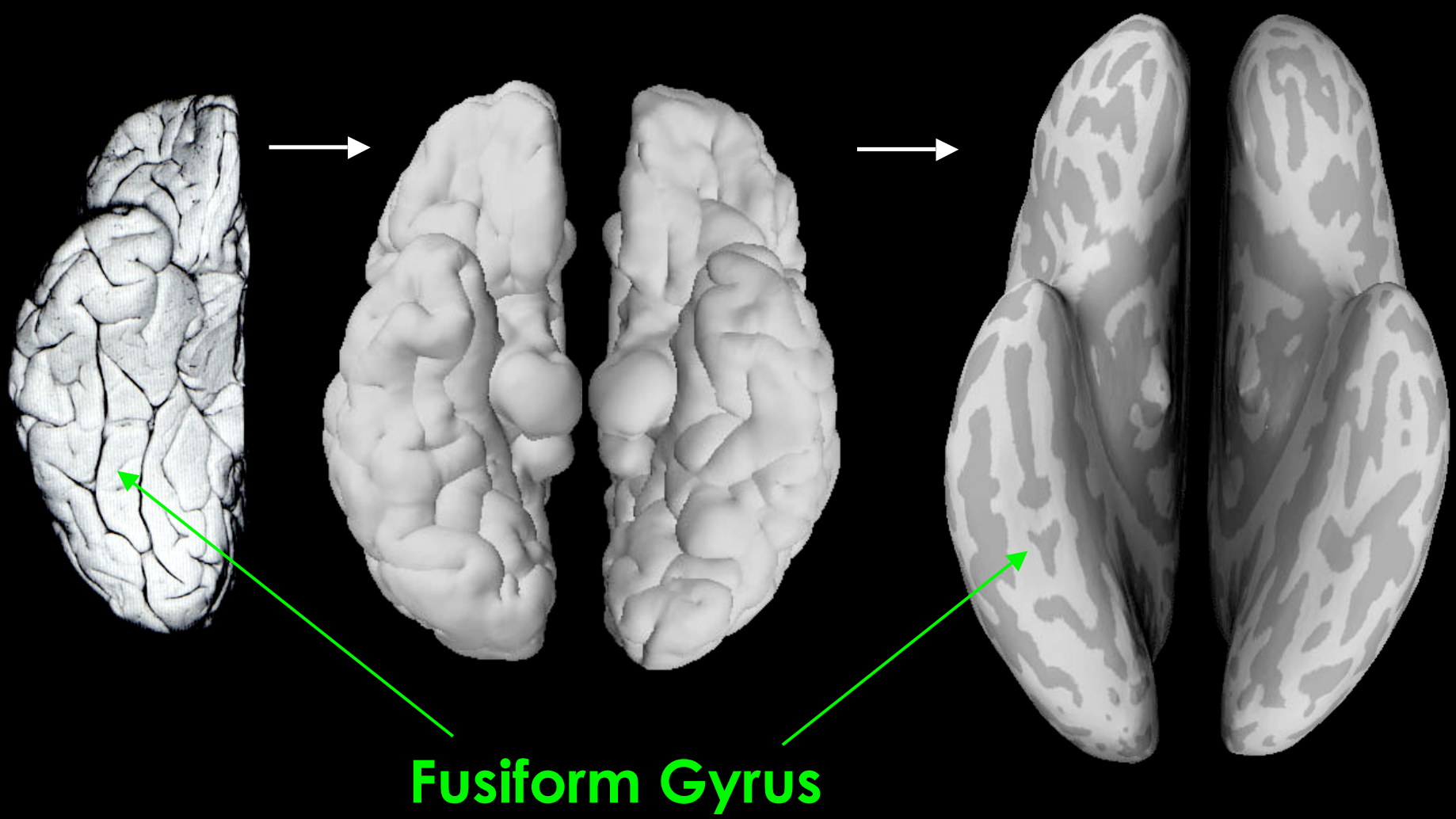
Ventral View



Fusiform Gyrus

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Recognized Objects
vs.
'Almost' Recognized Objects

$p<10^{-9}$

$p<10^{-4}$

Averaged Map (N=12)

left

Bar et al., *Neuron*, 2001

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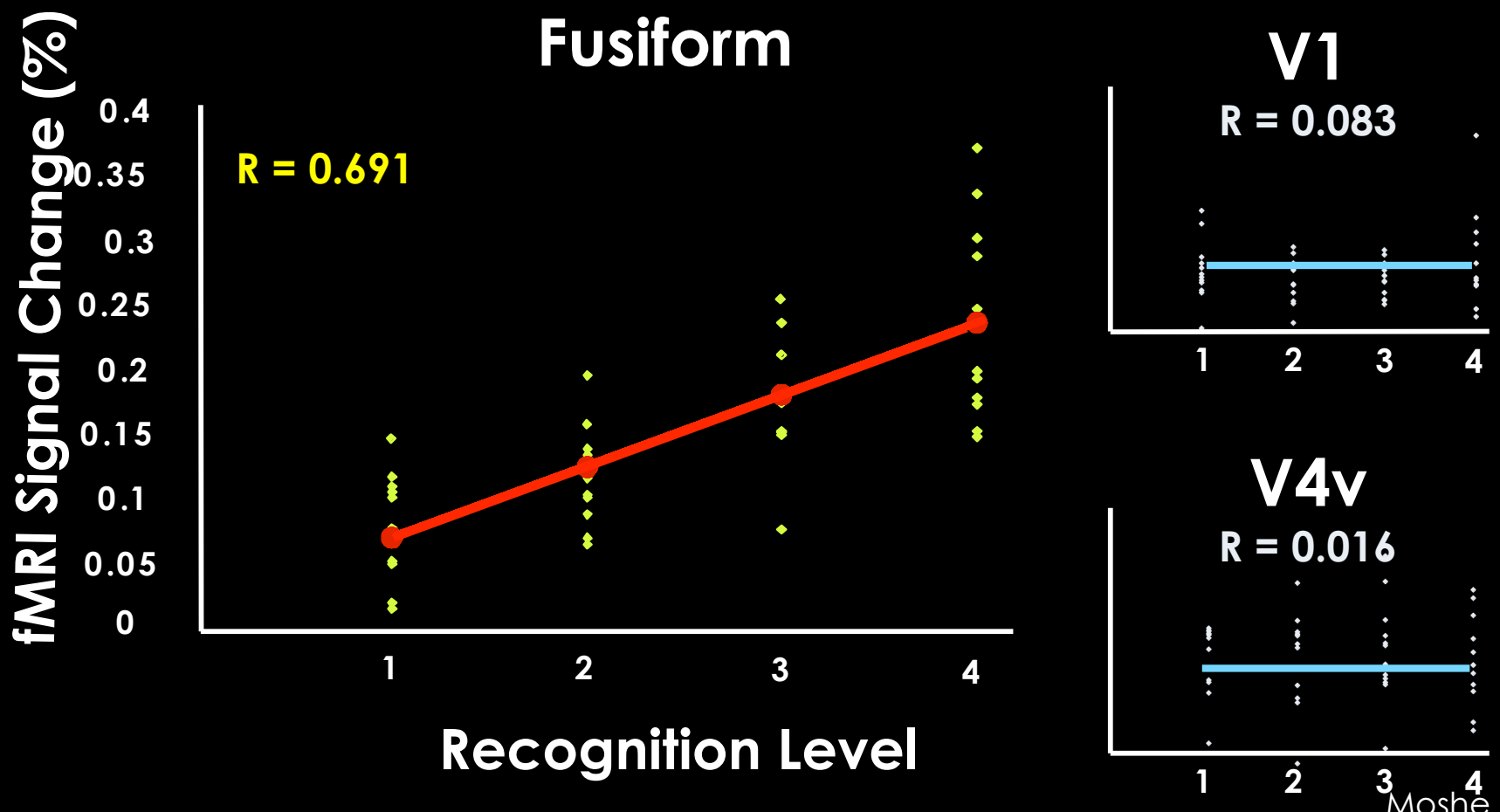
fMRI signal in the fusiform gyrus was linearly correlated with recognition performance



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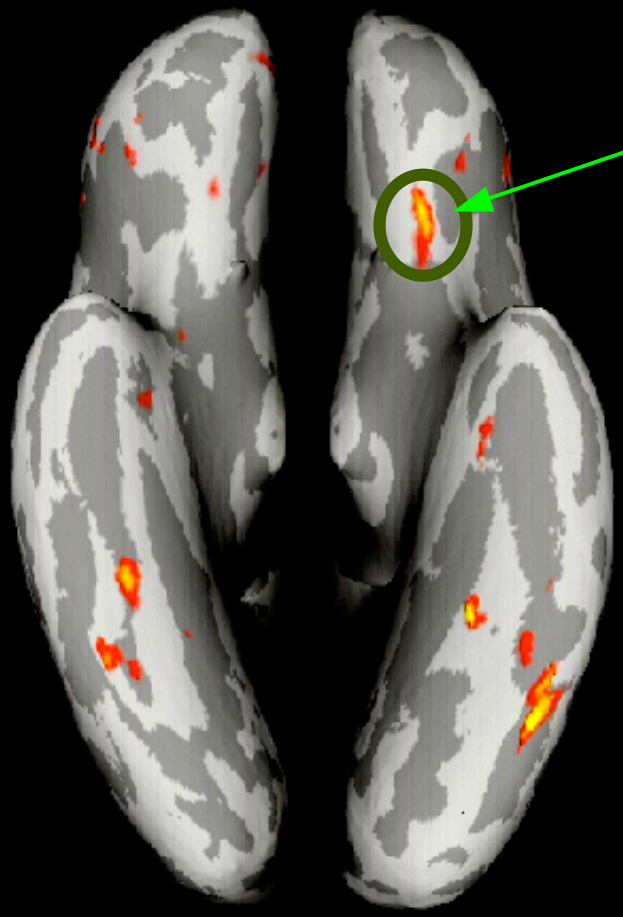
Recognized Objects
vs.
'Almost' Recognized Objects



Orbitofrontal Cortex (OFC)

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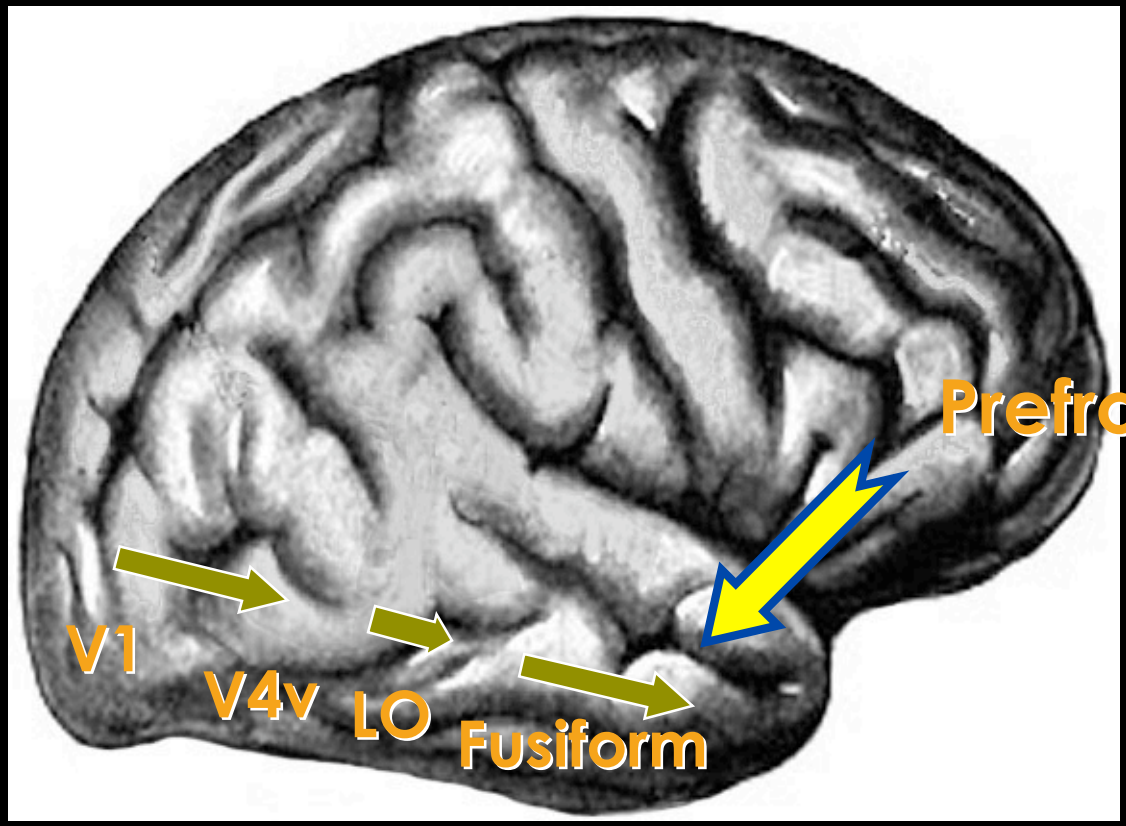
Cortical Processing in Object Recognition



Comparing input with representations in memory

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Minimizing the search: Deciding "what is this like" based on very little

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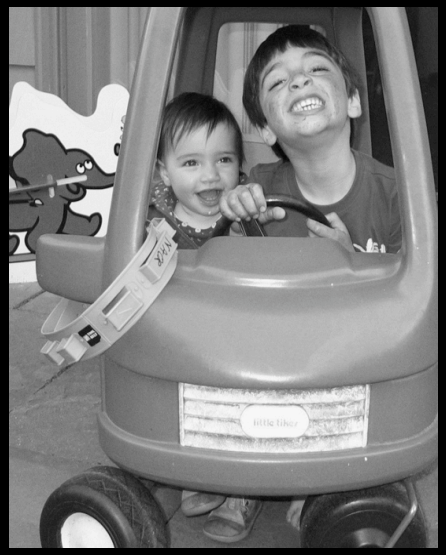
Spatial frequencies

low spatial frequencies



high spatial frequencies

Different timecourses (Magnocellular pathway).

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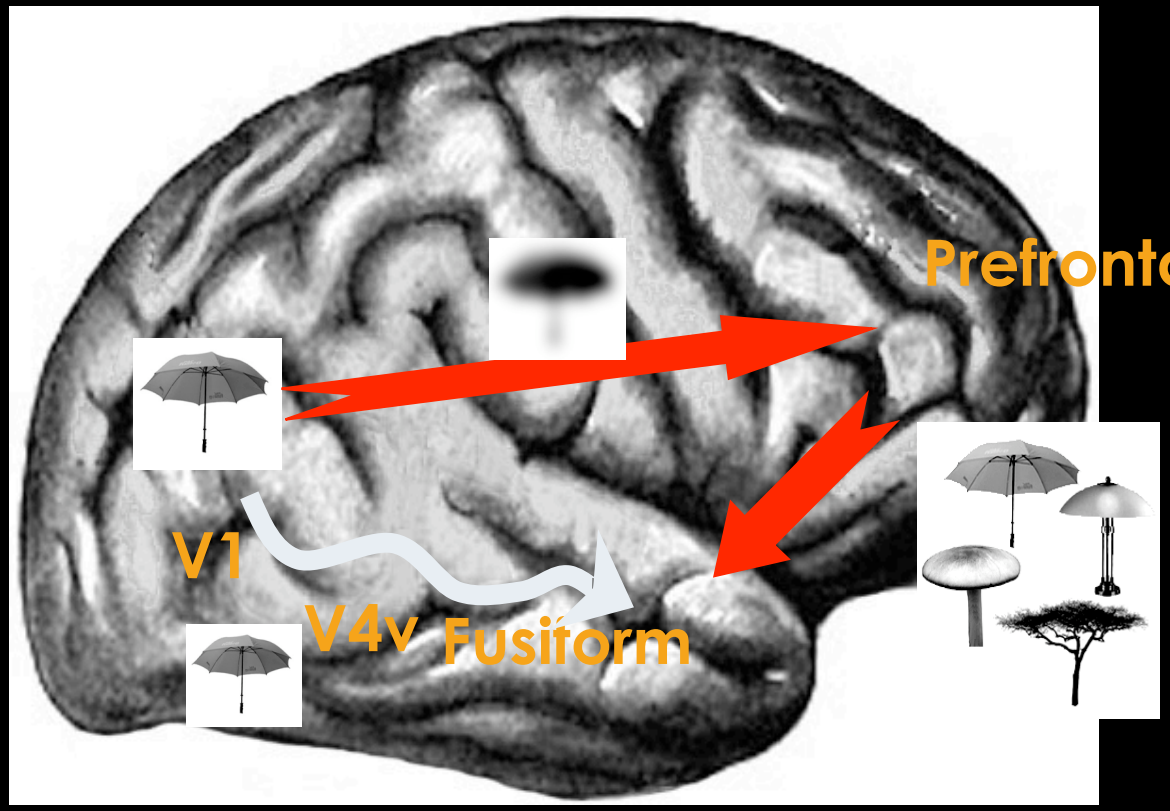
A Mechanism for Triggering Top-Down Processing in Object Recognition



Auto-predictions

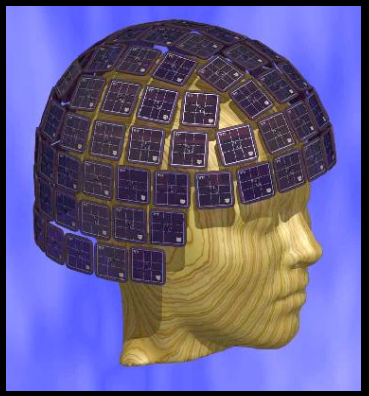
Bar, *Journal of Cognitive Neuroscience* (2003)

Key Predictions

1. ***Primacy*** - PFC activity related to object recognition develops before recognition is accomplished.

Magnetoencephalography (MEG)

NeuroMag Vectorview system



- Contains 306 sensors (2 planar gradiometers and 1 magnetometer at 102 locations)
- Measured with SQUIDs (superconducting quantum interference devices) @ –269°C
- Brain signals are ~10^{-14} T, urban noise is ~10^{-7} T

Karim Kassam

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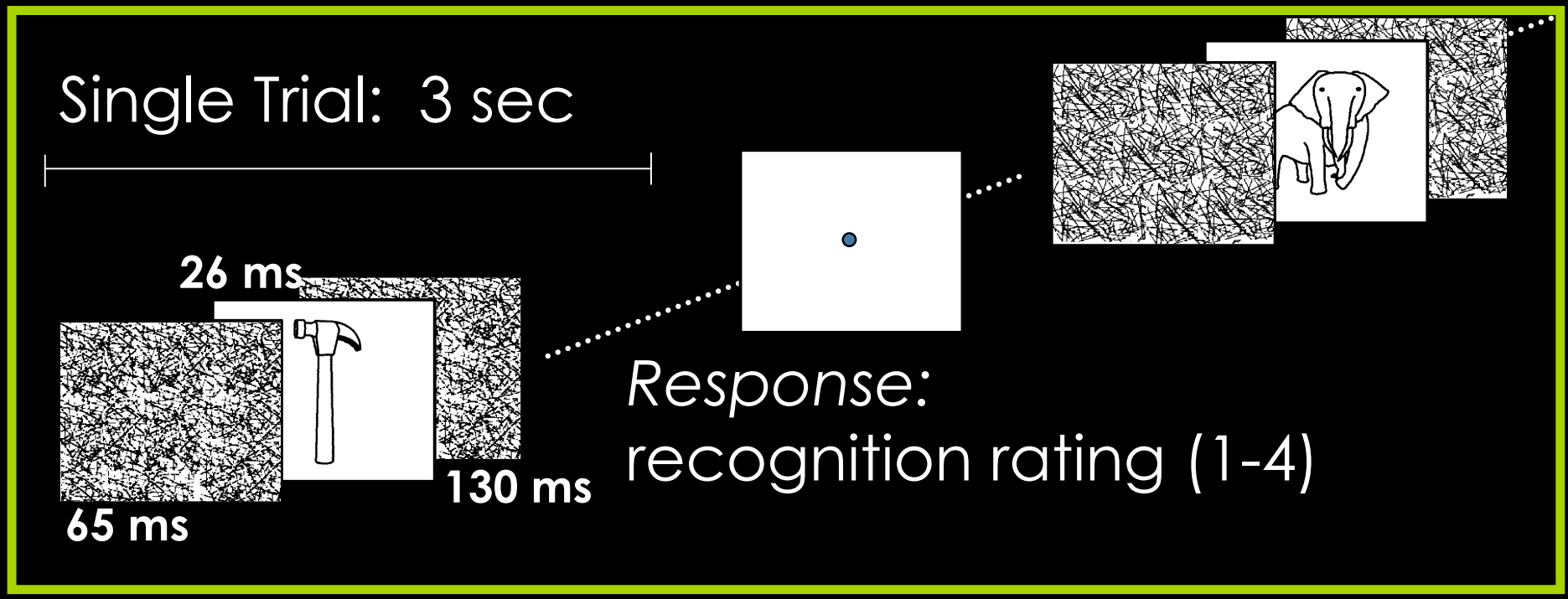
cortical mechanism specific to conscious object recognition



(Bar et al., Neuron 2001)

- Event-related design
- Five, randomly intermixed repetitions
- Subliminal Visual Priming (Bar & Biederman,1998)

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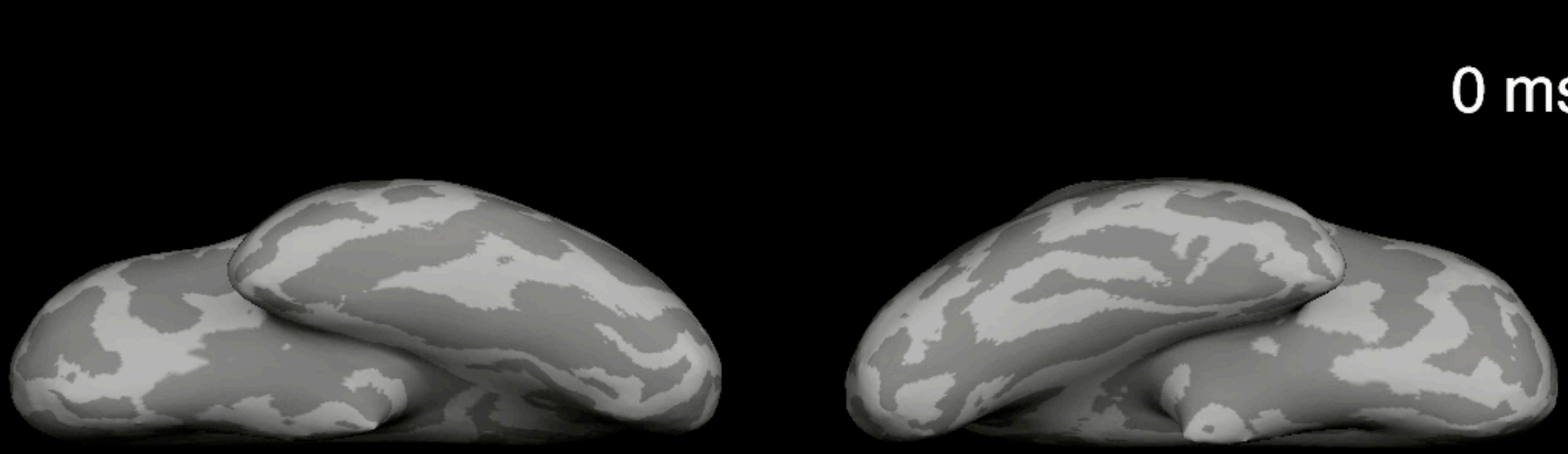
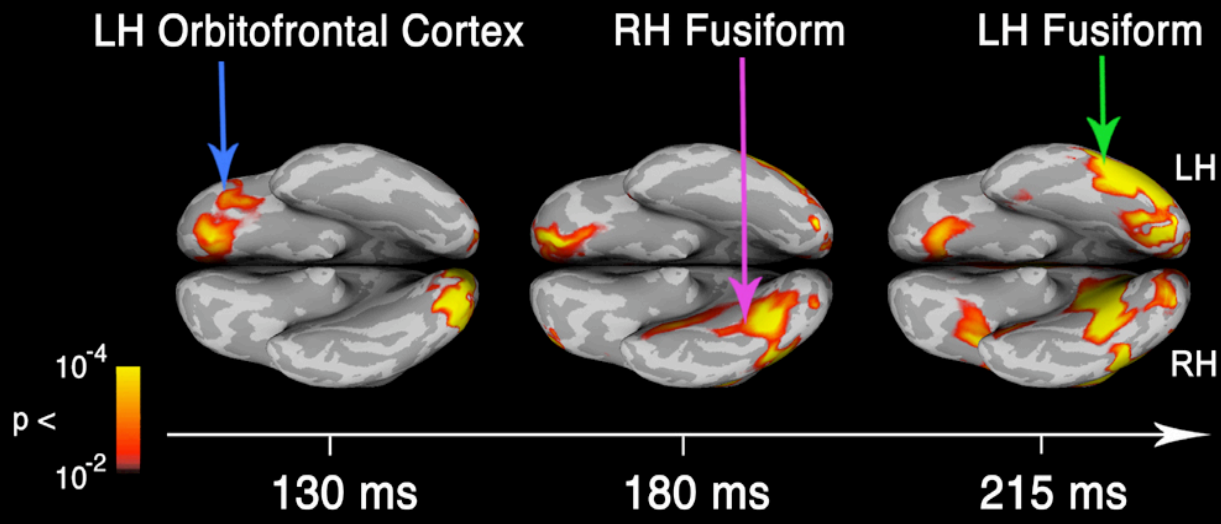
Recognized *vs.* Non-Recognized Trials

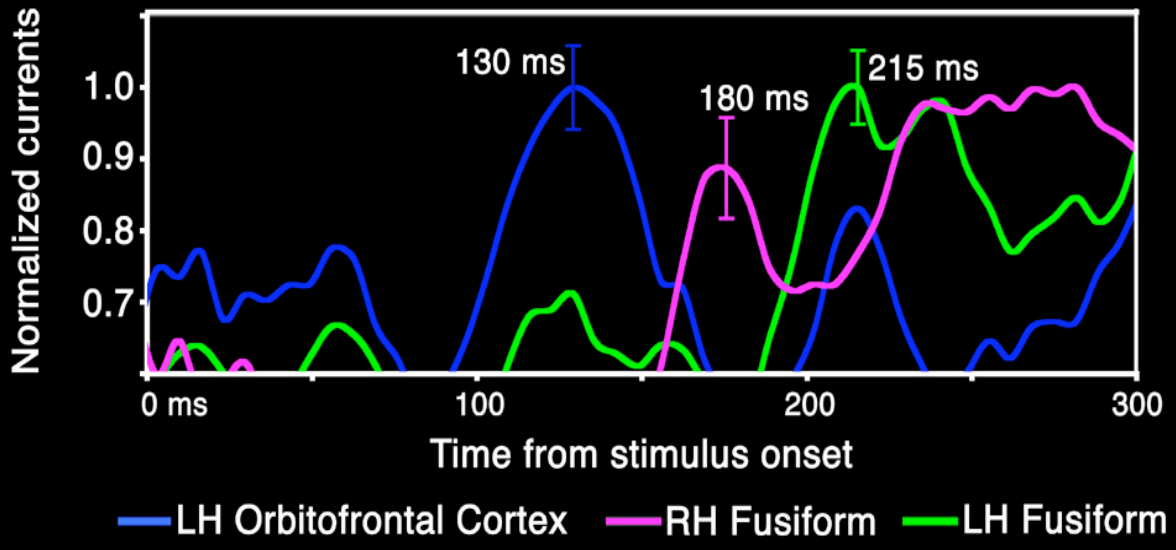


(magnetoencephalography; MEG)

(Bar et al., PNAS 2006)

Recognized vs. Non-Recognized Trials





(Bar et al., PNAS 2006)

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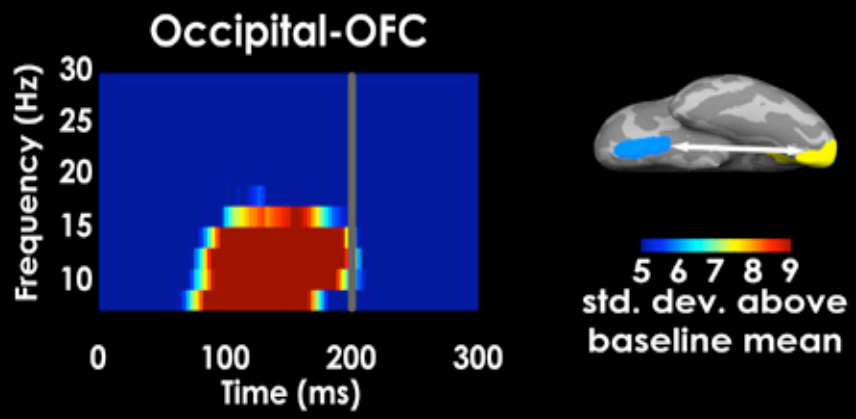
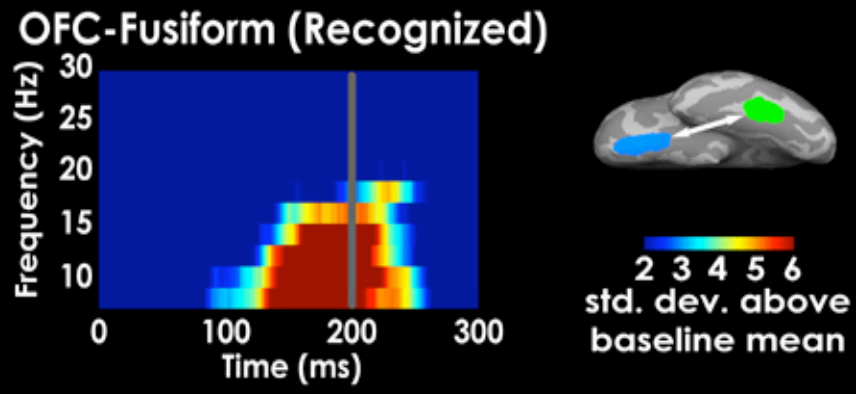
Cortical Interactions as Indicated by Phase-Locking Values

A)



B)



Avniel Ghuman

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Key Predictions

1. ***Primacy*** - PFC activity related to object recognition develops before recognition is accomplished.

2. ***Source*** - This early PFC activity is driven by low spatial frequencies in the image.

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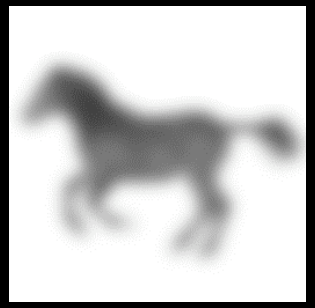
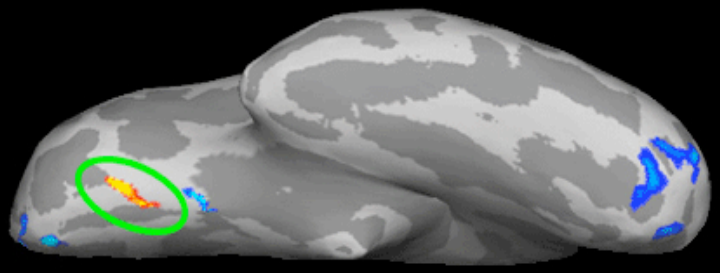
Low vs. High spatial frequencies



fMRI



MEG

110 - 140ms

⇒ OFC activity is early and driven by LSF

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Key Predictions

1. ***Primacy*** - PFC activity related to object recognition develops before recognition is accomplished.

2. ***Source*** - This early PFC activity is driven by low spatial frequencies in the image.

3. ***Content*** - Increased number of candidates results in a stronger PFC activation.

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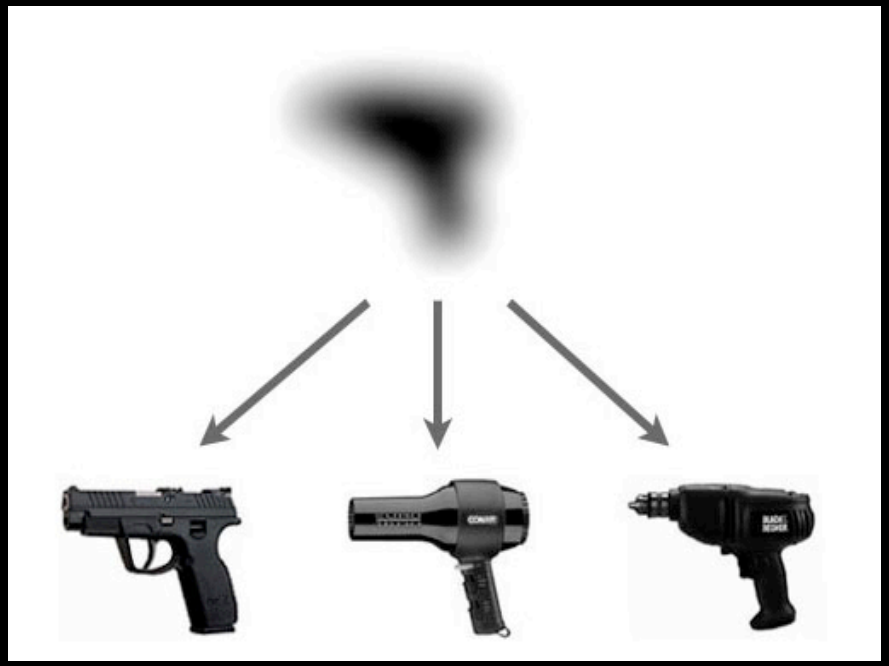
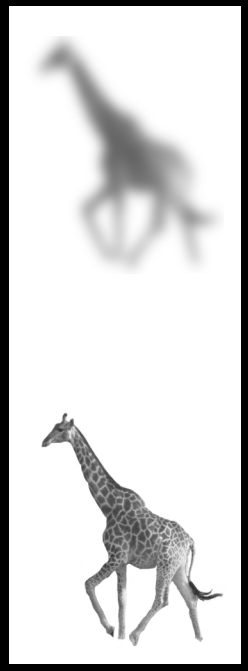
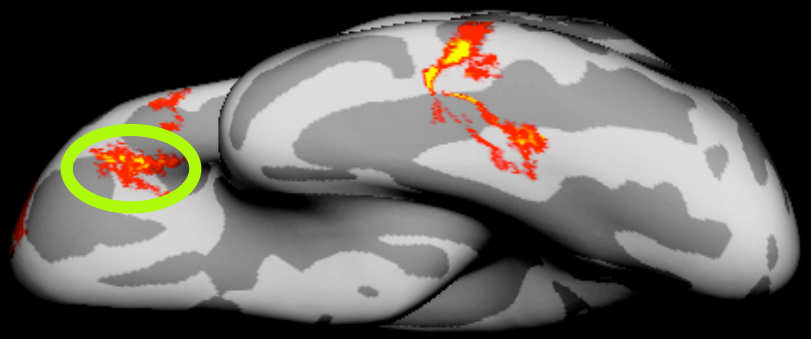
Number of candidates and OFC activation



vs.





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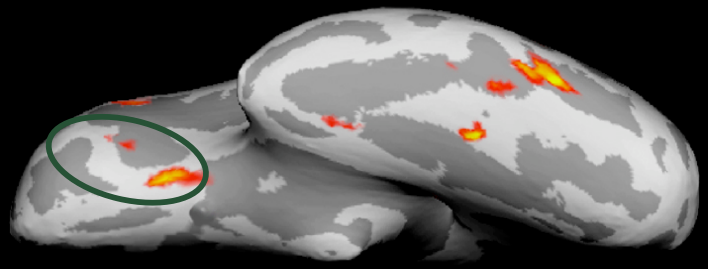
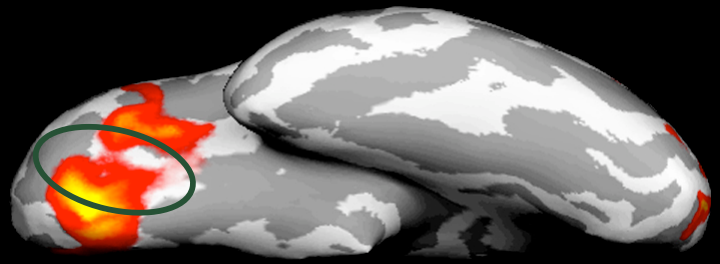
Orbitofrontal Cortex and Recognition

Masked Recognition (fMRI)



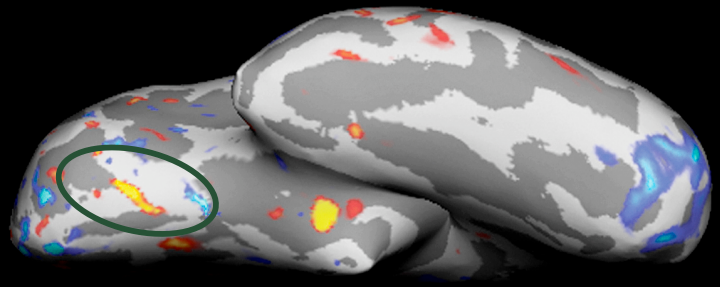
$p < 10^{-9}$ to 10^{-4}

Masked Recognition (MEG at 130 ms)



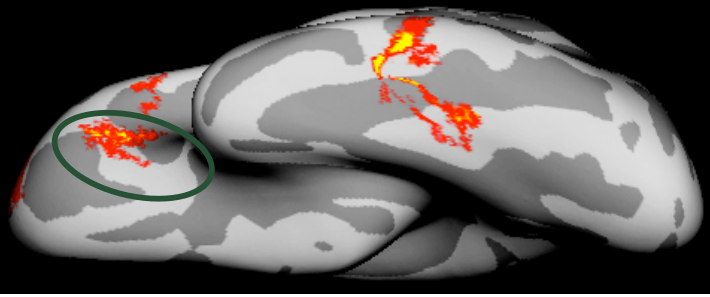
$p < 10^{-4}$ to 10^{-2}

Spatial Frequency (fMRI and MEG)



$p < 10^{-6}$ to 10^{-2}

Number of candidates (fMRI)



$p < 10^{-5}$ to 10^{-2}

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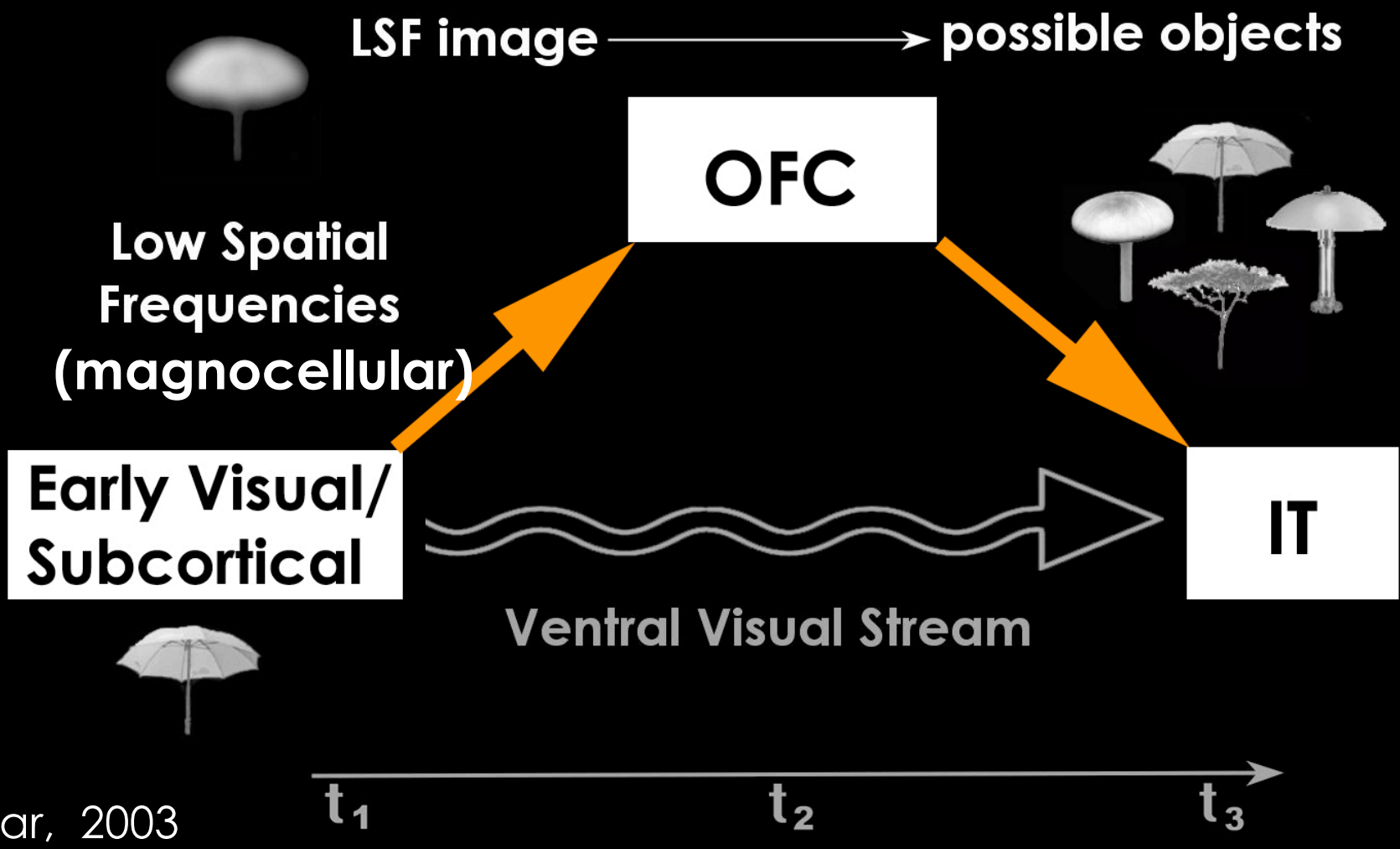
Top-down facilitation model



Bar, 2003

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Objects in our environment do not appear in isolation,
but rather in typical contexts.

How is the human brain sensitive to these contextual associations?

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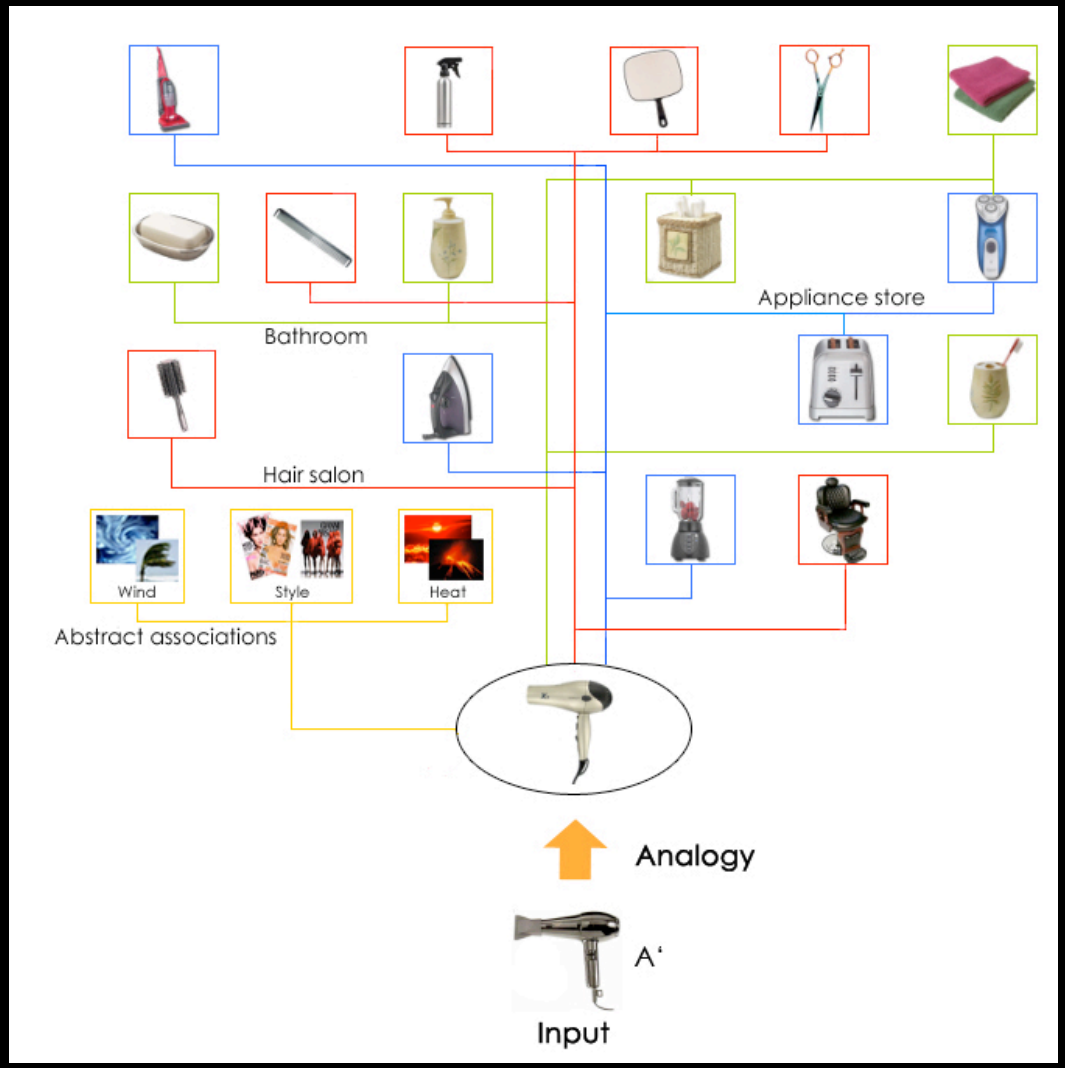
Appliance store
Bathroom
Hair salon
Wind
Style
Heat
Abstract associations
Analogy
A'
Input

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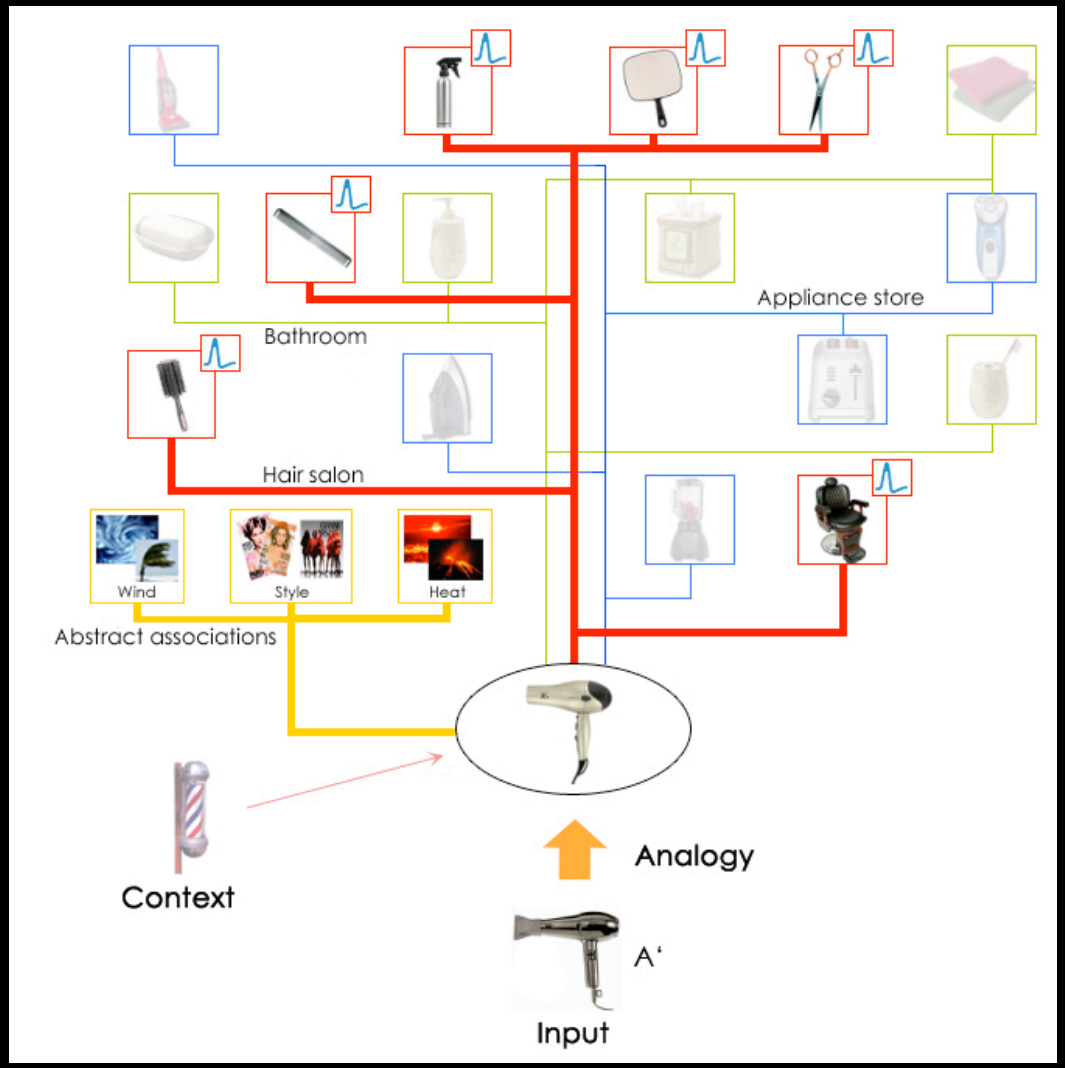

The co-activation of associated representations provides on-line, focused predictions (anticipating possibilities).

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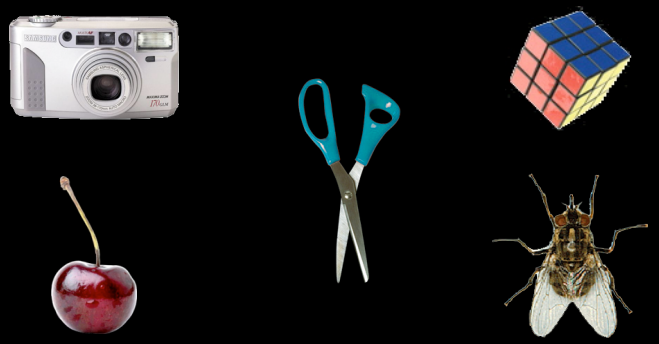
Strong Context

vs.

Weak Context



Bar and Aminoff, Neuron 2003

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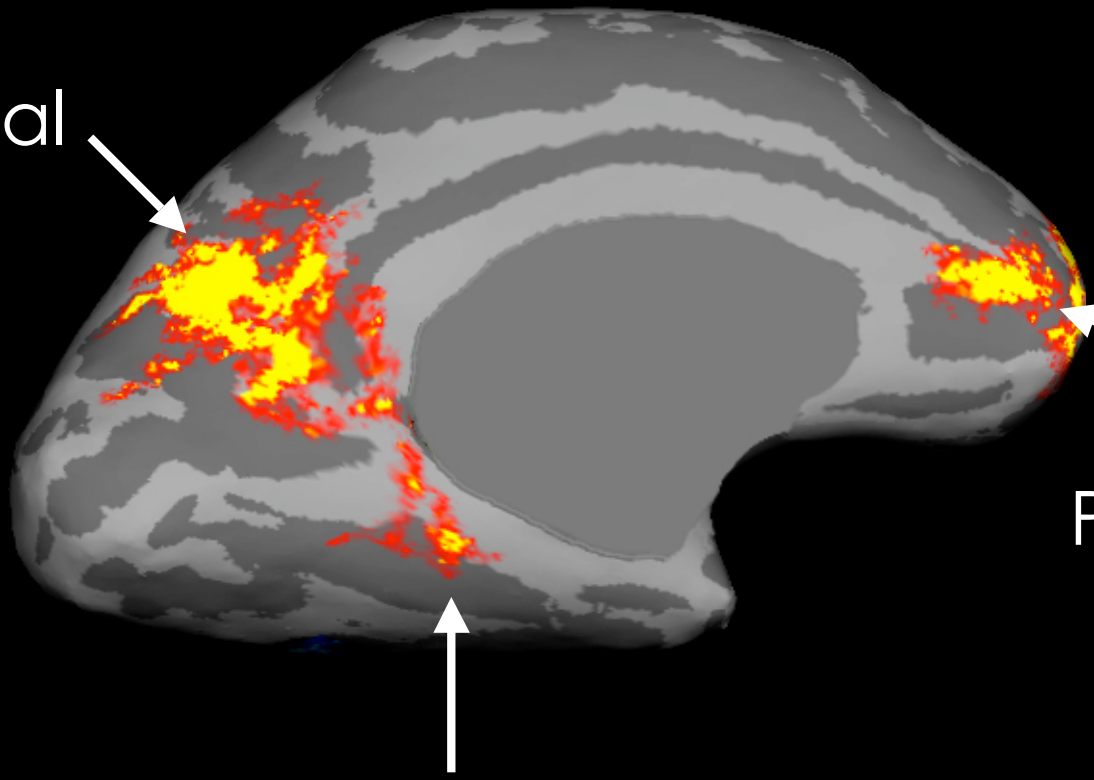
Neural network mediating contextual associative processing



Retrosplenial Complex (RSC)

Medial Prefrontal Cortex

Parahippocampal Cortex (PHC)

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- Contextual priming
- Spatial vs non-spatial context
- False-memory

Boundary Extension

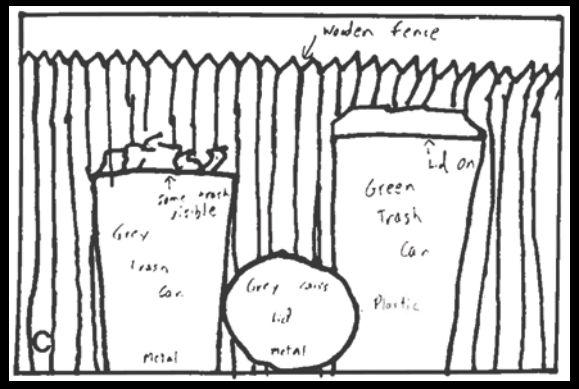
Boundary extension (BE): the tendency for remembering information that was not shown in the picture but that was likely to have existed just outside its boundaries

(Intraub et al., 1989, 1993, 1996)

Boundary Extension

Encode

Recall



Recognition: 5 pt scale
(much too close -> much too far)

"same"

"too close"

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Boundary Extension

Mental Schema

Facilitates the perception of a continuous visual environment

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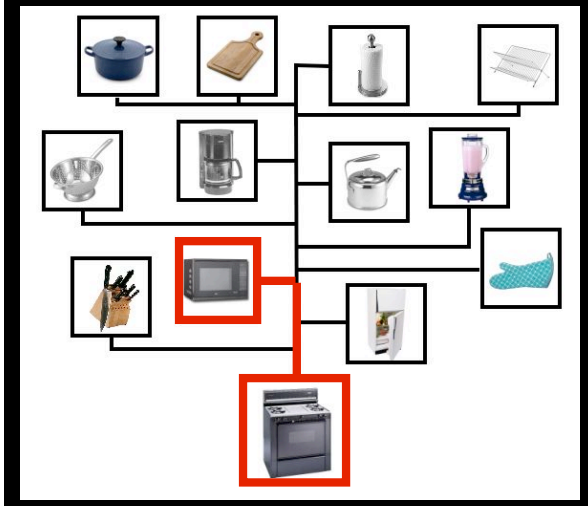
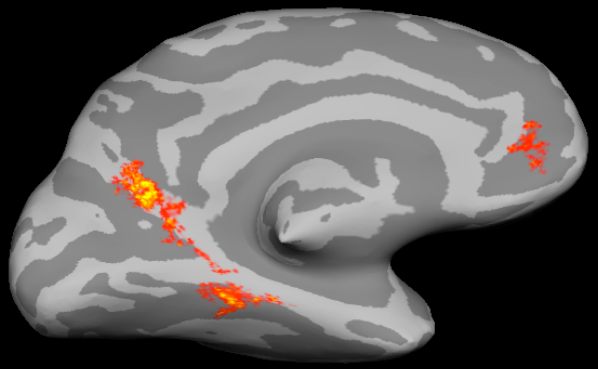
Can contextual processing lead to false recognition?





Contextual priming
And… false memory

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fMRI Analysis: Context based false recognition

Encoding (fMRI)

Test: using words
(1 day later)

Response
"Old" "New"

Strong Context

New-Related
crib

False Alarm

Correct Rejection

Region of Interest
N=16

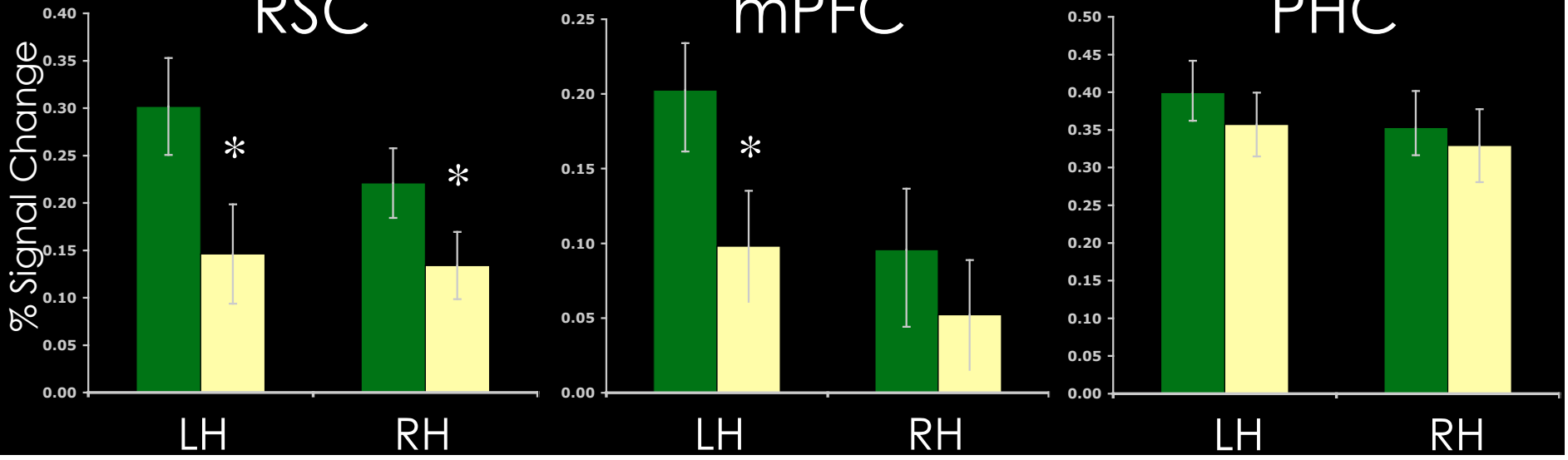
Subsequent False Alarm

Subsequent Correct Rejection

RSC

mPFC

PHC



Predictions in recognition
using associative *Context Frames*

Capture environmental regularities learned with experience (identities and relations).

Activated rapidly by preliminary information in the image (e.g., "key" objects, global features).

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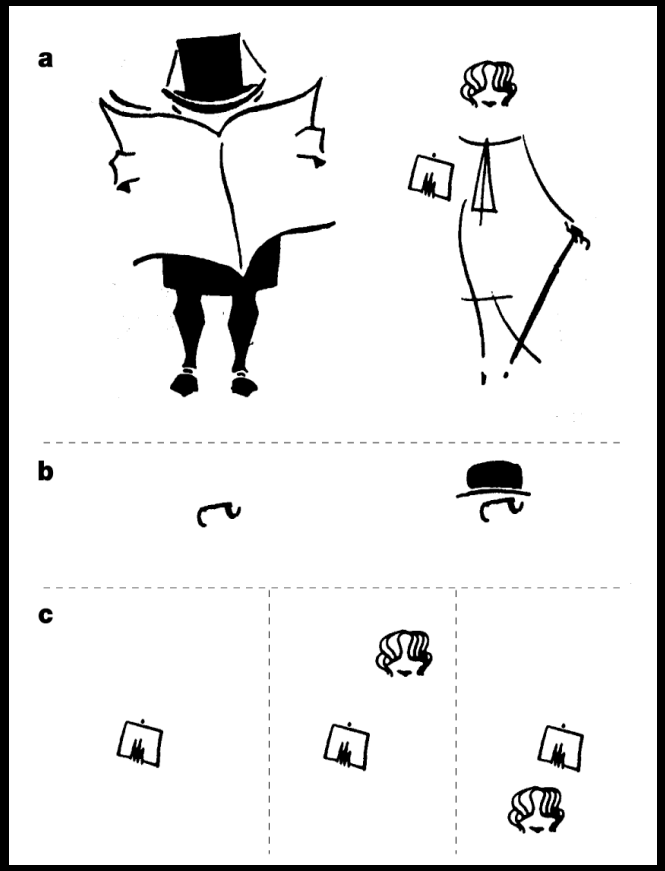

Bar and Ullman, 1996

Minimizing the search: Deciding "what is this like" based on very little

Oliva
Torralba

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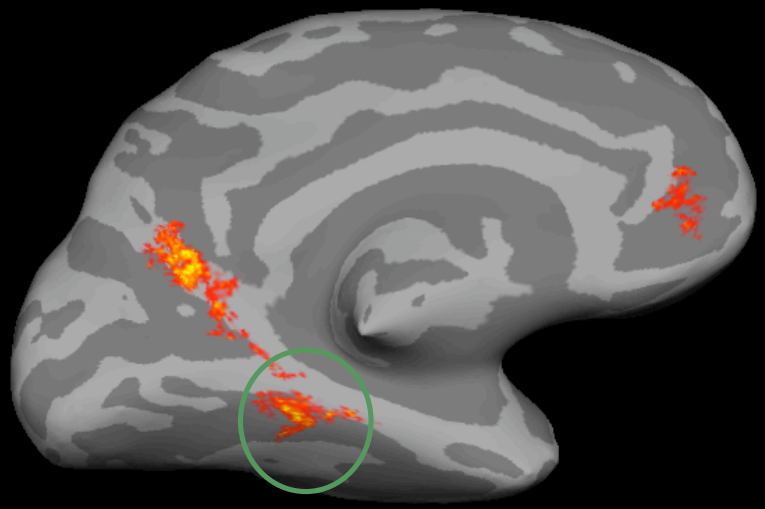
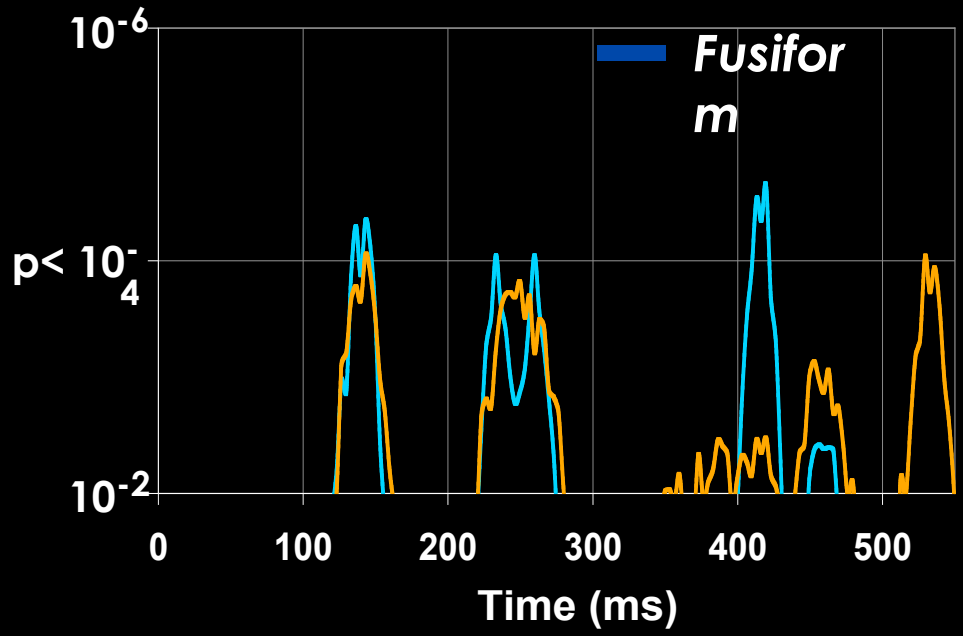
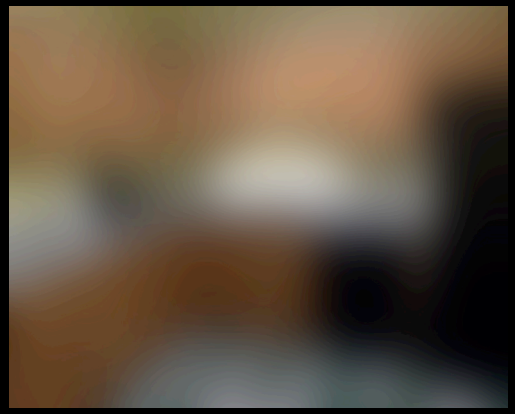
Strong Context vs. Weak Context

***fMRI* Map**



***MEG* ROI**





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Predictions in recognition

Associative *Context Frames*

Capture environmental regularities learned with experience (identities and relations).

Activated rapidly by preliminary information in the image (e.g., "key" objects, global features).

Facilitate object recognition by generating predictions.

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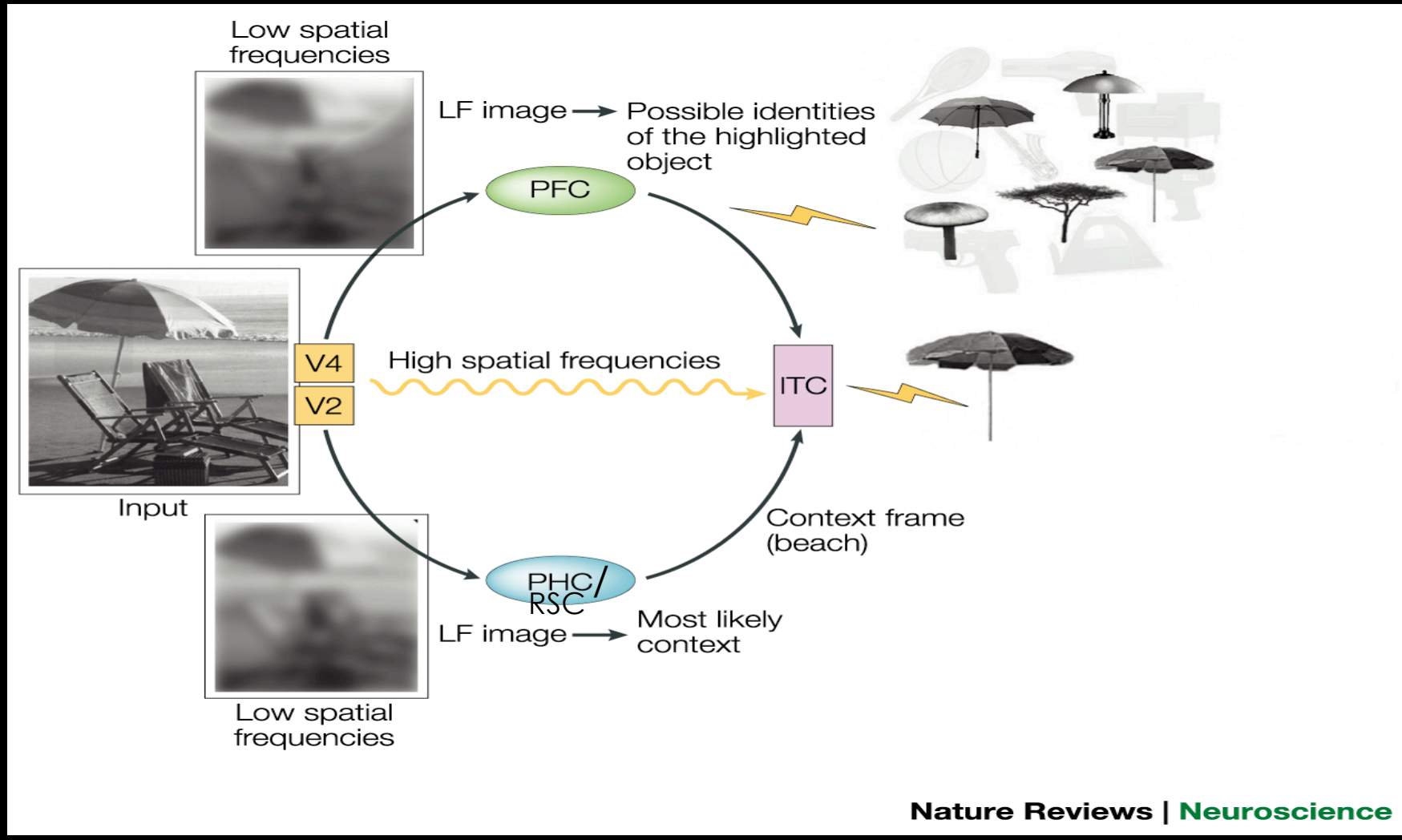
Low spatial frequencies
LF image
Possible identities of the highlighted object
PFC
V4
V2
High spatial frequencies
ITC
Input
Context frame (beach)
PHC/ RSC
LF image
Most likely context
Low spatial frequencies
Nature Reviews | Neuroscience

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Recognition of sensory input is mediated by rapid predictions that are derived from early, rudimentary information.

These predictions rely on existing associations

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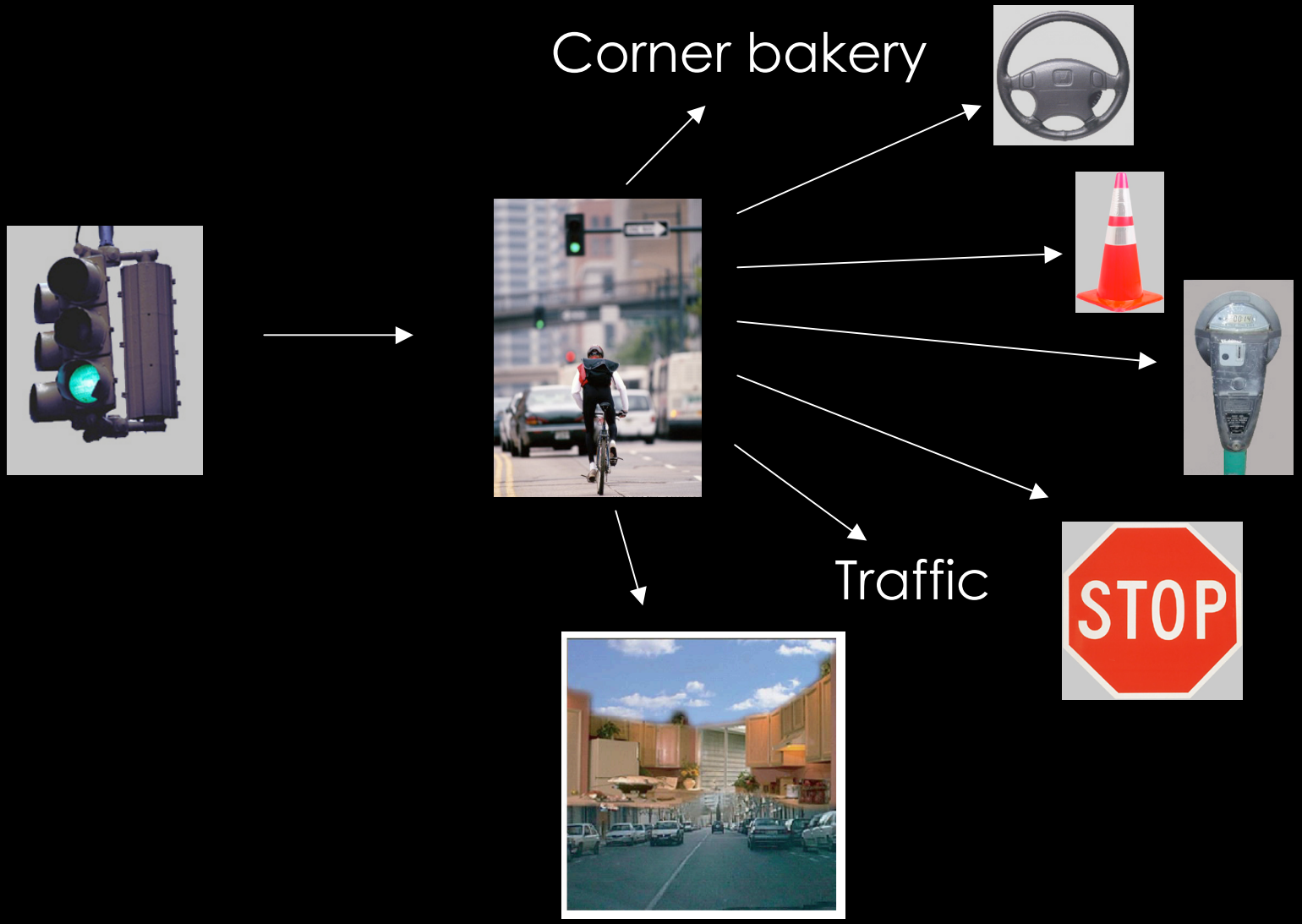
Associations as the building blocks of predictions



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Associations as the building blocks of predictions

Facilitate encoding and retrieval

and

Mediate the continuous activation of predictions

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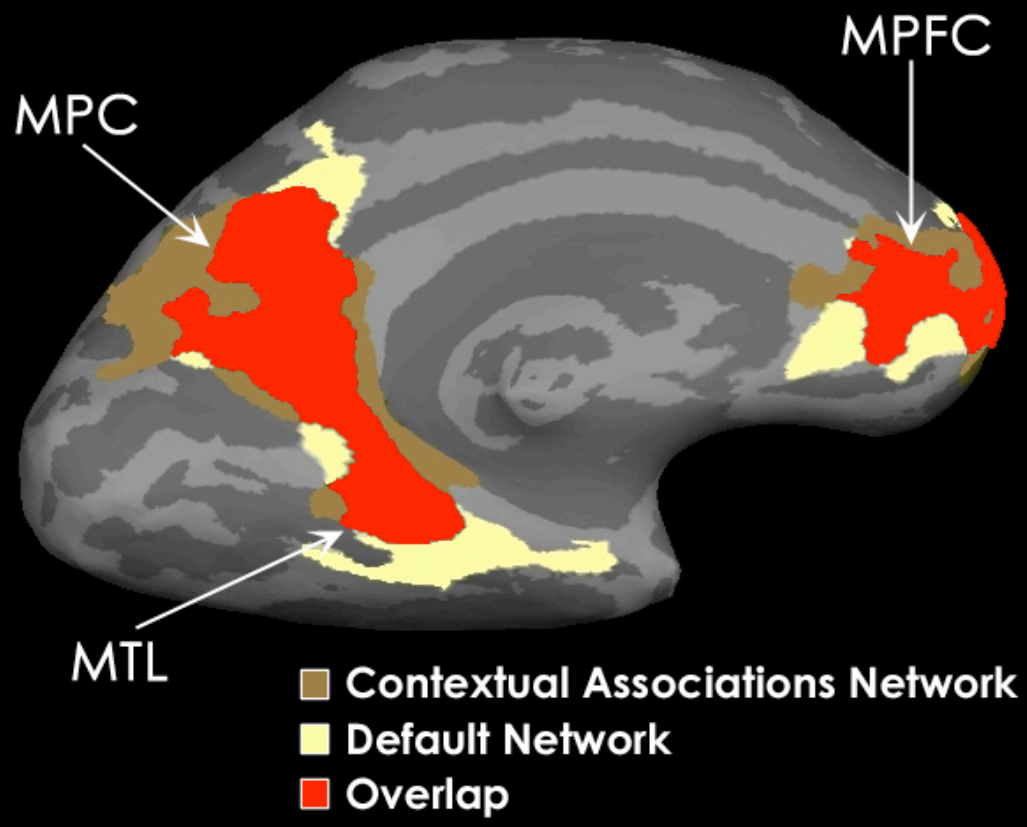
context-default overlap



Bar et al., Hippocampus, 2007

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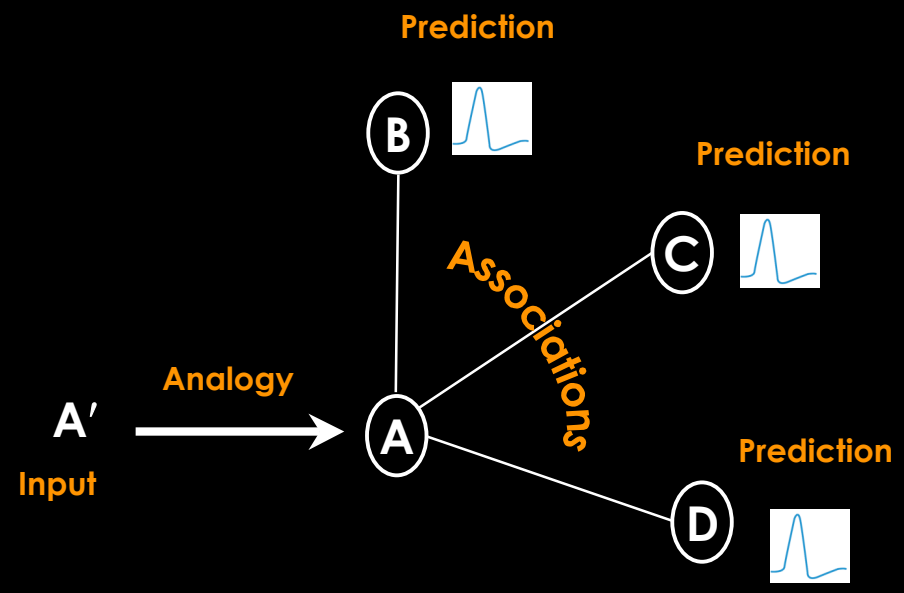
⇒ Associative activation is an integral process of default activity

Predictions are triggered by analogies

Analogy is typically seen as a sophisticated cognitive tool used in types of problem-solving and reasoning.



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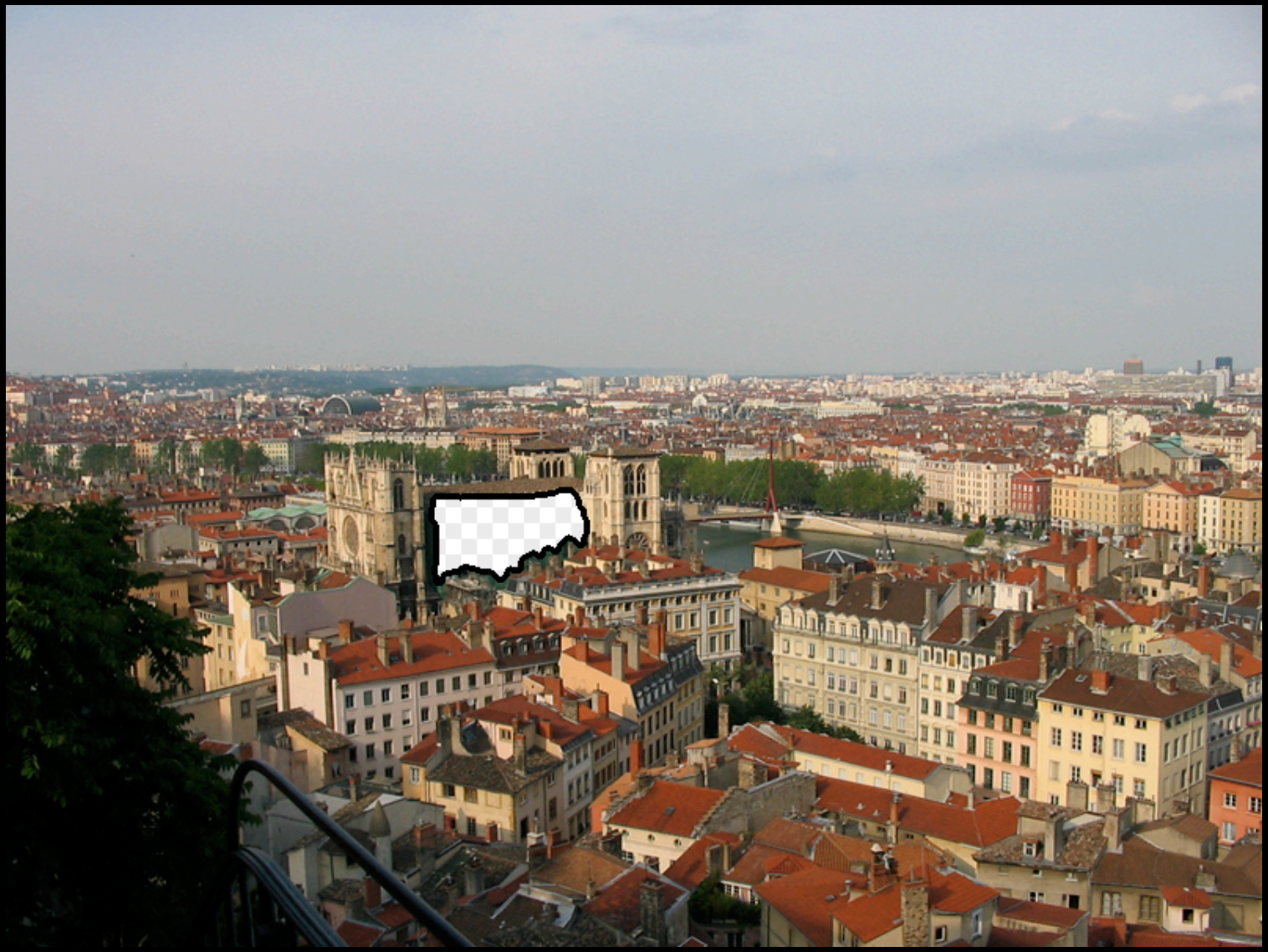
Hays and Efros, SIGGRAPH 2007



Hays and Efros, SIGGRAPH 2007


Hays and Efros, SIGGRAPH 2007

Hays and Efros, SIGGRAPH 2007

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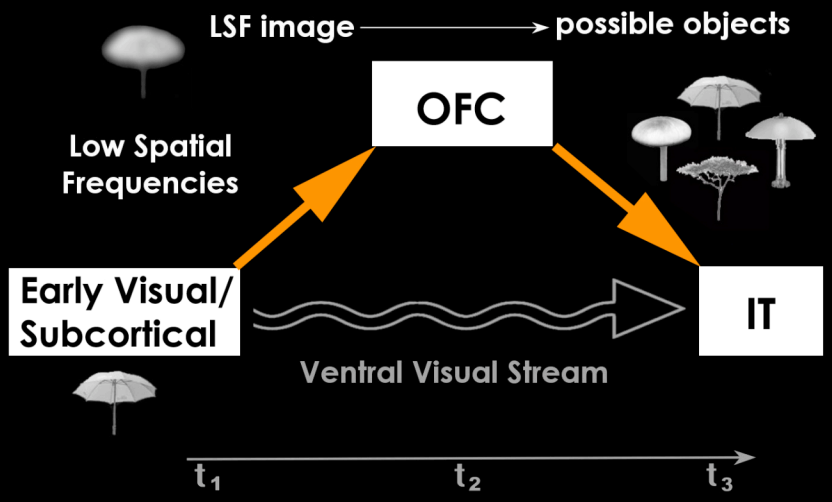
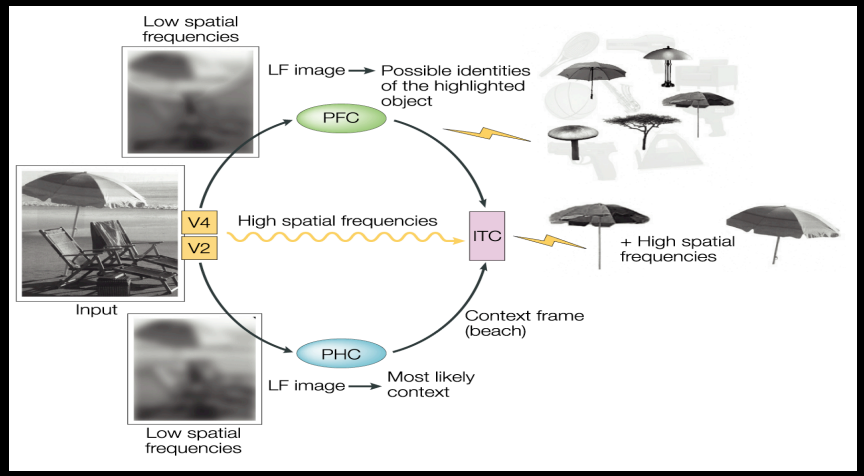
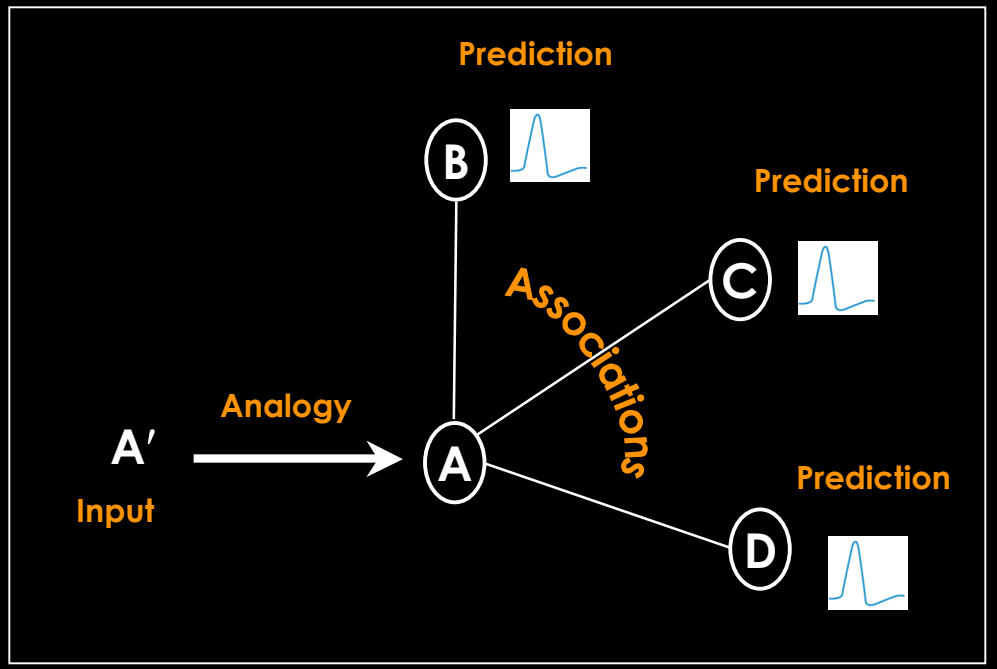

LSF image
possible objects
OFC
Low Spatial Frequencies
Early Visual/ Subcortical
IT
Ventral Visual Stream
t1
t2
t3


Low spatial frequencies
LF image
Possible identities of the highlighted object
PFC
V4
V2
High spatial frequencies
ITC
+ High spatial frequencies
Input
Context frame (beach)
PHC
LF image
Most likely context
Low spatial frequencies


Prediction
B
Prediction
C
Associations
Analogy
A′
Input
A
Prediction
D

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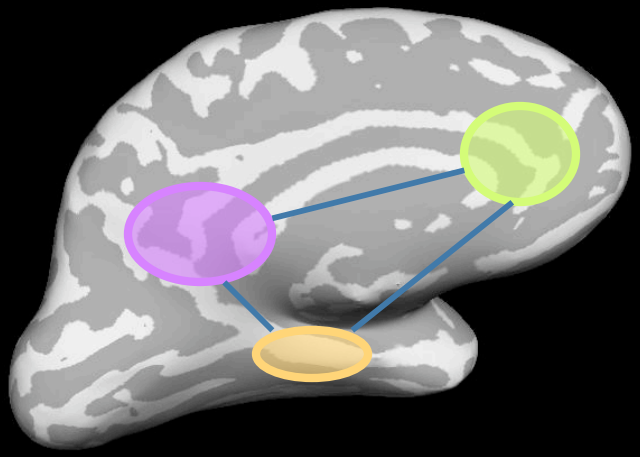
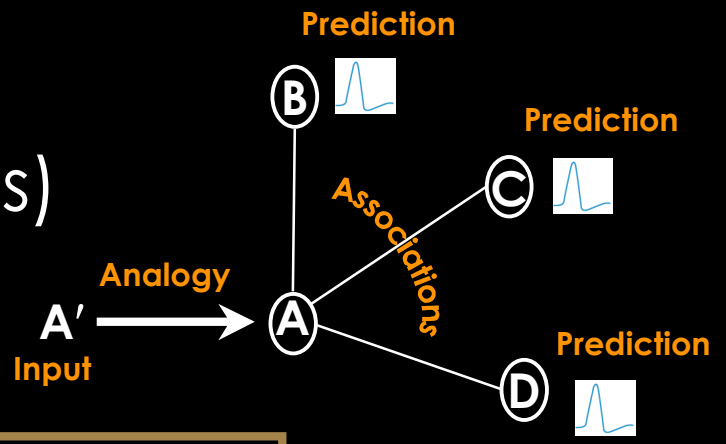
Possible neural underpinnings

- Correspondence (**analogies** input from sensory or from internal thought processes)
- **Associations** in memory (context frames)
- **Predictions** (offer possibilities)





A foresight network?

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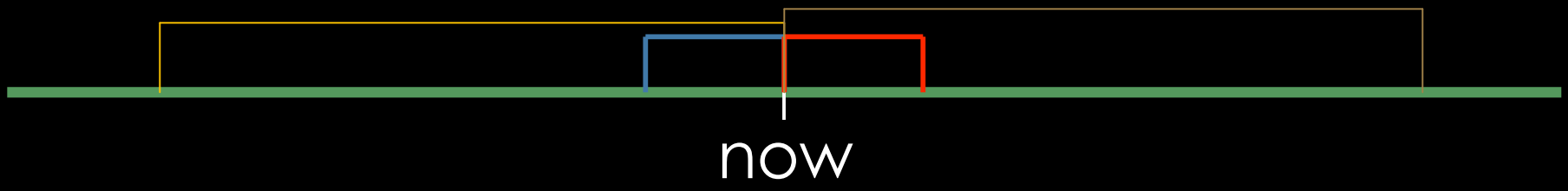

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Conclusions

- the brain is proactive in generating predictions (combining past and present to anticipate future possibilities)

- Interpretation, via analogies, is meant to answer "what is this like?"

- Associations play a central role in foresight

- The information stored in our memory exerts its contribution to behavior by way of predictions.

- Our perception of the environment relies on exiting knowledge as much as it does on incoming information.

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http://barlab.mgh.harvard.edu

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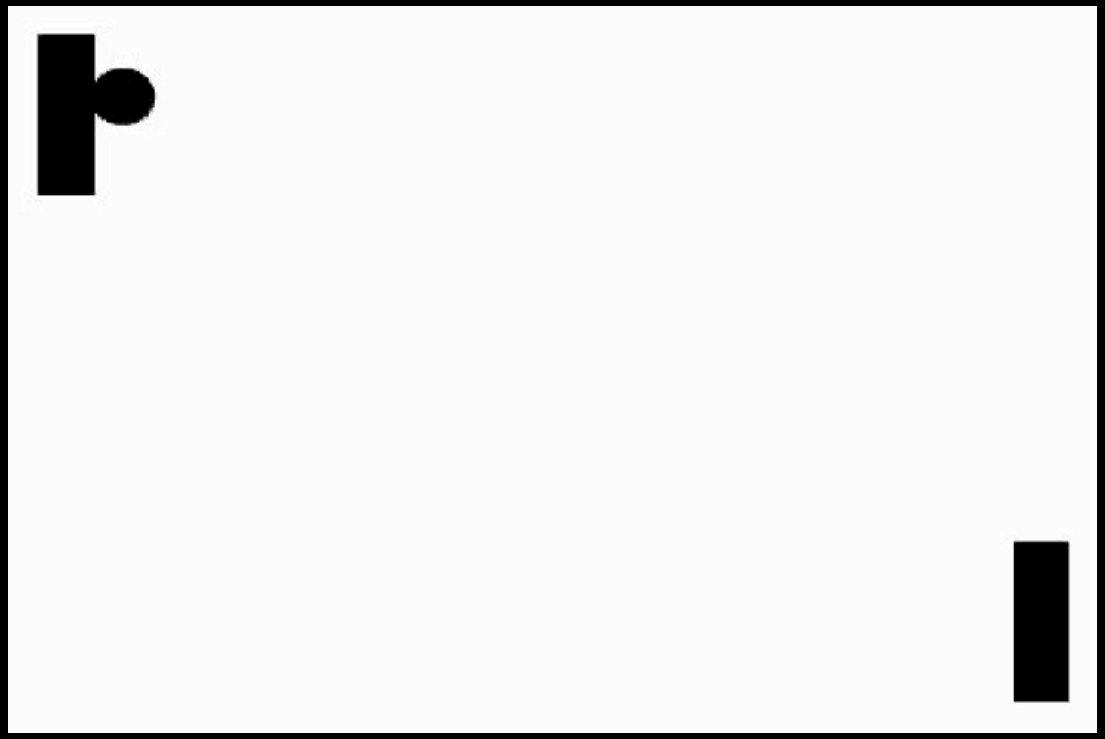
A moment encompasses memory and foresight



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