9.71 Functional MRI of High-Level Vision
Fall 2007

9.71 Lecture 3 Sept 20
The Problem of Object Recognition
and The Lateral Occipital Complex (LOC)

Outline for Today

I. Demo of an fMRI scan
II. Lecture: The Problem of Object Recognition:
    1. Why study it, what is entailed computationally
    2. The Lateral Occipital Complex (LOC)
        What does LOC do?
        What does LOC representation?
III. A few tips on doing presentations.
IV. If time: Discussion of B&Z]

Why Study Object Recognition?

OR is an important problem:

- Critical for survival
- We are very good at it
- A distinct domain of cognition

Object Recognition: A Distinct Domain of Cognition

Visual Agnosia: specific deficit in visual object recognition
without impaired visual acuity
without impaired object recognition by touch, sound, smell

The fact that visual OR can be selectively lost in brain damage implies
that it is a distinct domain of cognition,
with its own special neural hardware,
distinct from low-level visual processing,
and from knowledge of the meanings and names of objects.

(different kinds of agnosias can give us further dissociations…)

An example….

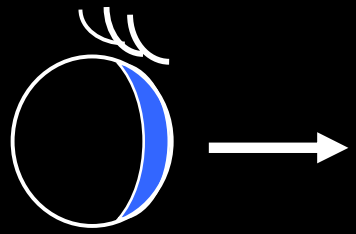
What does object recognition entail exactly, and what is to be explained?

Object Recognition as *Matching to Memory*

World/
Visual field

Photo courtesy
of Nick Devenish.

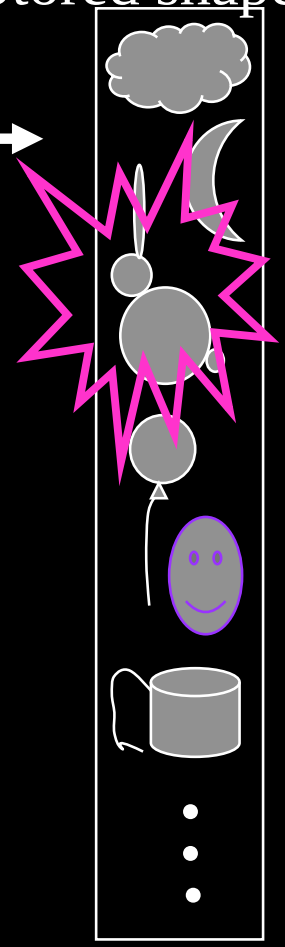
Eye/
Retinal image



Object Recognition.

Matching

Visual LTM:
thousands of
Stored shapes



A Theory of Object Recognition Would have to Specify:

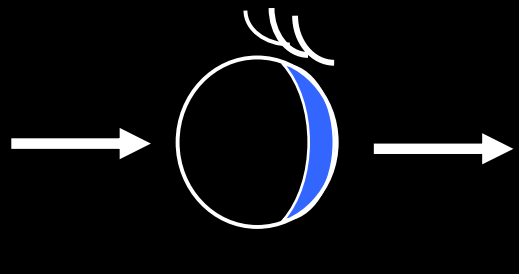
World/
Visual field

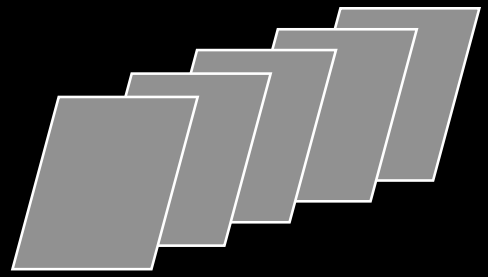
Eye/
Retinal image

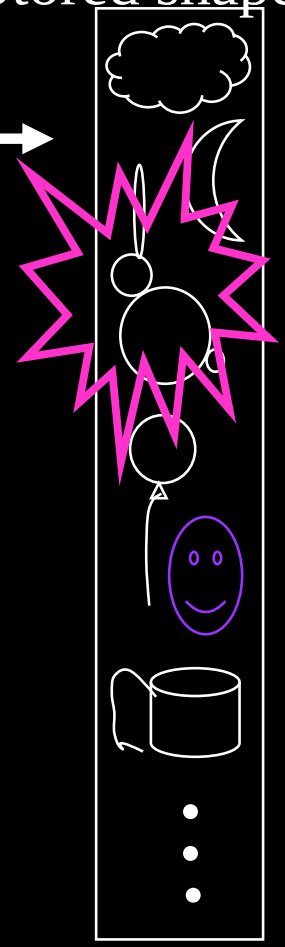
Visual Recognition

Visual LTM:
thousands of
Stored shapes

Photo courtesy
of Nick Devenish.







a. the nature of the stored visual representations in LTM

b. the nature of the intermediate representations

c. a computational account of how each intermediate representation can be derived from the previous one

d. a determination of whether the answers to a-d are different for different kinds of objects

Kinds of Cues Available for Visual Object Recognition

a. Characteristic motion (e.g. a fly).

b. Color/texture (e.g., lawn, ocean, beach)

c. Stored knowledge plus minimal cues (e.g. I left newspaper on dining table, that's what that blob must be).

d. The most important cue: SHAPE!
(which is the primary focus of most theories of object recognition)

What Makes Object Recognition (by Shape) Hard?

World/
Visual field

Eye/
Retinal image

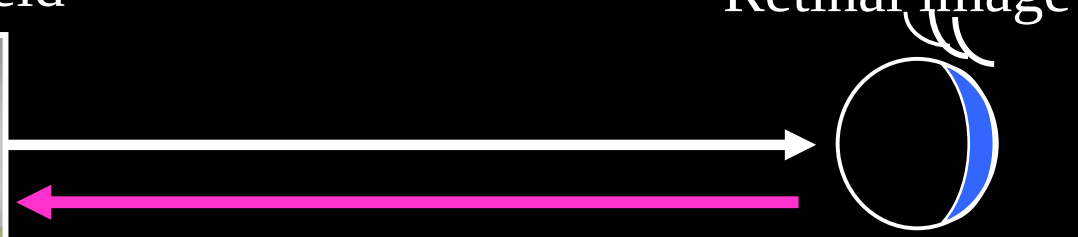
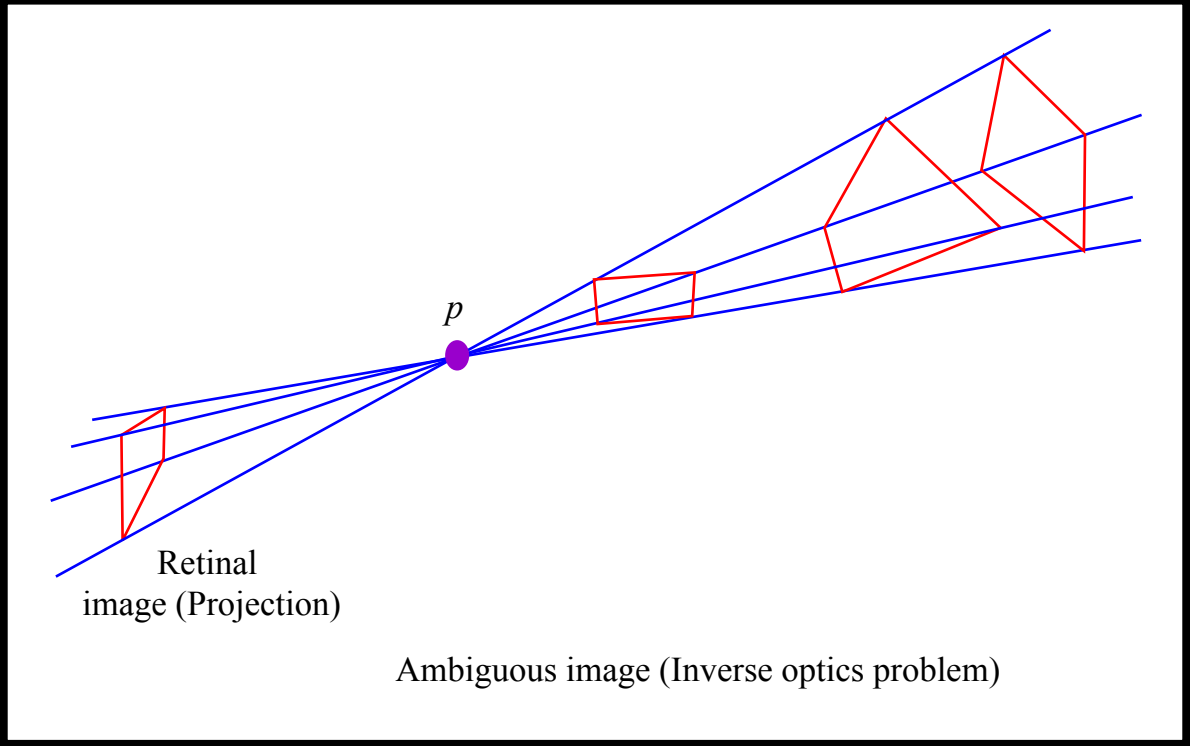


Photo courtesy of Nick Devenish.

Inverse optics problem



1. A single image can be cast by many different 3D objects

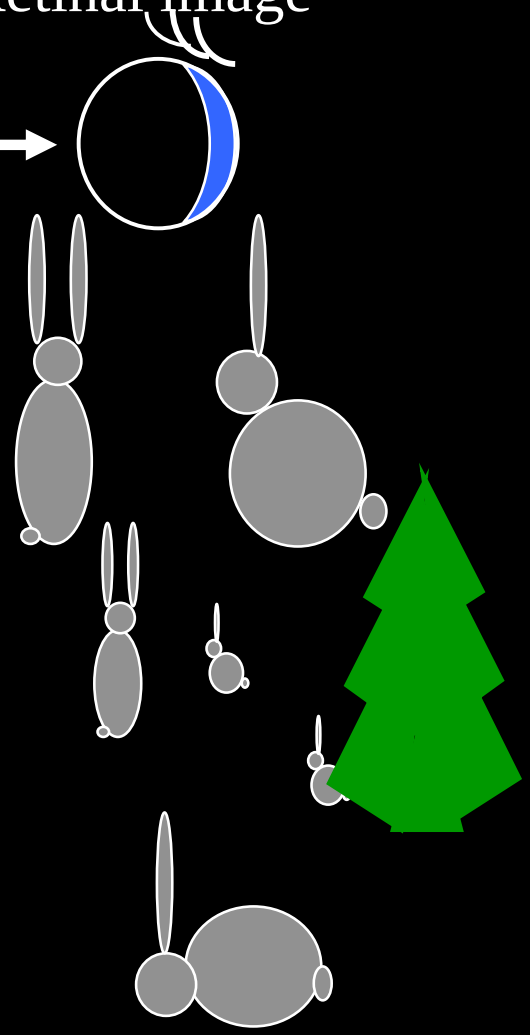
Figure by MIT OpenCourseWare.

What Makes Object Recognition Hard?

World/
Visual field

Photo courtesy
of Nick Devenish.

Eye/
Retinal image



2. A single Object can cast many Different retinal images that differ in….

Viewpoint

Distance/size

Occlusion

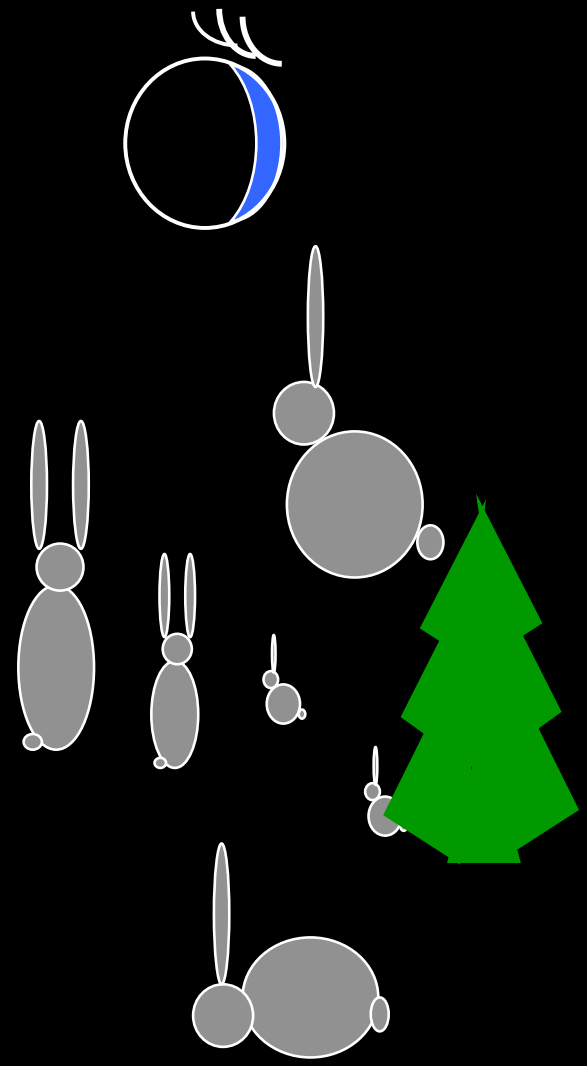
Configuration

Lighting, etc….

1. A single image can be cast by many different 3D objects ….

The Problem of Object Recognition

Given a Retinal Image such As this:



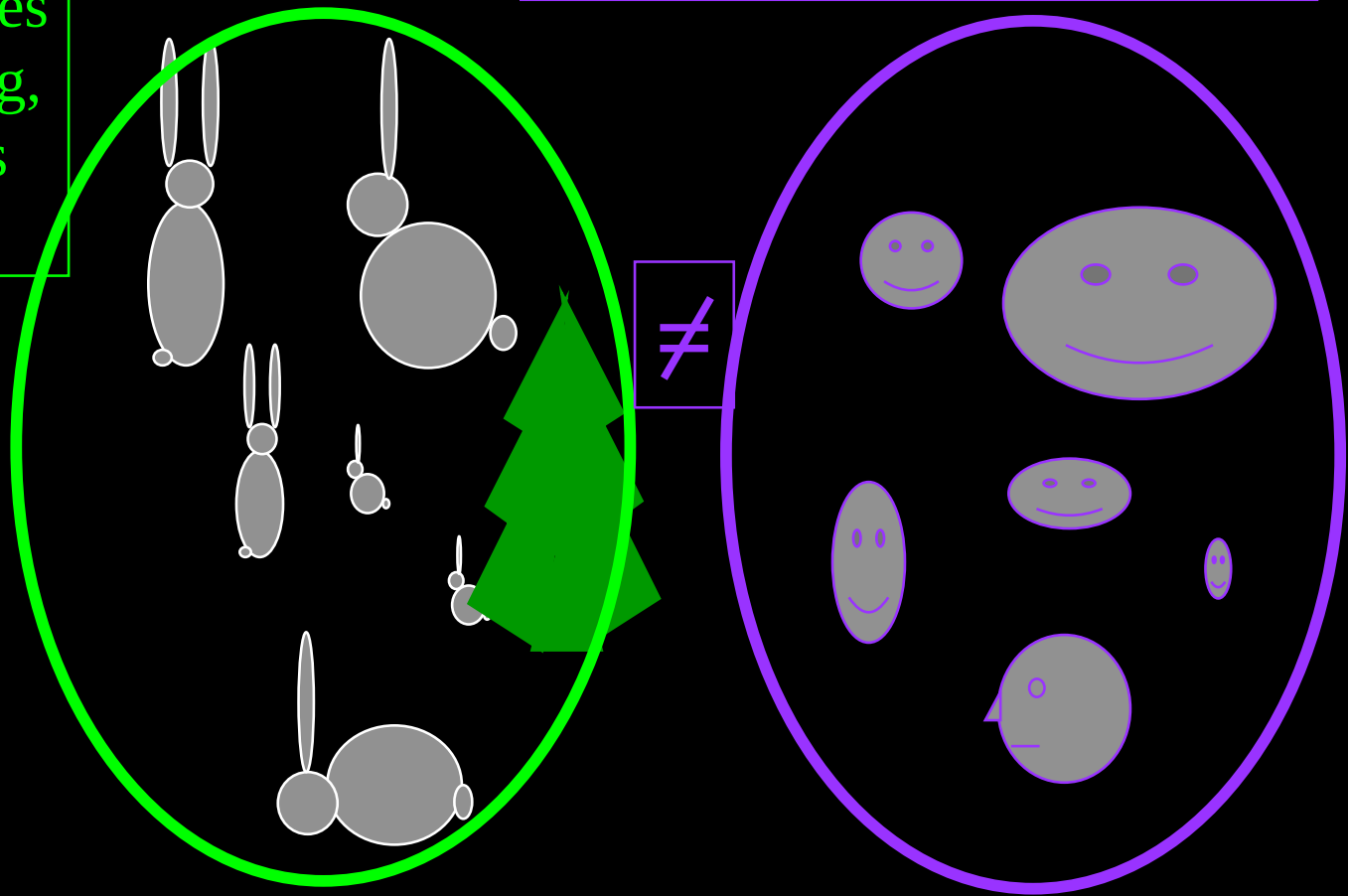
What is it?

Two main Challenges:

Specificity:
Appreciating the distinction between different categories.

Invariance/Tolerance:
Generalizing across changes in size, orientation, lighting, etc. to realize these images are all of the same thing:

Photo courtesy of Nick Devenish.



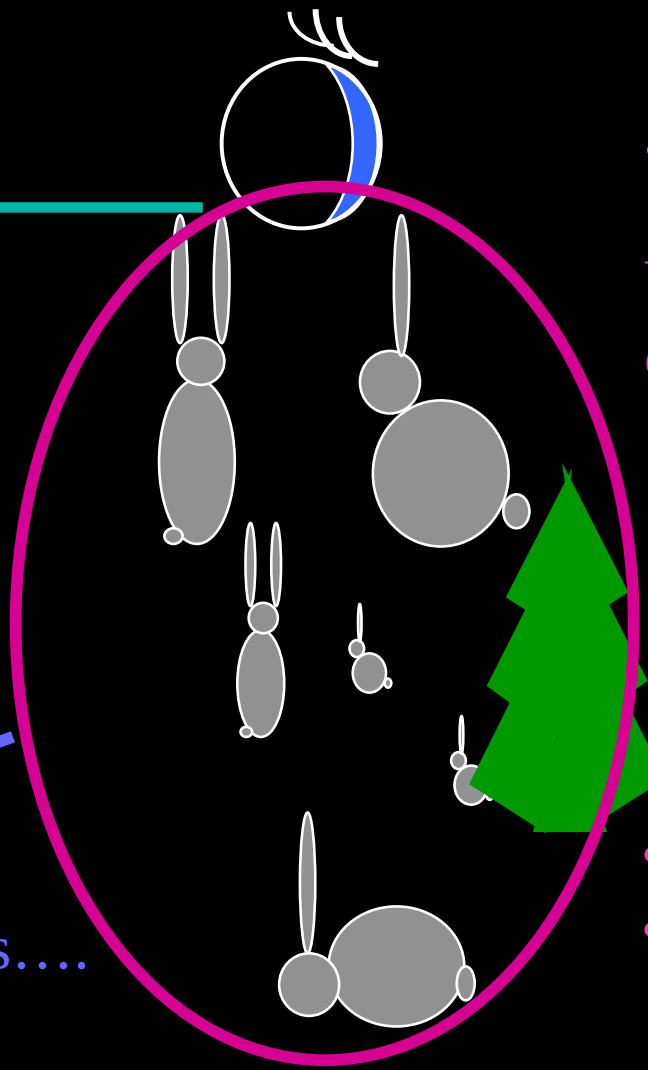
How do we solve this problem?
Options:

Photo courtesy of Nick Devenish.

1. Inverse Optics: Extract an abstract representation of 3D shape "invariant" to these image changes.

• an "ill-posed" problem.

3. Other intermediate descriptors
e.g. image fragments, parts….



2. Association: Store each possible Version of an object. Brute force.

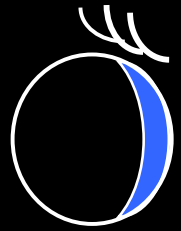
• That's a lot to store!
• What about novel views?
• Alignment

A Theory of Object Recognition Would have to Specify:

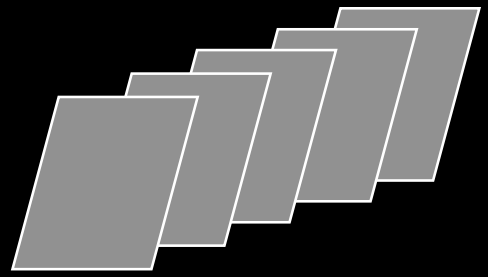
World/
Visual field

Photo courtesy of Nick Devenish.

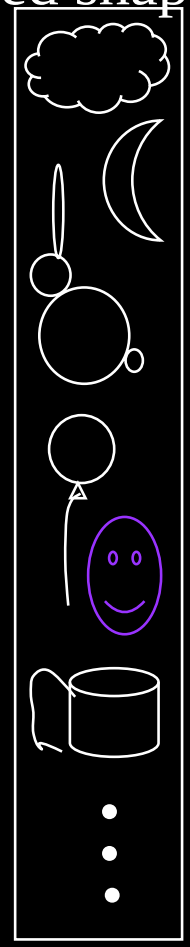
Eye/
Retinal image



Visual Recognition



Visual LTM:
thousands of
Stored shapes



How can brain imaging help?

a. the nature of the stored visual representations in LTM

b. the nature of the intermediate representations

c. a computational account of how each intermediate representation can be derived from the previous one

d. a determination of whether the answers to a-d are different for different kinds of objects

A Theory of Object Recognition Would have to Specify:

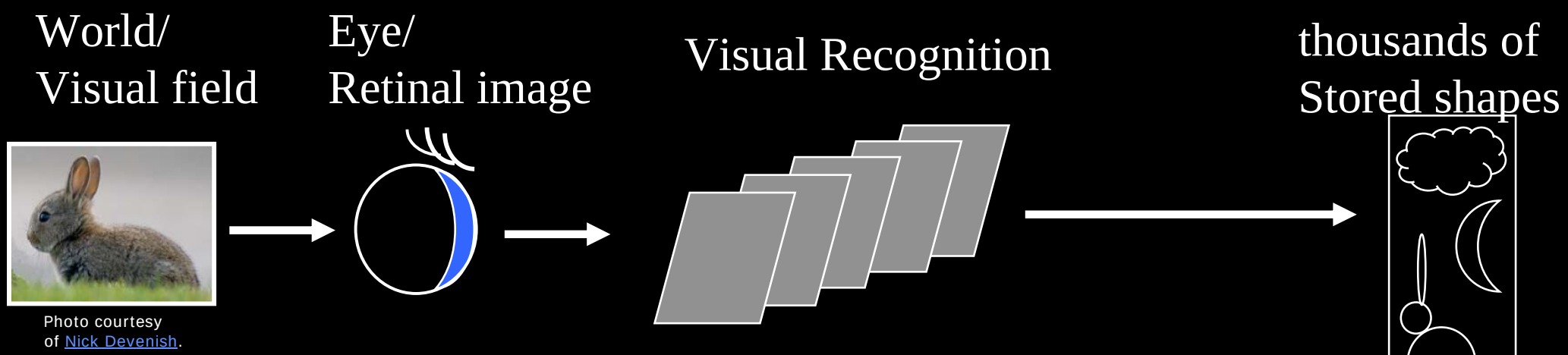


Photo courtesy of Nick Devenish.

How can brain imaging help?

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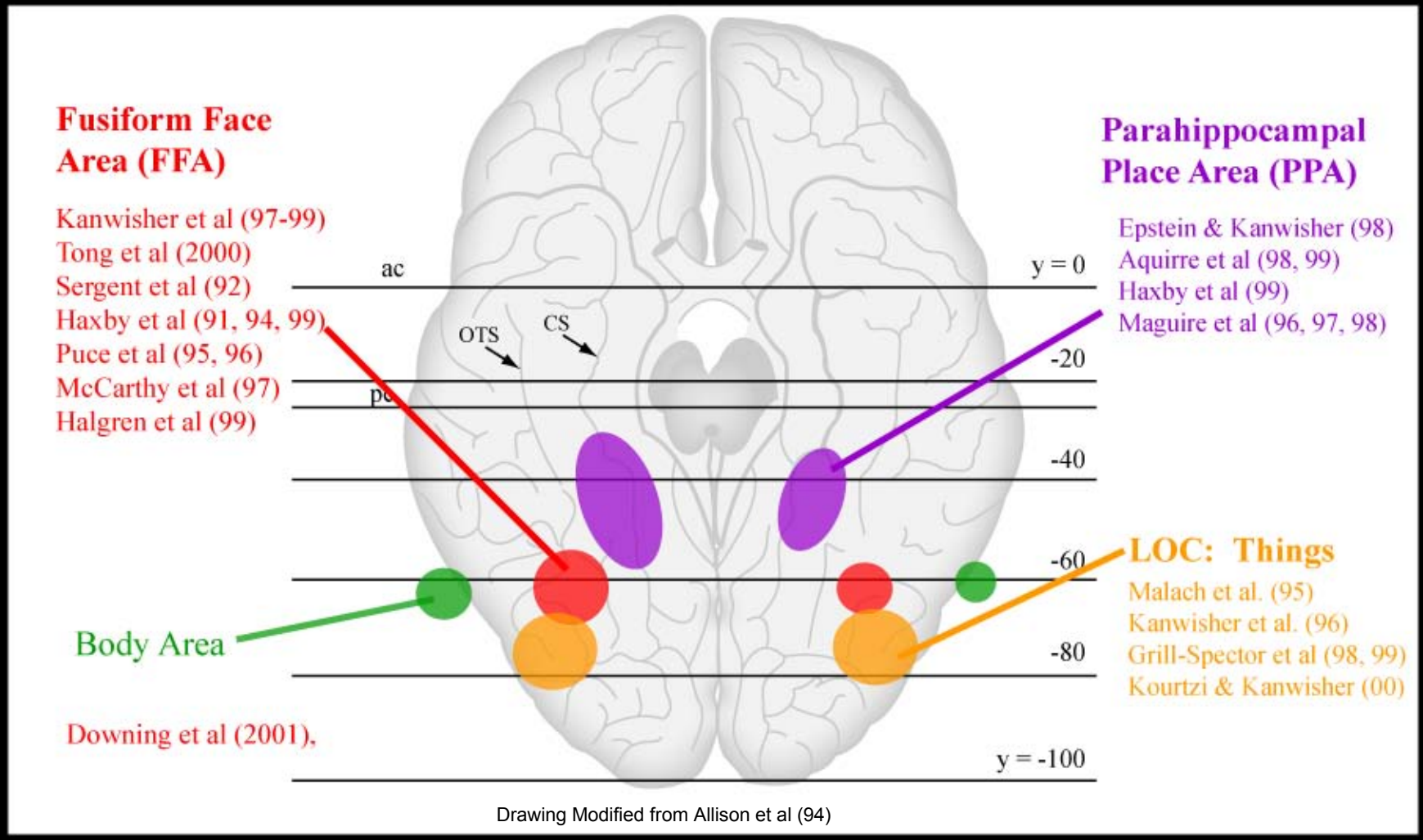
Brain Regions Involved in Visual Cognition



Drawing Modified from Allison et al (94)

Figure by MIT OpenCourseWare. After Allison, 1994.

The Lateral Occipital Complex (LOC):

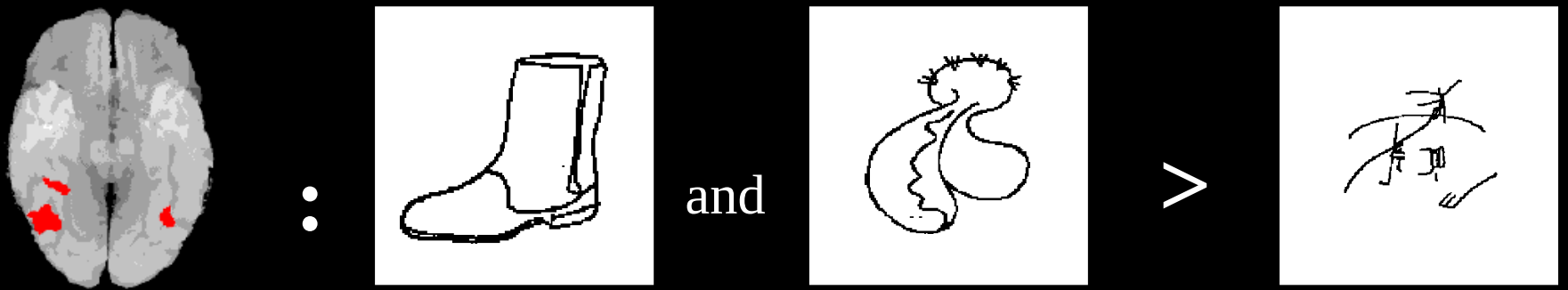
Cortical Regions Involved in Processing Object Shape

I Malach et al (1995), "LO"

Figure by MIT OpenCourseWare.

Courtesy of National Academy of Sciences, U. S. A. Used with permission.
Source: Malach, R. et. al. "Object-related activity revealed by functional magnetic resonance imaging in human occipital cortex." *Proc. Natl. Acad. Sci.* 92 (1995): 8135-8139. Copyright © 1995, National Academy of Sciences, U.S.A.

II Kanwisher et al (1996) - a similar region



Object-Selective Regions in the Human Brain: LOC in one Subject

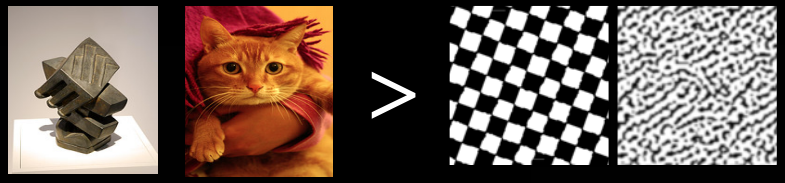


Photo courtesy of caspermoller.

Photo courtesy of Enid Yu.

lateral

right h

10^{-10}

10^{-4}

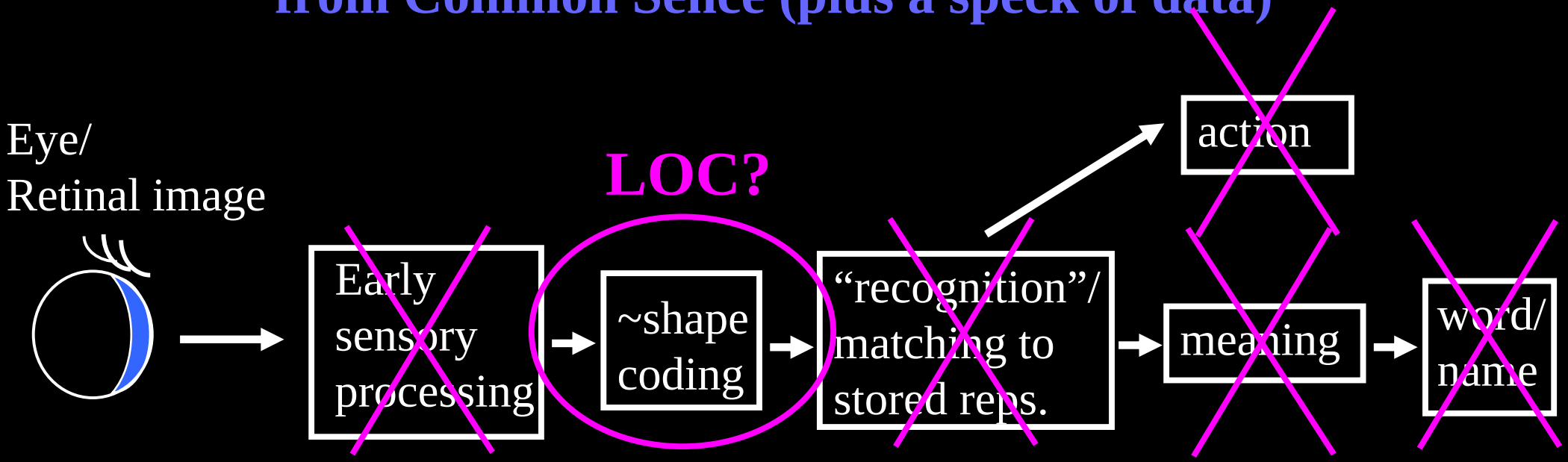
What does this region *do*?

ventral view

subject: NT

Kalanit Grill-Spector

Components of Object Recognition from Common Sence (plus a speck of data)



LOC: familiarity/meaning/name apparently not important
not processing very low-level information

(Is this what is messed up in the "lock guy"?)

Is this region *necessary* for perceiving shape?
fMRI can't tell you this, but……

Patient DF: no form visual perception

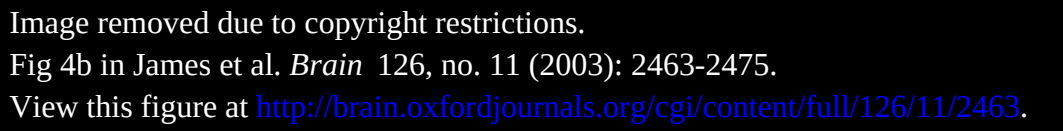
Patient DF has a "ventral stream" lesion

Object agnosia (a diff. Kind from the "lock guy")

- Cannot identify line drawings of common objects
- Cannot copy line drawings
- Can draw from memory as long as she doesn't lift hand from paper

Slide adapted from Jody Culham

LOC in Normals and Lesion site in DF



Apparently, LOC is *necessary* for object recognition.

James, Culham, Humphrey, Milner, & Goodale (2003)

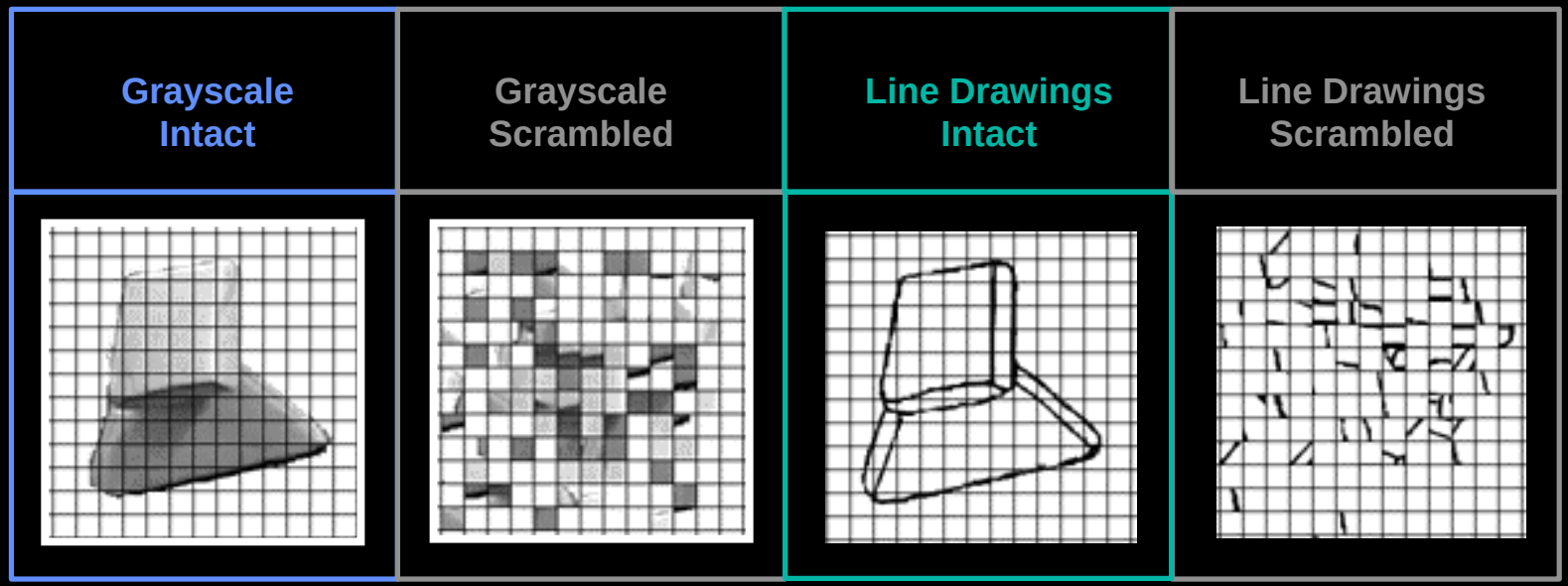
Characterizing Representations and Processes in the LOC □

Are shape representations in LOC

- **independent of how shape is represented, i.e. independent of**
  - **form-cues (motion, luminance, texture)?**
  - **contours?**
- **Independent of changes in the size, position, viewpoint, etc?**

Cool method: fMRI adaptation

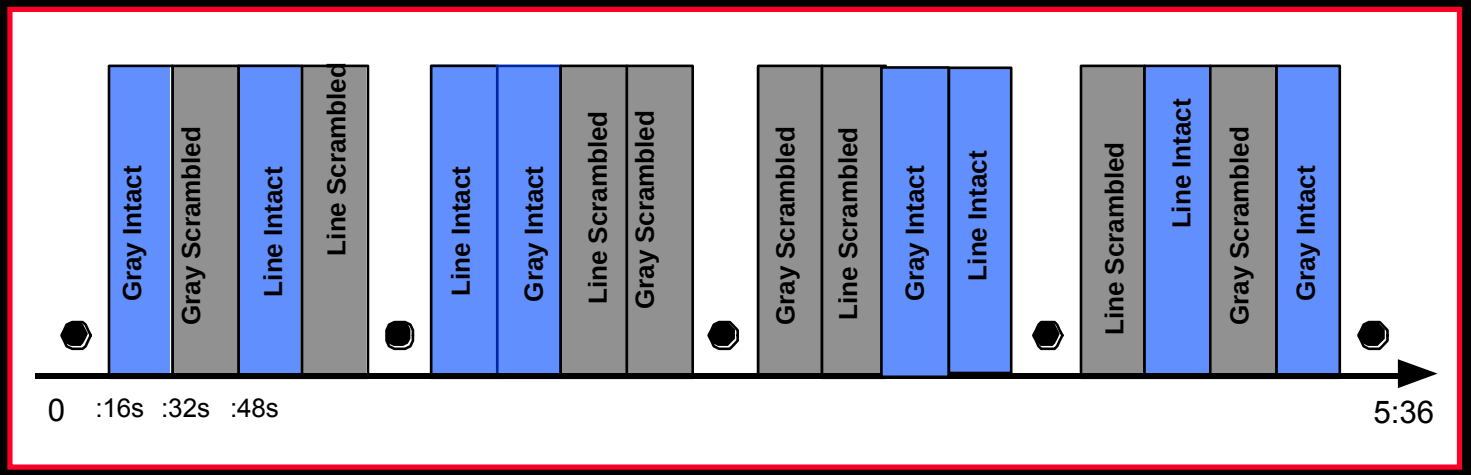
Are common regions involved in processing object structure independent of the cues defining the object's shape (e.g. line contours, surface shading)?



Kourtzi & Kanwisher, 2000

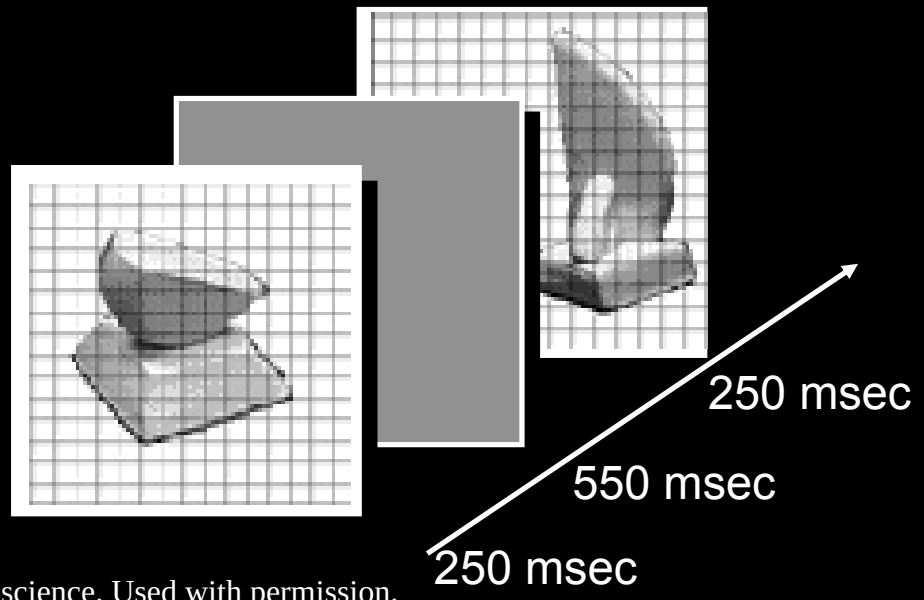
Procedure

Each Scan:



Each Epoch:

(20 pictures per epoch)

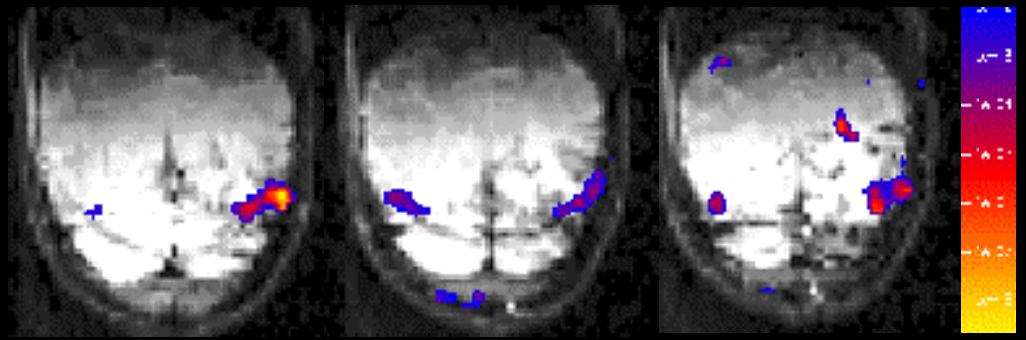


Tasks: Passive Viewing

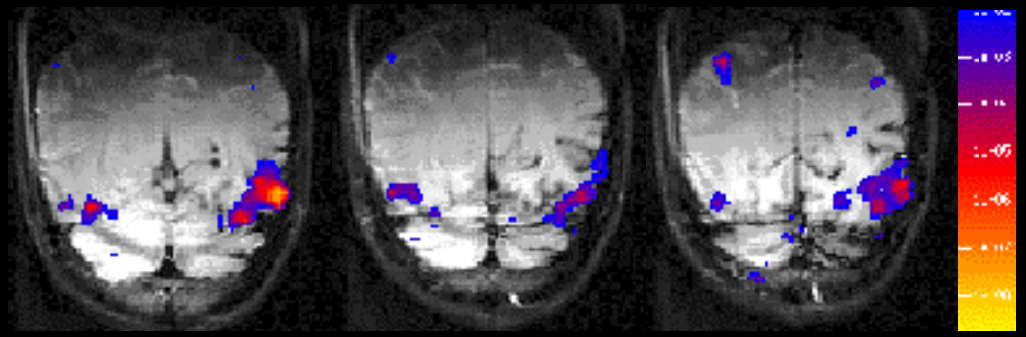
Kourtzi & Kanwisher, 2000

Activations in one subject for:

a. Intact versus Scrambled Grayscale images



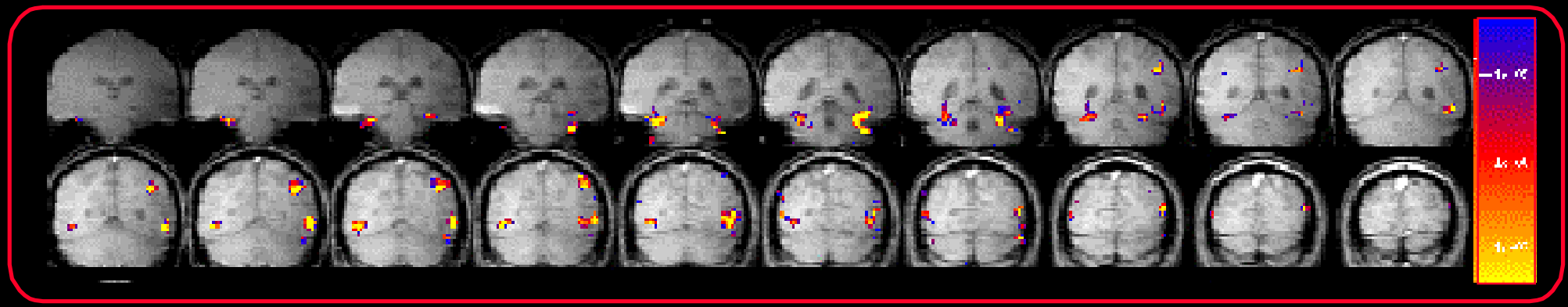
b. Intact versus Scrambled Line Drawings

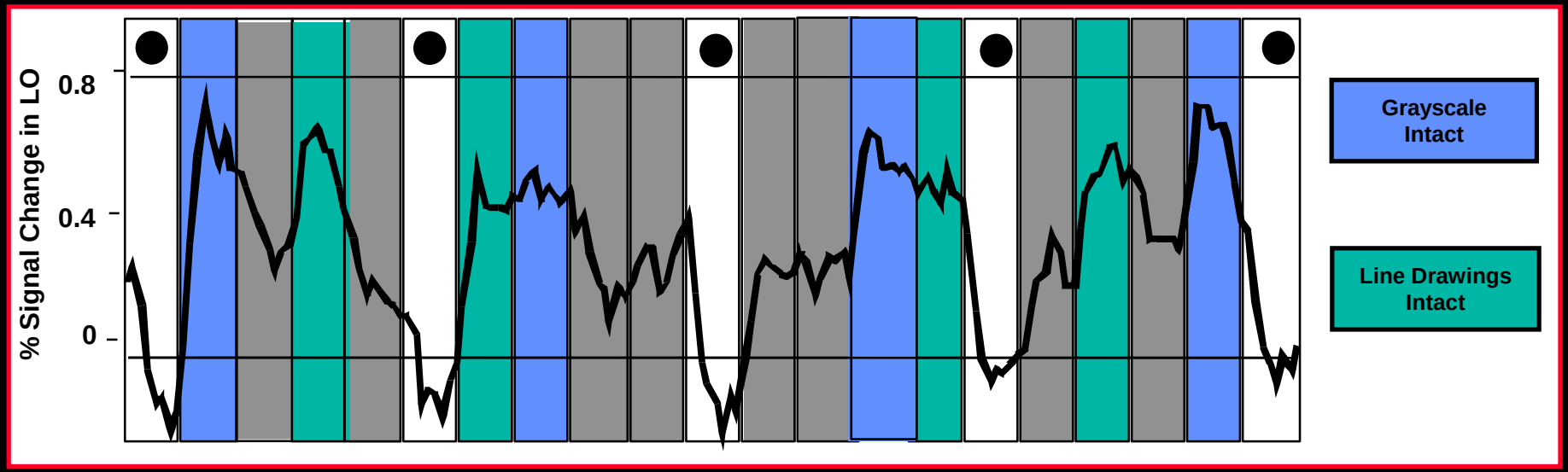


Kourtzi & Kanwisher, 2000

Experiment 1: Results

Activation Map for Intact-Scrambled Images averaged across subjects
A big chunk of cortex is more active for intact than scrambled shapes.

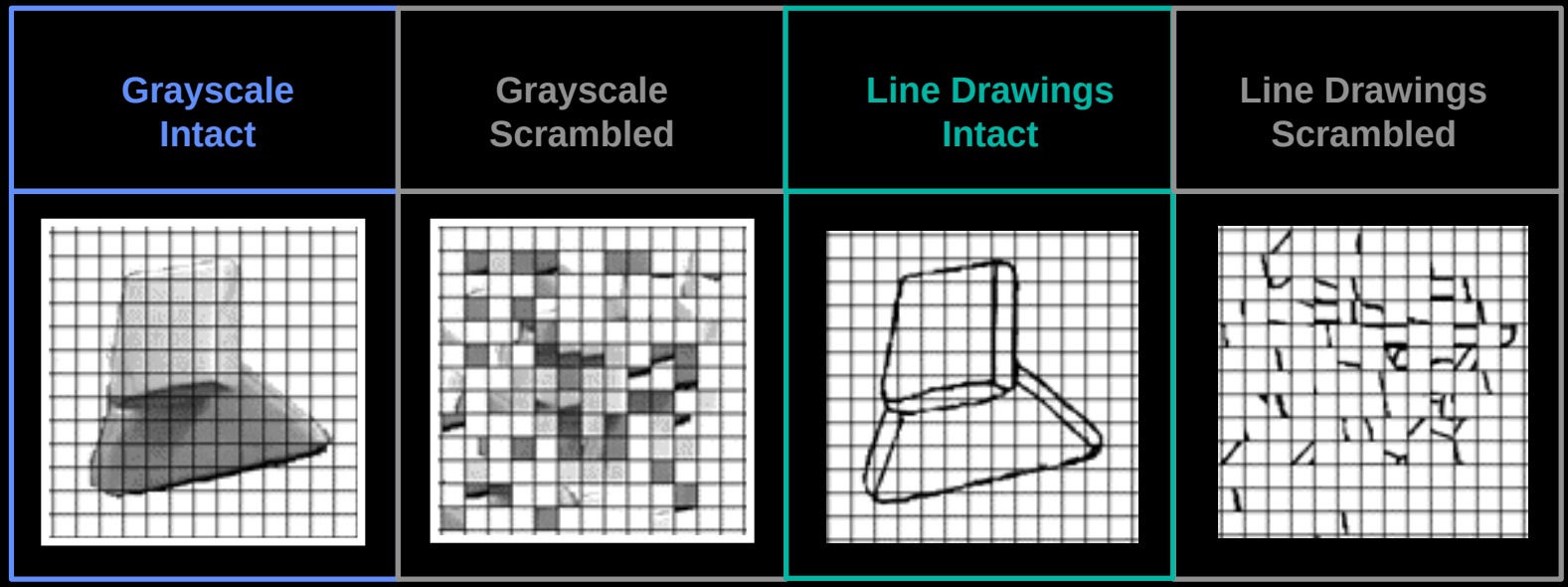




Are common regions involved in processing object structure independent of the cues defining the object's shape (e.g. line contours, surface shading)? **YES!**

Are the *same neurons* responsive to photos and drawings?

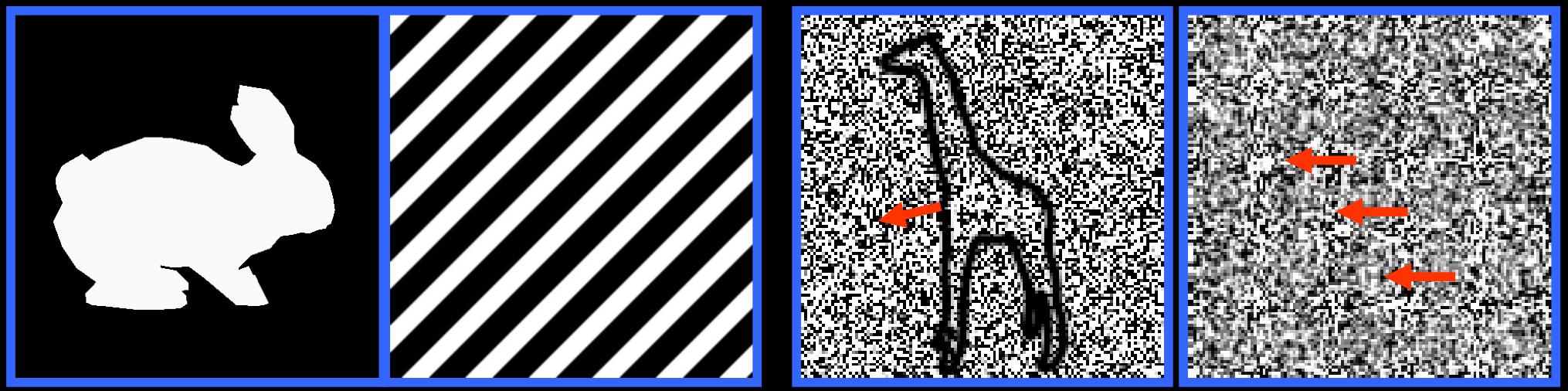
Does it respond to shapes defined in other ways?



Kourtzi & Kanwisher, 2000

Objects from Motion Experiment

Are object-selective regions preferentially activated by objects from Luminance? Motion? Texture?

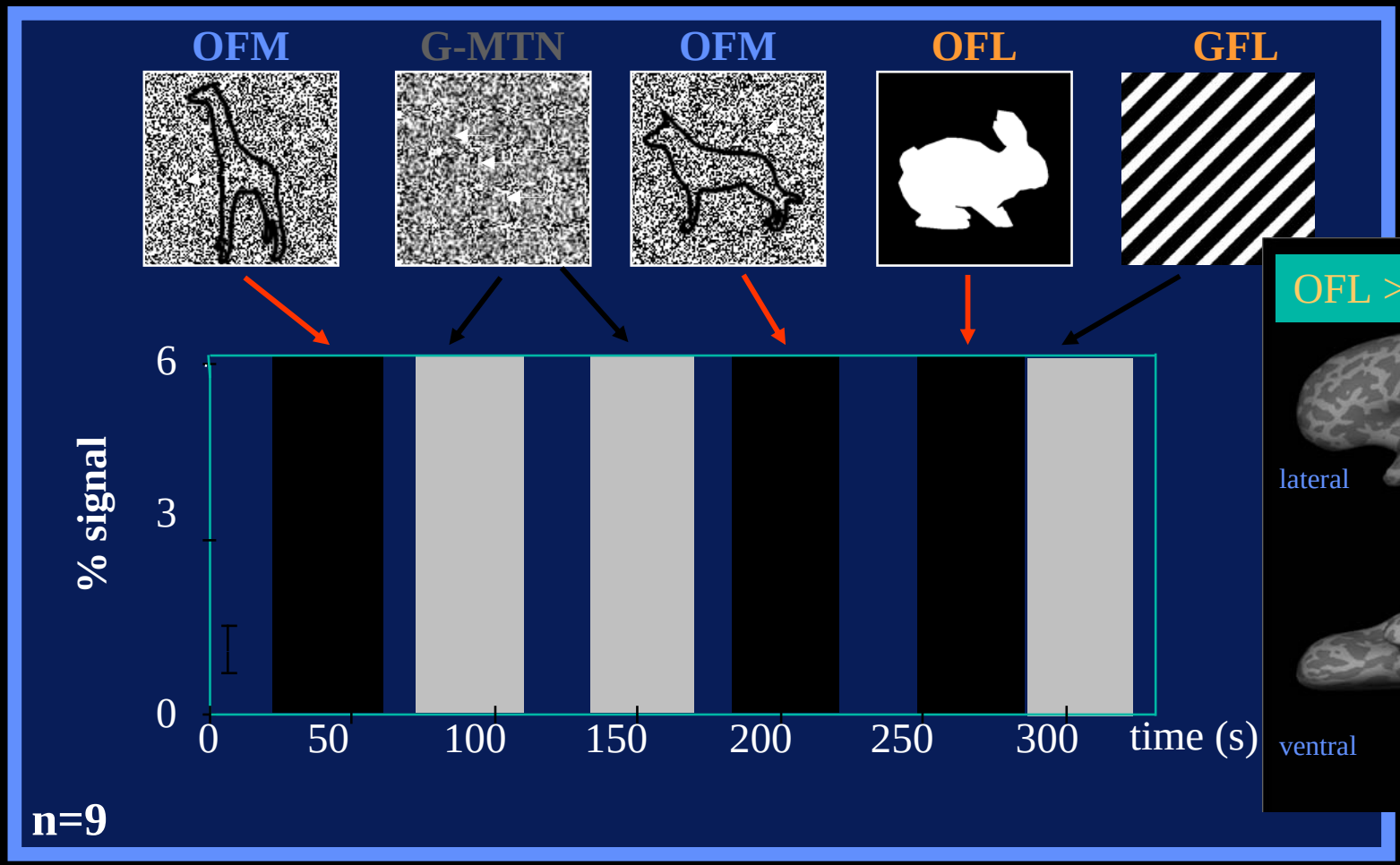


15 different images per block
presented rate: 0.5Hz

Grill-Spector et al. , Neuron 1998

Objects from Motion Experiment

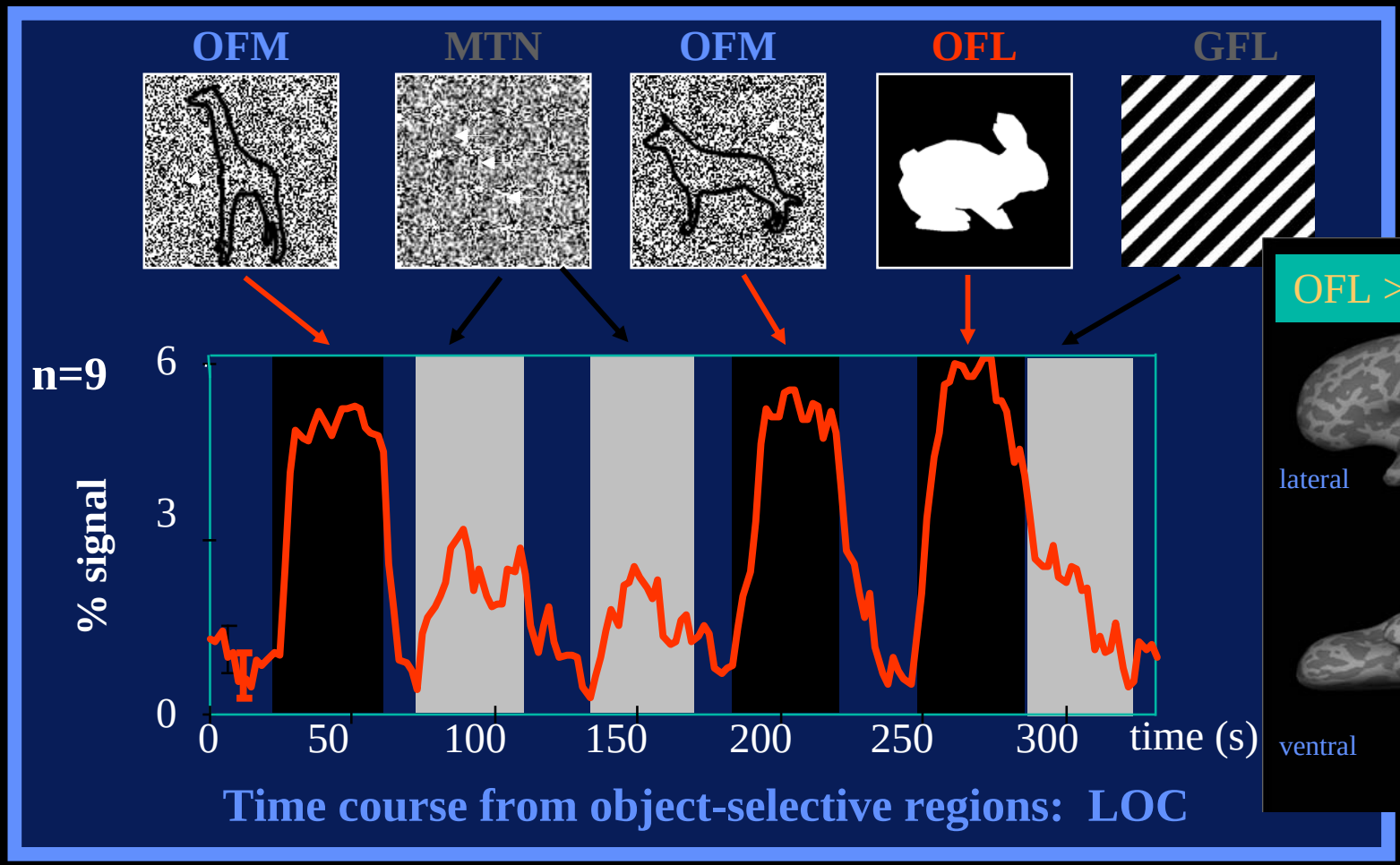
Define object selective regions: OFL > GFL

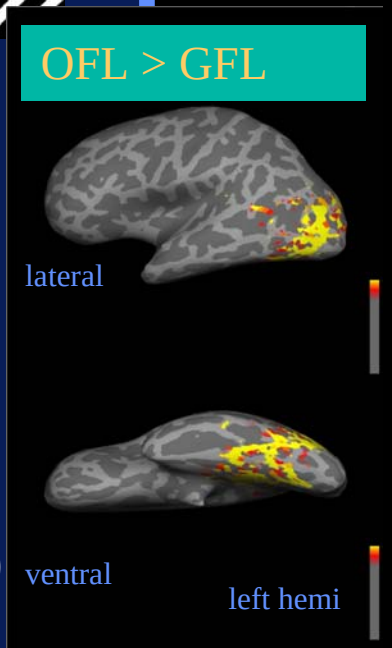


Grill-Spector et al. , Neuron 1998

Objects from Motion Experiment

Define object selective regions: OFL > GFL

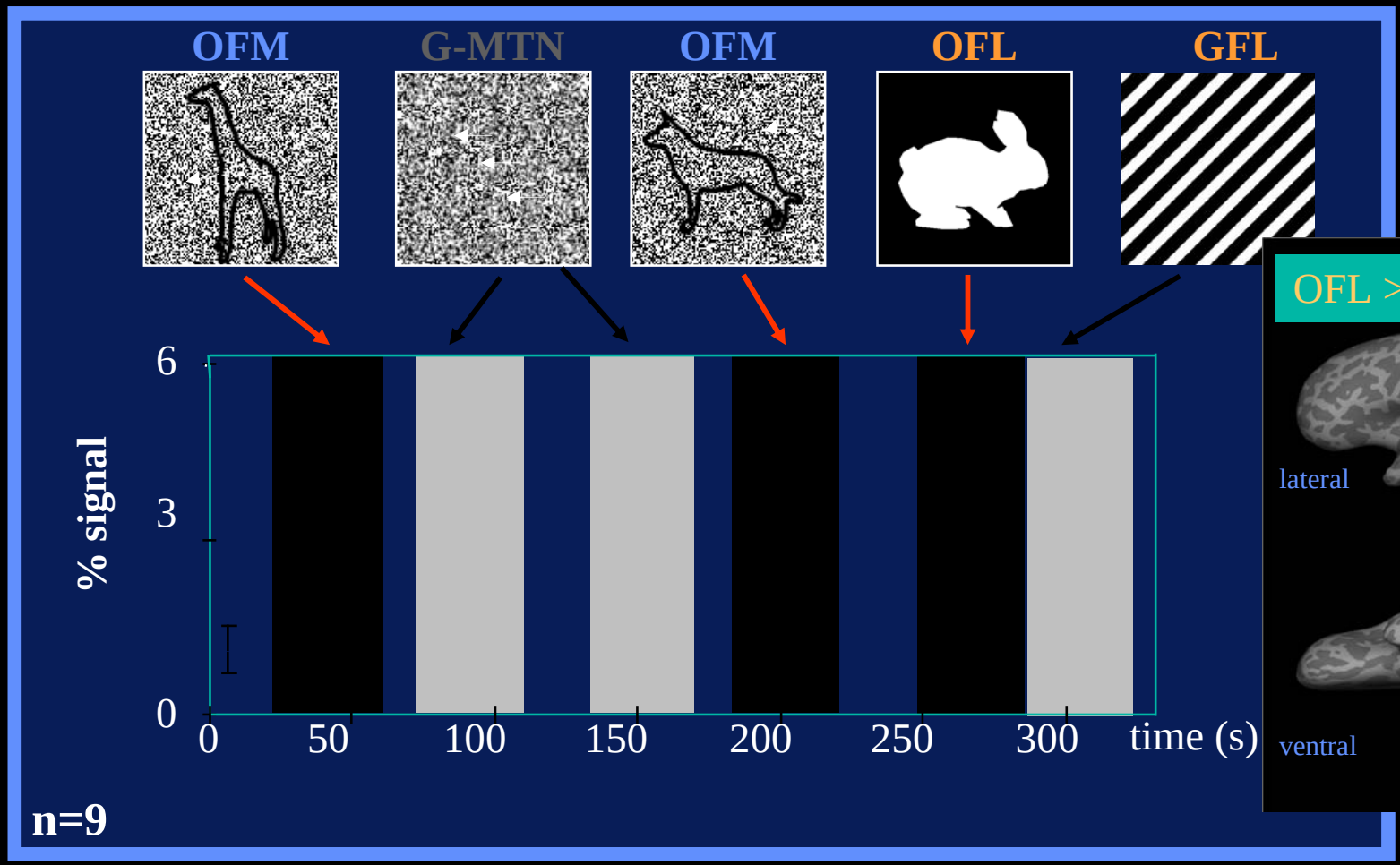




Grill-Spector et al. , Neuron 1998

Objects from Motion Experiment

Define object selective regions: OFL > GFL

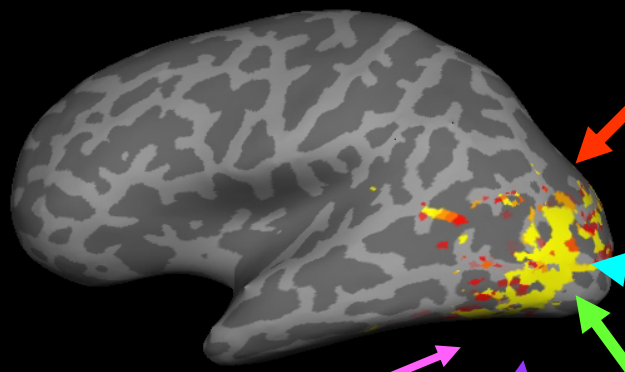


Grill-Spector et al. , Neuron 1998

Conclusion: Cue-independent Representations of Object Shape

Objects from motion

Courtesy Elsevier, Inc., http://www.sciencedirect.com. Used with permission.

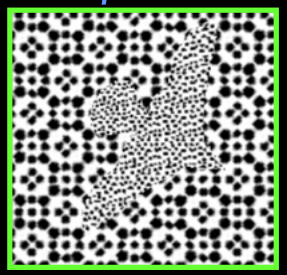


Courtesy of National Academy of Sciences, U. S. A. Used with permission. Source: Malach, R. et. al. "Object-related activity revealed by functional magnetic resonance imaging in human occipital cortex." *Proc. Natl. Acad. Sci.* 92 (1995): 8135-8139. Copyright © 1995, National Academy of Sciences, U.S.A.

Objects from luminance

Courtesy Elsevier, Inc., http://www.sciencedirect.com. Used with permission.

Objects from texture



Objects from greyscale photos

Objects from line drawings

Grill-Spector et al. , Neuron 1998

Characterizing Representations and Processes in the LOC □

Are shape representations in LOC

independent of how shape is represented, i.e. independent of form-cues (motion, luminance, texture)? probably contours?

Independent of changes in the size, position, viewpoint, etc?

Cool method: fMRI adaptation

BUT: Have I shown you evidence that the *very same* neurons respond to form independent of how that form is defined?

Event-Related fMRI Adaptation

Basic idea: Any measure that is sensitive to the sameness vs. difference between 2 stimuli can reveal what the system takes to be the same and diff.

Example: If brain region X discriminate between two similar stimuli, say….

Then if we measure fMRI response in that region to same vs. different trials:

DIFFERENT

Photo courtesy of Trpster.

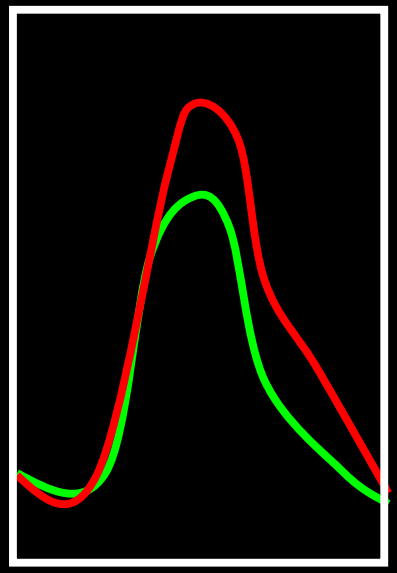
Photo courtesy of floridapfe.

250ms 500ms 250ms

Photo courtesy of floridapfe.

Photo courtesy of floridapfe.

We see this:



Then region X can discriminate these 2 stimuli.

Event-Related fMRI Adaptation

Basic idea: Any measure that is sensitive to the sameness vs. difference between 2 stimuli can reveal what the system takes to be the same.

TEST

Photo courtesy of floridapfe.

Photo courtesy of floridapfe.

DIFFERENT

Photo courtesy of Trpster.

Photo courtesy of floridapfe.

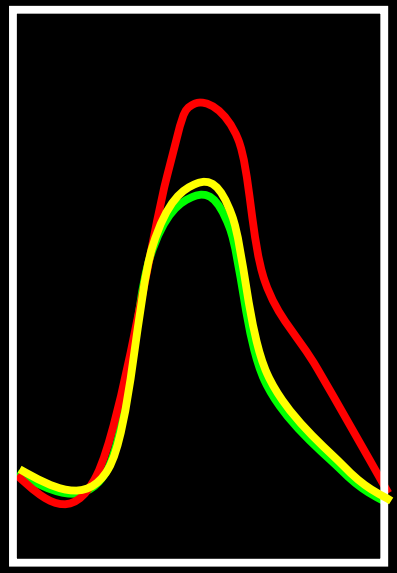
250ms 500ms 250ms

SAME

Photo courtesy of floridapfe.

Photo courtesy of floridapfe.

What is the answer if we see this:



Does region X "think" these images are the same?
Then region X can discriminate these 2 stimuli.

Now we can also ask what images region X "thinks" are the same, e.g.…

Characterizing Representations and Processes in the LOC □

Are shape representations in LOC

independent of how shape is represented, i.e. independent of form-cues (motion, luminance, texture)? probably

contours?

Independent of changes in the size, position, viewpoint, etc?

Cool method: fMRI adaptation

Is LOC "Contour Invariant"?

If the LOC represents object shape, independent of the contours defining that shape, then if the two stimuli have……..

1. Diff. Contours But Same Shape → **Adaptation**

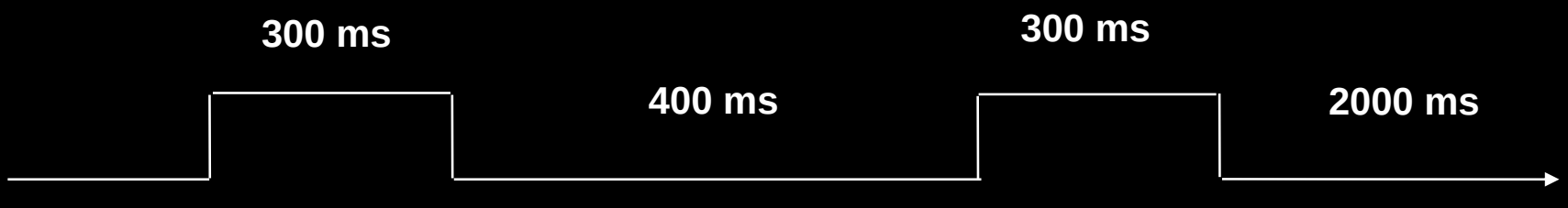
2. Same Contours But Different Shape → **No Adaptation**

Kourtzi & Kanwisher (2001)

1. Diff. Contours But Same Shape

Is there neural adaptation in the LOC for objects that have different contours but the same perceived shape?

Image removed due to copyright restrictions.
Fig. 2 in Kourtzi, Zoe, and Nancy Kanwisher. "Representation of Perceived Object Shape by the Human Lateral Occipital Complex." *Science*, 24 AUGUST 2001 VOL 293.
(http://web.mit.edu/bcs/nklab/media/pdfs/KourtziKanwisherScience01.pdf)



Experiment 1: Results

- **Define the LOC for intact versus scrambled images in each subject (n=10).**
- **Average time course of activation in the LOC.**

Image removed due to copyright restrictions.
Fig. 3 in Kourtzi, Zoe, and Nancy Kanwisher. "Representation of Perceived Object Shape by the Human Lateral Occipital Complex." *Science*, 24 AUGUST 2001
VOL 293.
(http://web.mit.edu/bcs/nklab/media/pdfs/KourtziKanwisherScience01.pdf)

- **Significant adaptation for identical shapes ($p<0.05$).**

Kourtzi & Kanwisher

Experiment 1: Results

- **Define the LOC for intact versus scrambled images in each subject (n=10).**
- **Average time course of activation in the LOC.**

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Fig. 3 in Kourtzi, Zoe, and Nancy Kanwisher. "Representation of Perceived Object Shape by the Human Lateral Occipital Complex." *Science*, 24 AUGUST 2001
VOL 293.
(http://web.mit.edu/bcs/nklab/media/pdfs/KourtziKanwisherScience01.pdf)

Kourtzi & Kanwisher

- **Significant adaptation for displays with the same shape but different contours ($p<0.05$).**

If the LOC represents object shape, independent of the contours defining that shape, then if the two stimuli have……..

1. Diff. Contours Same Shape → **Adaptation** √

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Fig. 2 in Kourtzi, Zoe, and Nancy Kanwisher. "Representation of Perceived Object Shape by the Human Lateral Occipital Complex." *Science*, 24 AUGUST 2001 VOL 293.
(http://web.mit.edu/bcs/nklab/media/pdfs/KourtziKanwisherScience01.pdf)

2. Same Contours Different Shape → **No Adaptation** ?

Kourtzi & Kanwisher

2. Same Contours But Different Shape

Is there neural adaptation for stereoscopically defined shapes that share the same contours but have different shape?

Image removed due to copyright restrictions.
Fig. 2B in Kourtzi, Zoe and Kanwisher, Nancy. "Representation of Perceived Object Shape by the Human Lateral Occipital Complex." *Science*, 24 AUGUST 2001 VOL 293.
(http://web.mit.edu/bcs/nklab/media/pdfs/KourtziKanwisherScience01.pdf)

Kourtzi & Kanwisher

Experiment 2: Results

- **Define the LOC for intact versus scrambled images in each subject (n=10).**
- **Average time course of activation in the LOC.**

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Fig. 4 in Kourtzi, Zoe and Kanwisher, Nancy. "Representation of Perceived Object Shape by the Human Lateral Occipital Complex." *Science*, 24 AUGUST 2001
VOL 293.
(http://web.mit.edu/bcs/nklab/media/pdfs/KourtziKanwisherScience01.pdf)

- **Significant adaptation for identical shapes ($p<0.01$).**

Experiment 2: Results

- **Define the LOC for intact versus scrambled images in each subject (n=10).**
- **Average time course of activation in the LOC.**

Image removed due to copyright restrictions.
Fig. 4 in Kourtzi, Zoe and Kanwisher, Nancy. "Representation of Perceived Object Shape by the Human Lateral Occipital Complex." *Science*, 24 AUGUST 2001
VOL 293.
(http://web.mit.edu/bcs/nklab/media/pdfs/KourtziKanwisherScience01.pdf)

- **No significant adaptation for displays with the same contours but different shape.**

Conclusions

1. Diff. Contours Same Shape → **Adaptation**

Image removed due to copyright restrictions.
Fig. 2 in Kourtzi, Zoe, and Nancy Kanwisher. "Representation of Perceived Object Shape by the Human Lateral Occipital Complex." *Science*, 24 AUGUST 2001 VOL 293.
(http://web.mit.edu/bcs/nklab/media/pdfs/KourtziKanwisherScience01.pdf)

2. Same Contours Different Shape → **No Adaptation**

Image removed due to copyright restrictions. Fig. 2B in Kourtzi, Zoe, and Nancy Kanwisher. "Representation of Perceived Object Shape by the Human Lateral Occipital Complex." *Science*, 24 AUGUST 2001 VOL 293.
(http://web.mit.edu/bcs/nklab/media/pdfs/KourtziKanwisherScience01.pdf)

The adaptation effects in the LOC suggest that these neural populations represent object shape independent of the contours defining the shape.

Kourtzi & Kanwisher

Characterizing Representations and Processes in the LOC □

Are shape representations in LOC

independent of how shape is represented, i.e. independent of form-cues (motion, luminance, texture)? **probably**

contours? **Yes!**

Independent of changes in the size, position, viewpoint, etc?

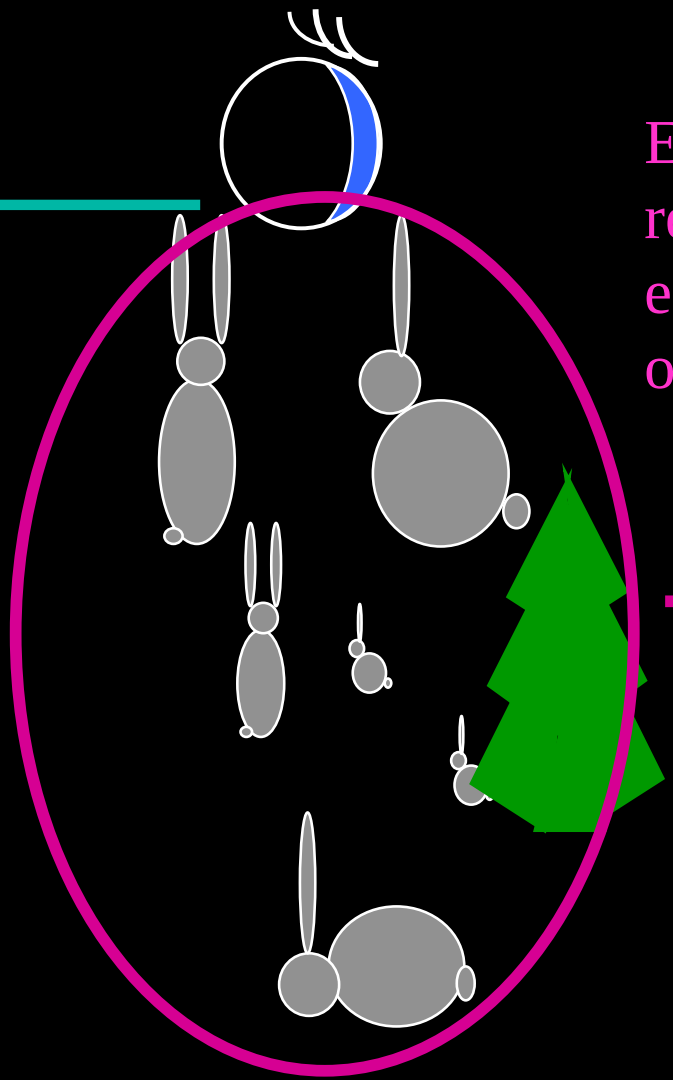
Uh, why does this matter again?

Cool method: fMRI adaptation

How do we Recognize Objects despite Variations in the Image of Each Object?

Photo courtesy of Nick Devenish.

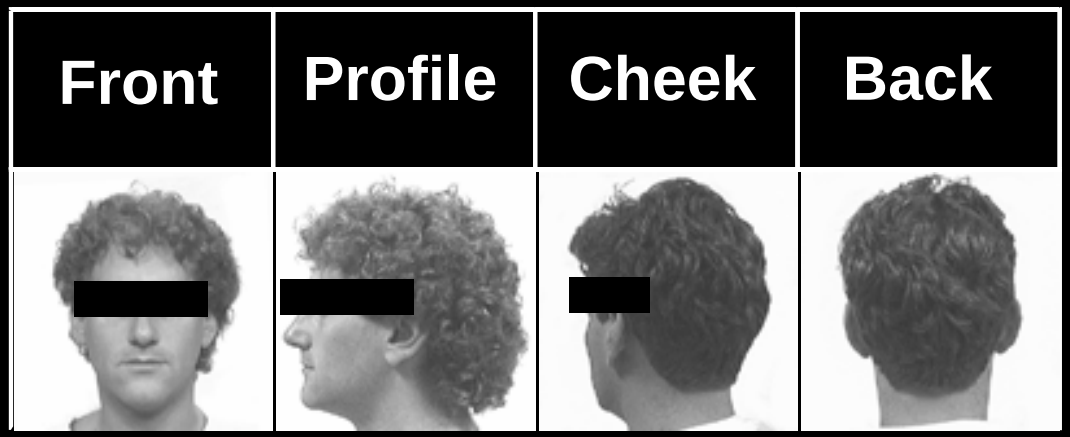
Extract one common representation from each of these that is "invariant" to changes in size, position, viewpoint, etc.



Extract a different representation for each, then map all of these to "rabbit".

Rabbit

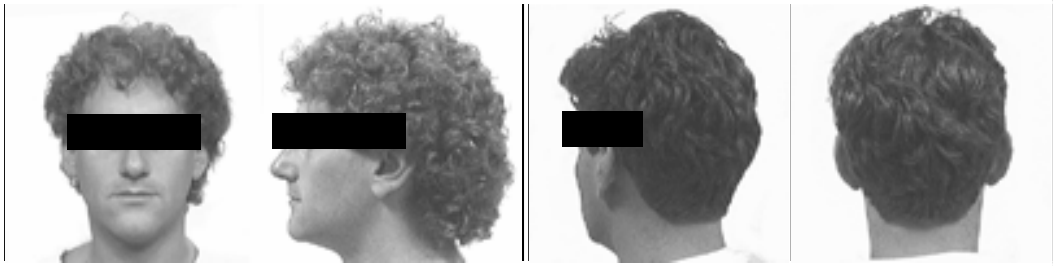
Changes in Viewpoint



Face photos modified by OCW for privacy considerations.

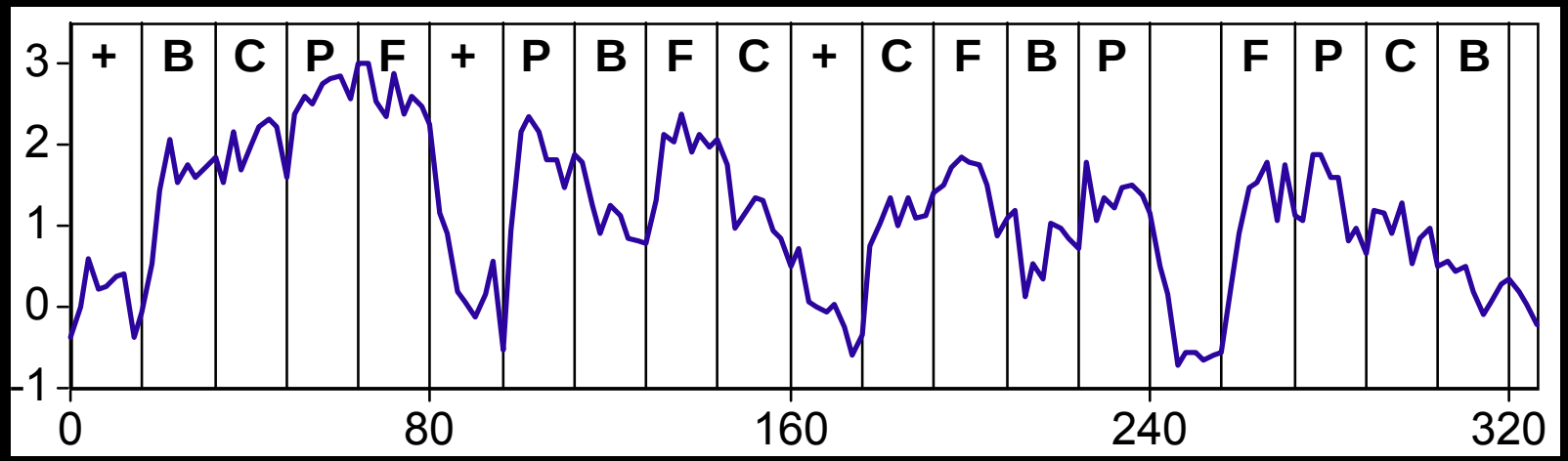
- Are responses to faces tuned to specific viewpoints of faces?

Tong, Kanwisher, & Nakayama, 2000

	Front	Profile	Cheek	Back
				
PSC in FFA (n=5)	1.8	1.8	1.3	0.9

Face photos modified by OCW for privacy considerations.

Does this mean that the same neurons response to front & profile views of faces?

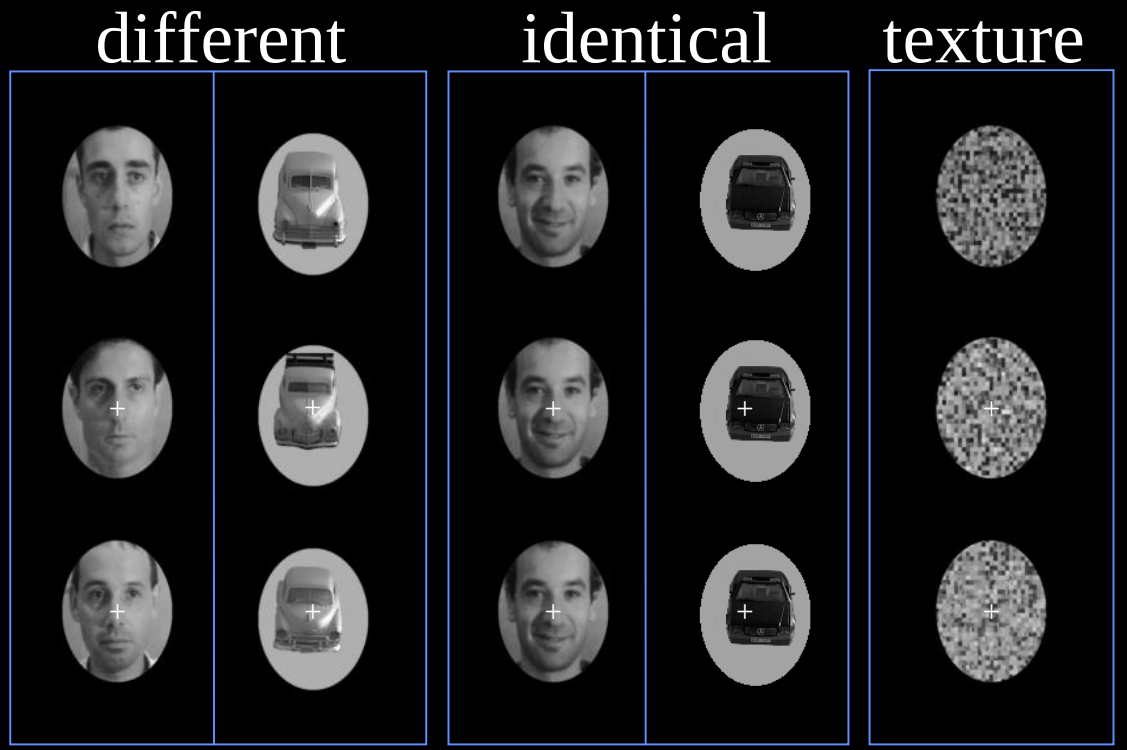


Tong, Kanwisher, & Nakayama, 2000

Using Adaptation to Test for Invariances

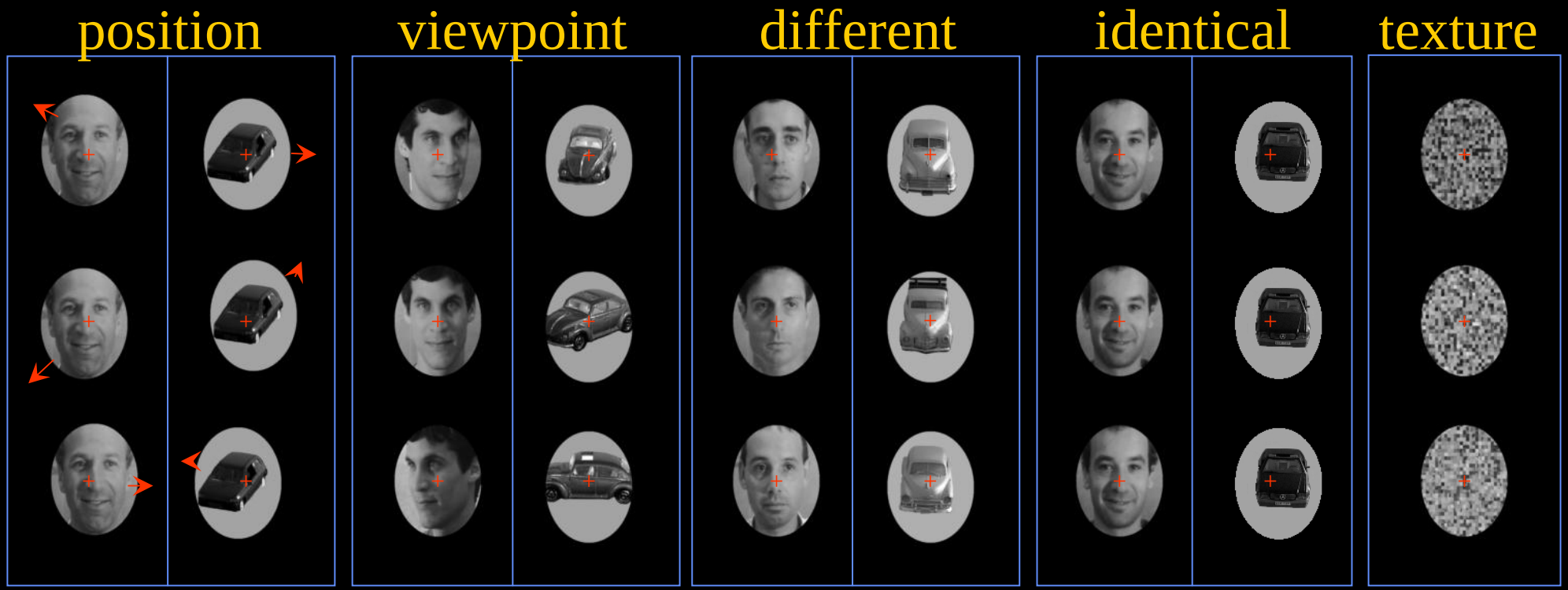
Expect lower responses for blocks of identical images than blocks of different faces/cars.

Then use that effect to test for invariances across changes in position, etc….



(Grill-Spector et al. 1999)

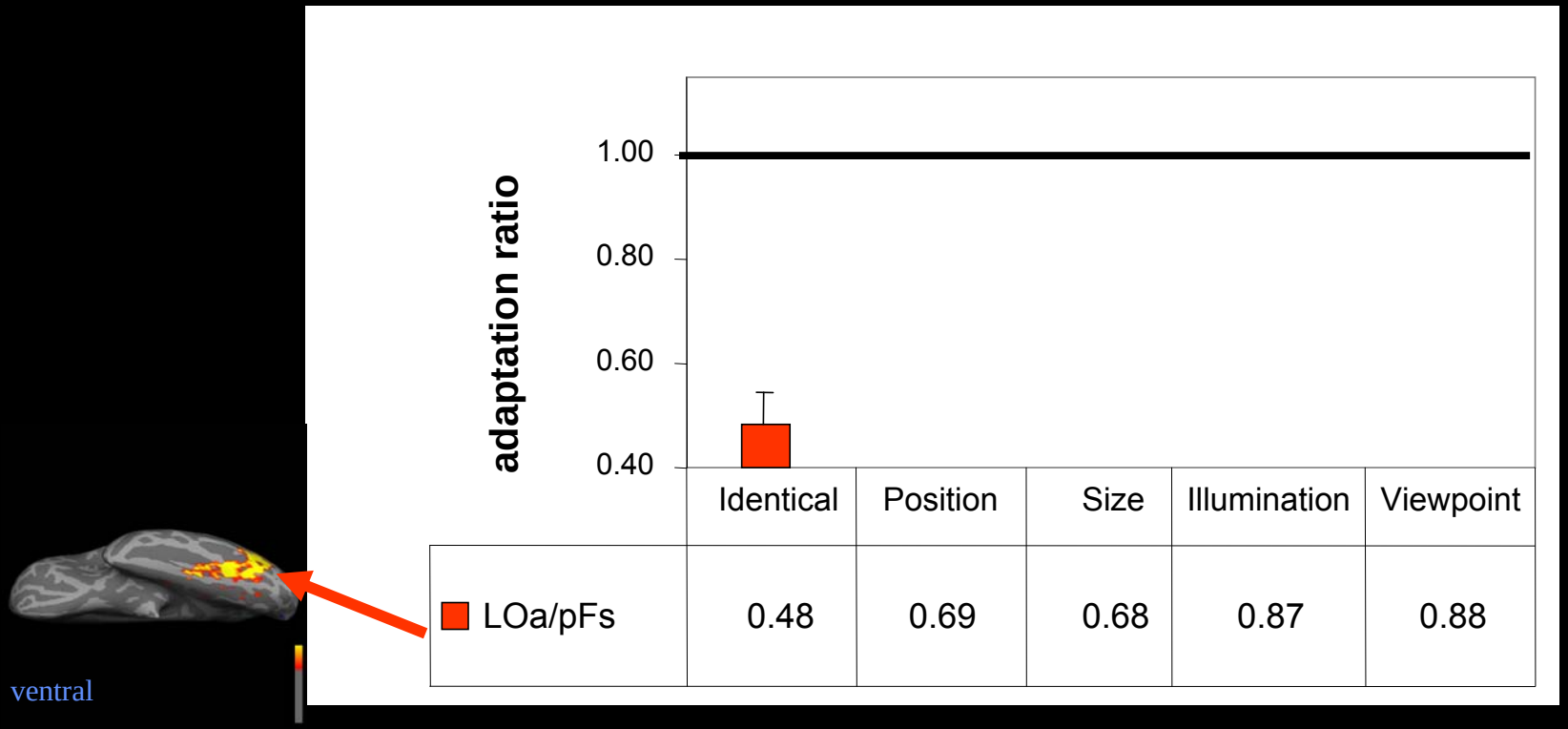
Using Adaptation to Test for Invariances



Do images that vary only in position or viewpoint count as the “same” and hence get adapted, or do they count as “different” and not get adapted?

(Grill-Spector et al. 1999)

Differential Invariance in Anterior-Ventral Object-Selective Areas: LOa /pFs



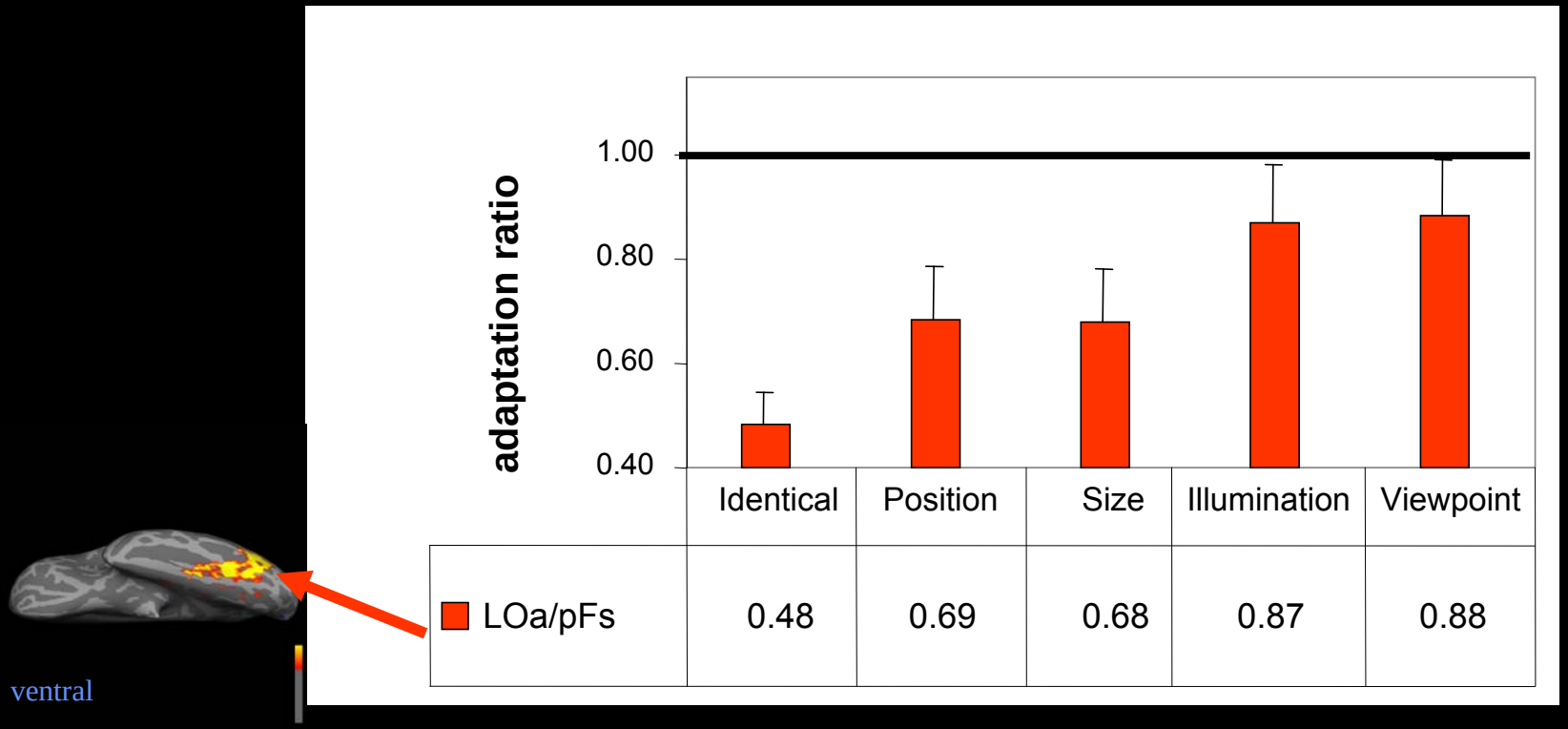
$$\text{ratio} = \frac{\%\ \text{signal condition}}{\%\ \text{signal different}}$$

ratio = 1.0 there is no adaptation

ratio < 0.7 * significant adaptation ($p<0.01$)

(Grill-Spector et al. 1999)

Differential Invariance in Anterior-Ventral Object-Selective Areas: LOa /pFs



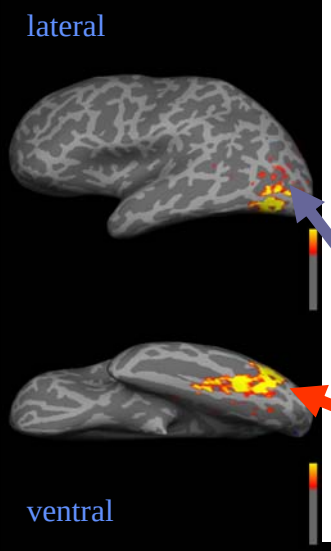
$$\text{ratio} = \frac{\%\ \text{signal condition}}{\%\ \text{signal different}}$$

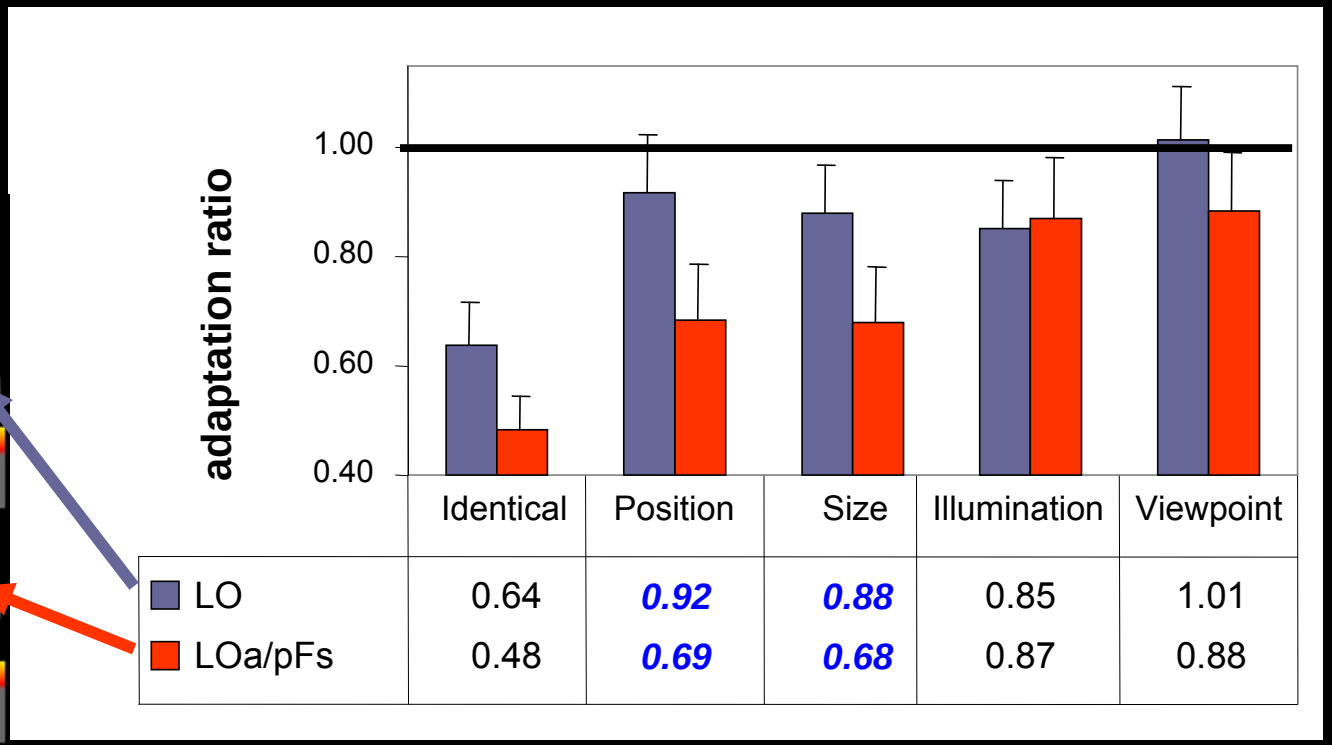
ratio = 1.0 there is no adaptation

ratio < 0.7 * significant adaptation ($p<0.01$)

(Grill-Spector et al. 1999)

Differential Invariance in Subdivisions of LOC





	Identical	Position	Size	Illumination	Viewpoint
LO	0.64	***0.92***	***0.88***	0.85	1.01
LOa/pFs	0.48	***0.69***	***0.68***	0.87	0.88

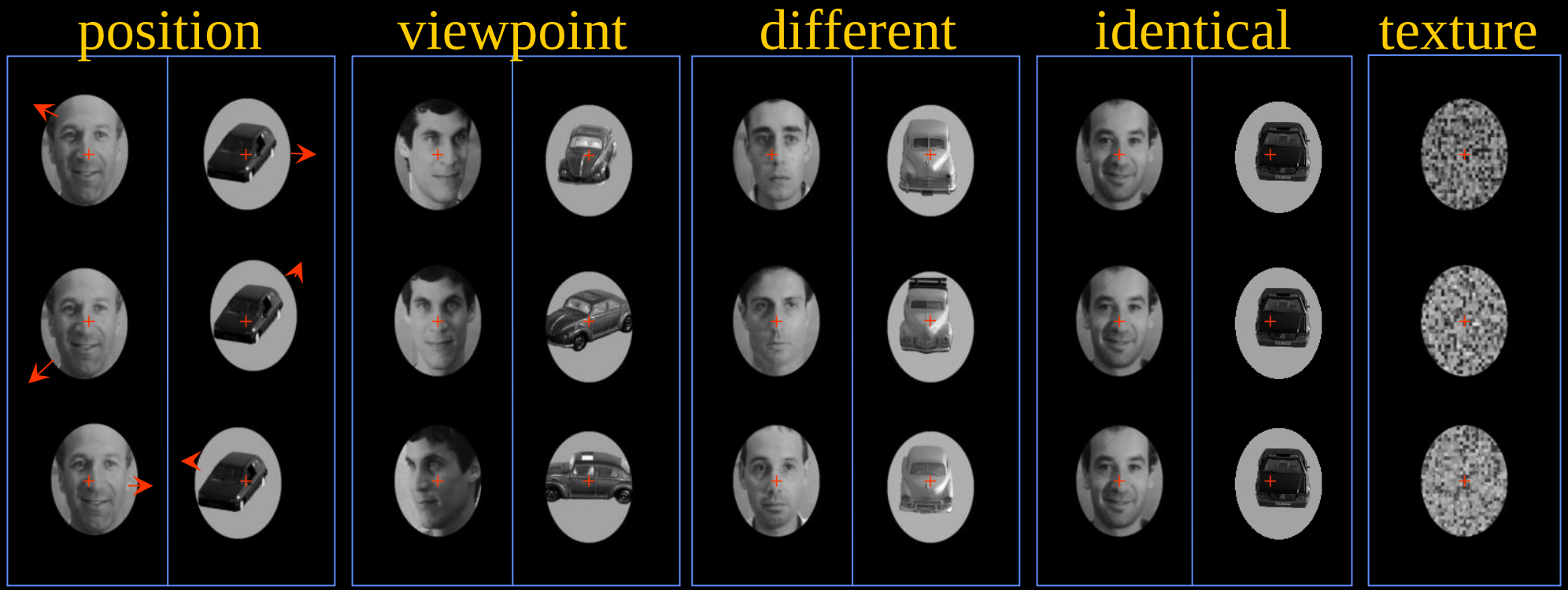
$$\text{ratio} = \frac{\%\ \text{signal condition}}{\%\ \text{signal different}}$$

ratio = 1.0 there is no adaptation

ratio < 0.7 * significant adaptation ($p<0.01$)

(Grill-Spector et al. 1999)

Using Adaptation to Test for Invariances



Do images that vary only in position or viewpoint count as the “same” and hence get adapted, or do they count as “different” and not get adapted?

(Grill-Spector et al. 1999)

Characterizing Representations and Processes in the LOC □

Are shape representations in LOC

independent of how shape is represented, i.e. independent of form-cues (motion, luminance, texture)? **probably**

contours? **Yes!**

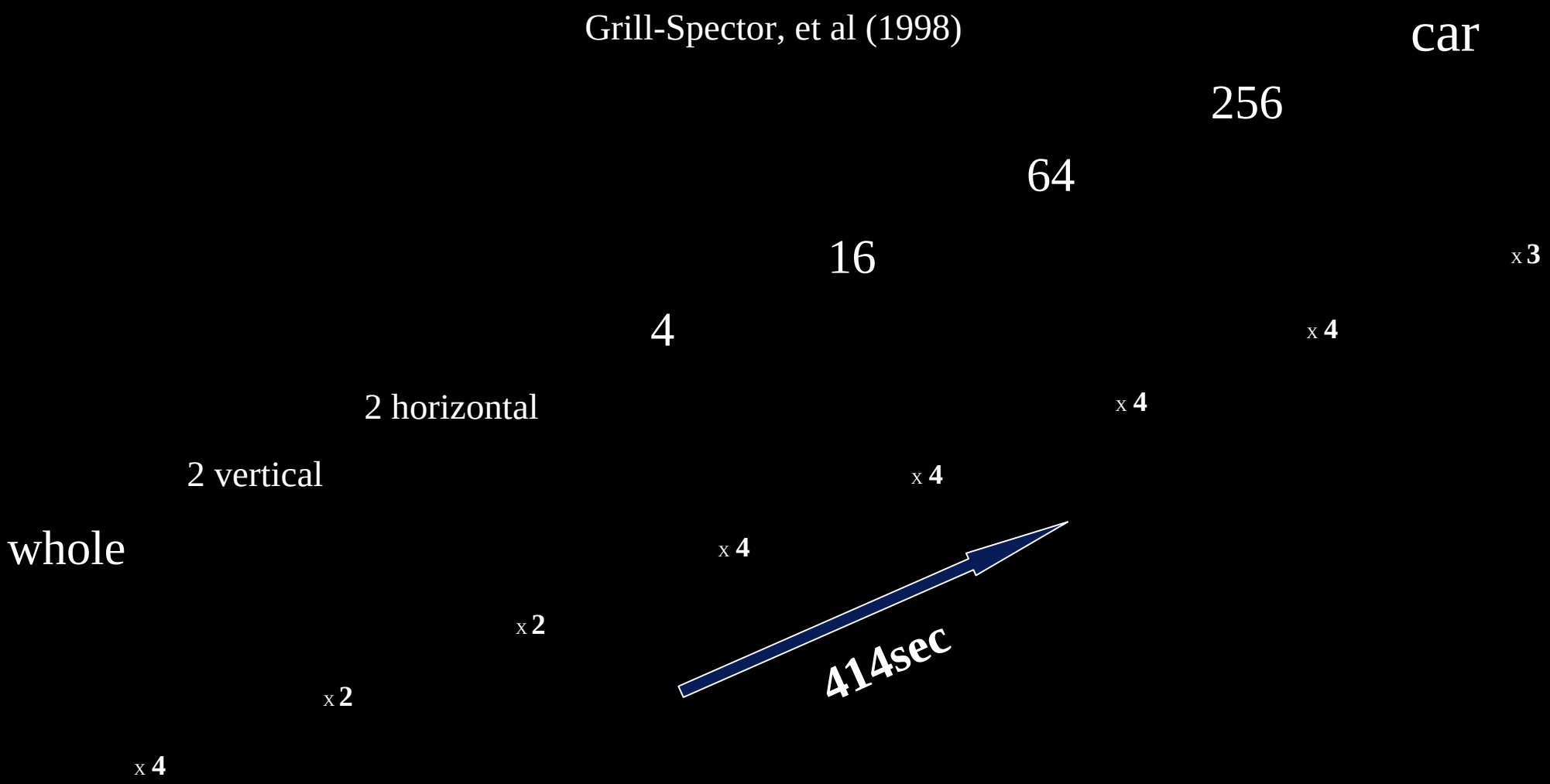
Independent of changes in the size, position, viewpoint, etc?

Partly. More to size & position than viewpoint.

Cool method: fMRI adaptation

Face Scrambling Experiment

Grill-Spector, et al (1998)



Whole vs. Parts

Grill-Spector, Malach, others (1998)

R. Malach
Weizmann. Inst.

Comments on Papers

1. Writing *matters* in life; learn to do it well now. You cannot be a successful scientist unless you write well. Probably true for most other professions as well.

2. One strong argument (or maybe tops 3) is much more effective than 12 weak ones. "Kitchen sink" papers are ineffective.

3. Start the paper with a statement of what was found & claimed.

4. A paper (or talk) is not a note to me >> it should pass the "roomate test".

5. Don't just say X is a problem; say WHY!

6. Paragraph structure.

7. Write it, print it, get away from it, come back, and read it. READ IT ALOUD.

8. If you have a paragraph with 3-5 separate ideas that related to thes same point, it helps to indicate in advance, and enumerate them. E.g., "There are four problems with this design…"

9. Distinguish between design problems that matter versus those that don't.

Variability Across Individual Subjects

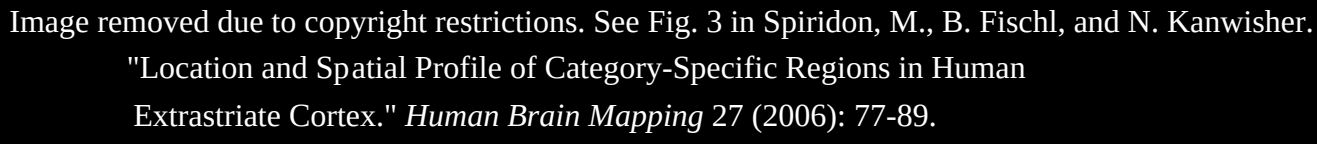
Contrasts

moving>
stationary

body parts>
objects

faces>
objects

scenes>
objects



• some discontiguities are apparent in individual regions.

• locations are overlapping but not identical across subjects

Coregister data across subjects using “spherical coordinates”, then ask which regions show a significant response in a given contrast in the same location in at least 30% of Ss.

Population overlap Maps on Cortical Surface, Spherical Coords.

With Bruce Fischl & Mona Spiridon

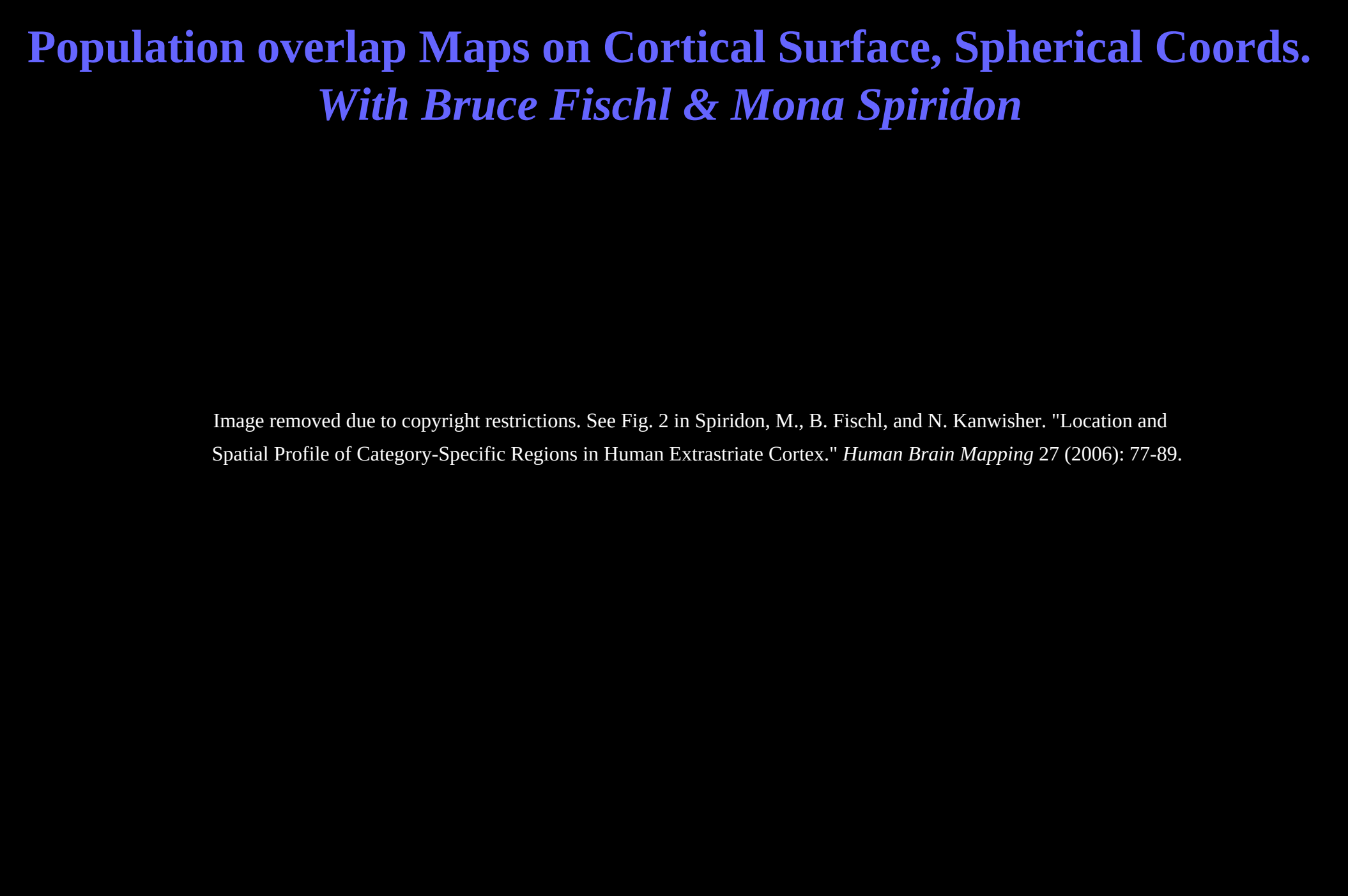


Image removed due to copyright restrictions. See Fig. 2 in Spiridon, M., B. Fischl, and N. Kanwisher. "Location and Spatial Profile of Category-Specific Regions in Human Extrastriate Cortex." *Human Brain Mapping* 27 (2006): 77-89.

Potter (1971)

Presented a random sequence of complex scenes to subjects at a rate of around 7/second. Found that subjects could get the gist of pretty much each one. (e.g., detect a “picnic”).

Implies:

i) don’t need “top-down” prediction to recognize objects

ii) object/scene recognition is FAST!