Visual Object Recognition: Computational Models and Neurophysiological Mechanisms

Neurobiology 130/230. Harvard College/GSAS 78454

Web site: http://tinyurl.com/visionclass (Class notes, readings, etc)

Location: Biolabs 2062

Time: Mondays 03:30 – 05:30

Lectures:

Faculty: Gabriel Kreiman and invited guests

TA: Yuchen Xiao

Class 6: Frederico A. C. Azevedo

Contact information:

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gabriel.kreiman@tch.harvard.edu
617-919-2530
Office Hours: After Class. Mon 05:30-06:30 or by appointment

Yuchen Xiao
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Visual Object Recognition: Computational Models and Neurophysiological Mechanisms

Neurobiology 130/230. Harvard College/GSAS 78454

Class 1. Introduction to pattern recognition [Kreiman]

Class 2. Why is vision difficult? Visual input. Natural image statistics. The retina. [Kreiman]

Class 3. Lesion studies in animal models. Neurological studies of cortical visual deficits in humans. [Kreiman]

Class 4. Psychophysics of visual object recognition [Jiye Kim]

October 9: University Holiday

Class 5. Introduction to the thalamus and primary visual cortex [Camille Gomez-Laberge]

Class 6. Adventures into terra incognita. Neurophysiology beyond V1 [Frederico Azevedo]

Class 7. First steps into inferior temporal cortex [Carlos Ponce]

Class 8. From the highest echelons of visual processing to cognition [Leyla Isik]

Class 9. Correlation and causality. Electrical stimulation in visual cortex [Kreiman]

Class 10. Theoretical neuroscience. Computational models of neurons and neural networks. [Kreiman]

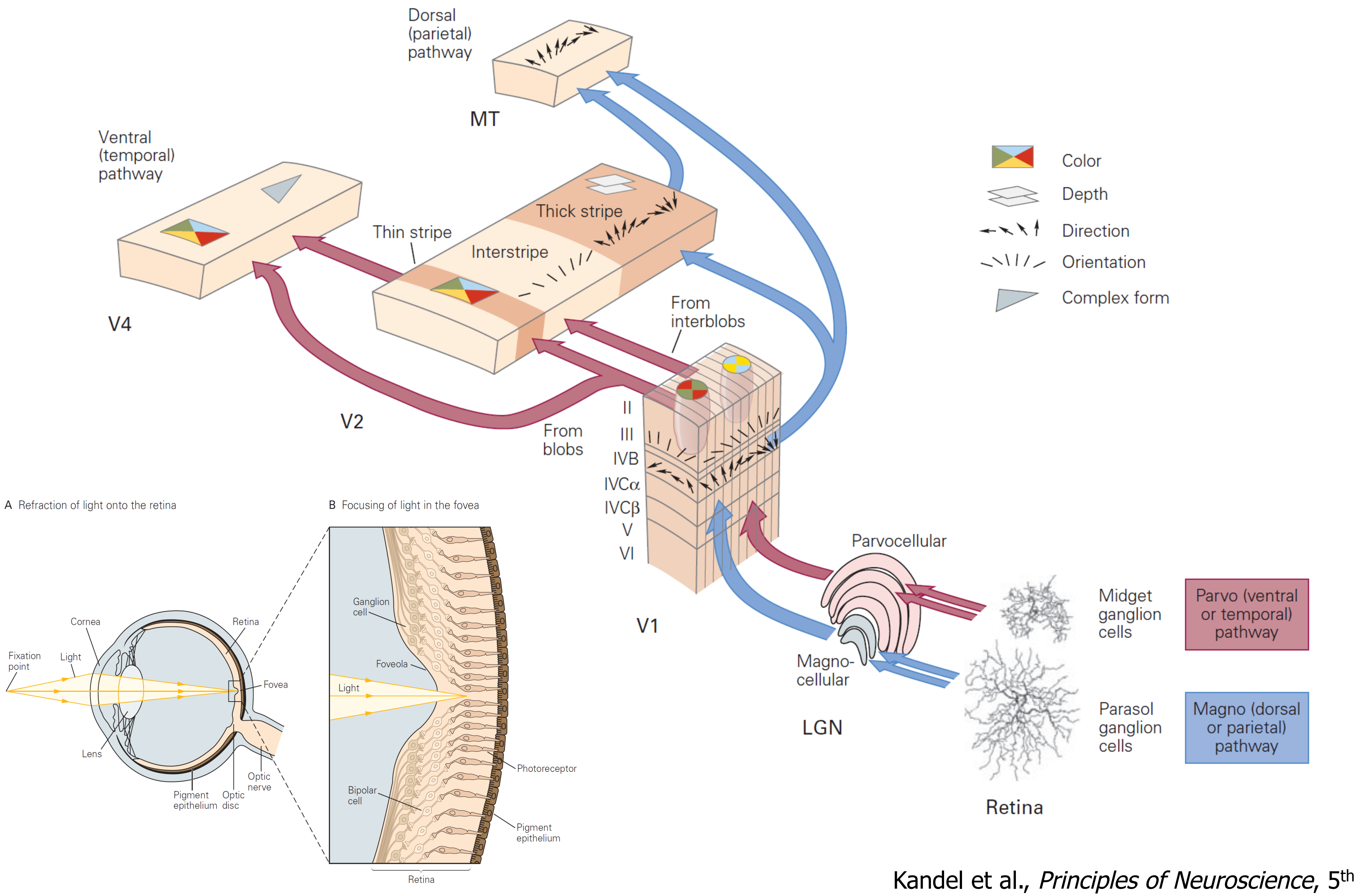
Class 11. Computer vision. Towards artificial intelligence systems for cognition [Bill Lotter]

Class 12. Vision and Language [Andrei Barbu]

Class 13. **[Extra class]** Towards understanding subjective visual perception. Visual consciousness. [Kreiman]

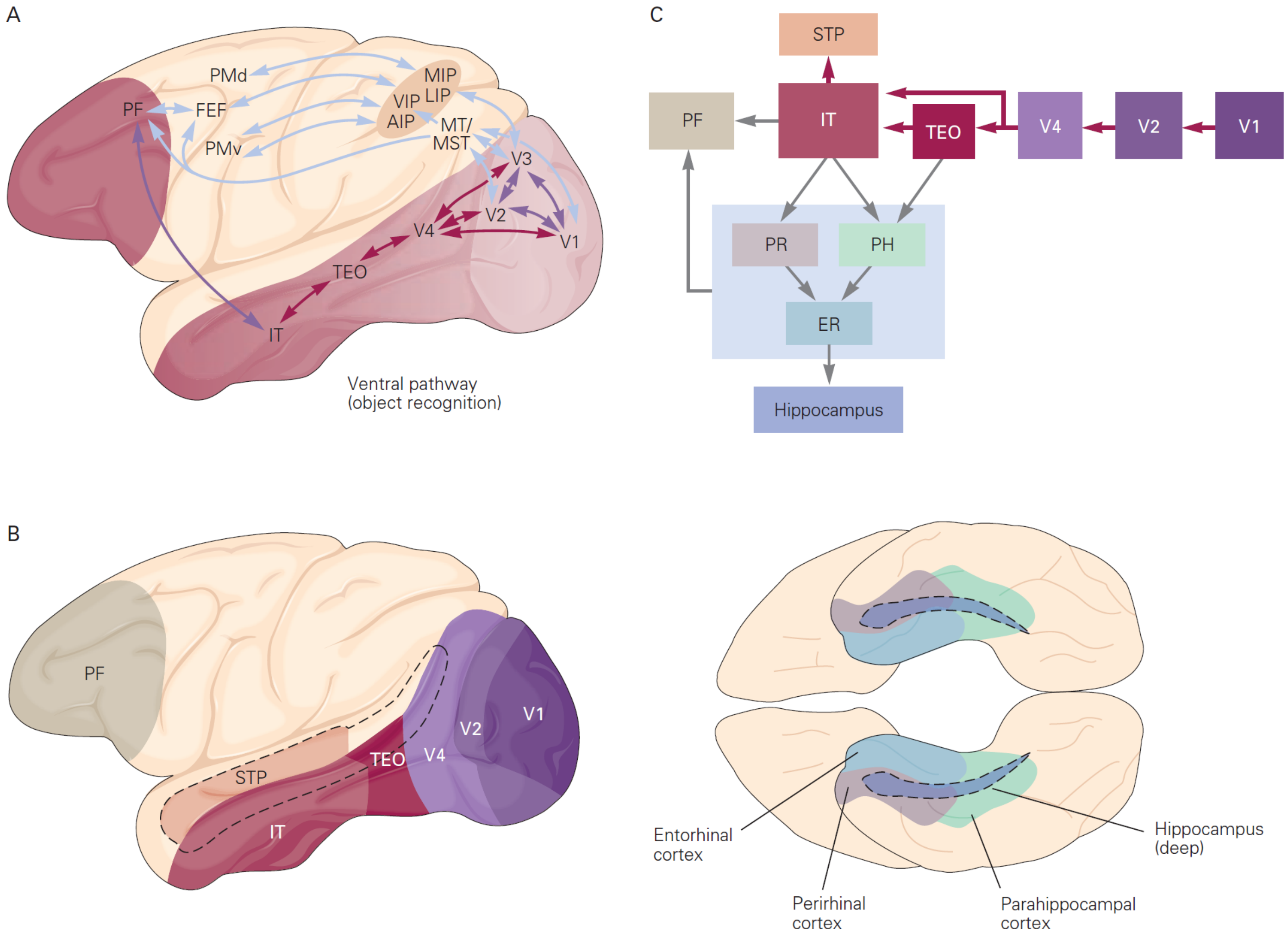
FINAL EXAM

Visual processing [1-min review]



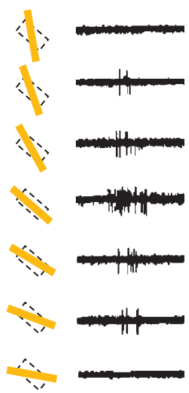
Kandel et al., *Principles of Neuroscience*, 5th ed.

Ventral pathway



Kandel et al., *Principles of Neuroscience*, 5th ed.

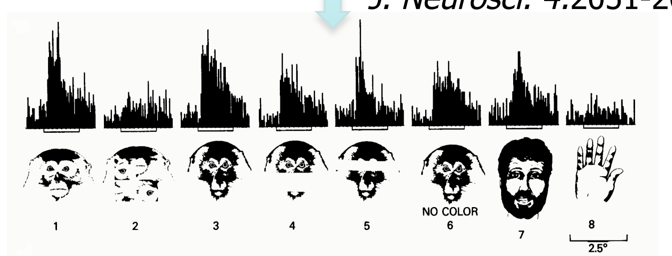
How do we go from oriented lines to complex shapes?

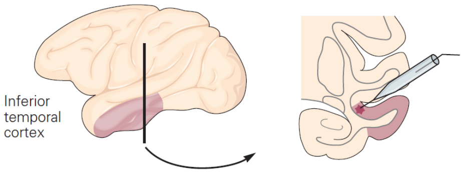


Hubel and Wiesel (1959) J. Physiol. **148**: 574-591

terra incognita

Desimone *et al* (1984) *J. Neurosci. 4*:2051-2062



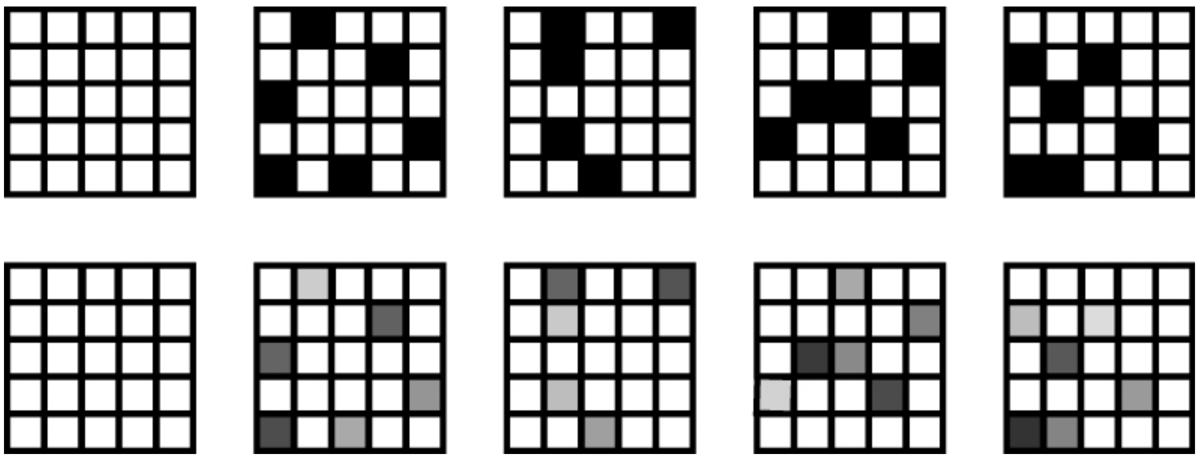


Divide and conquer strategy: multiple small steps are required to solve a complex task

The curse of dimensionality

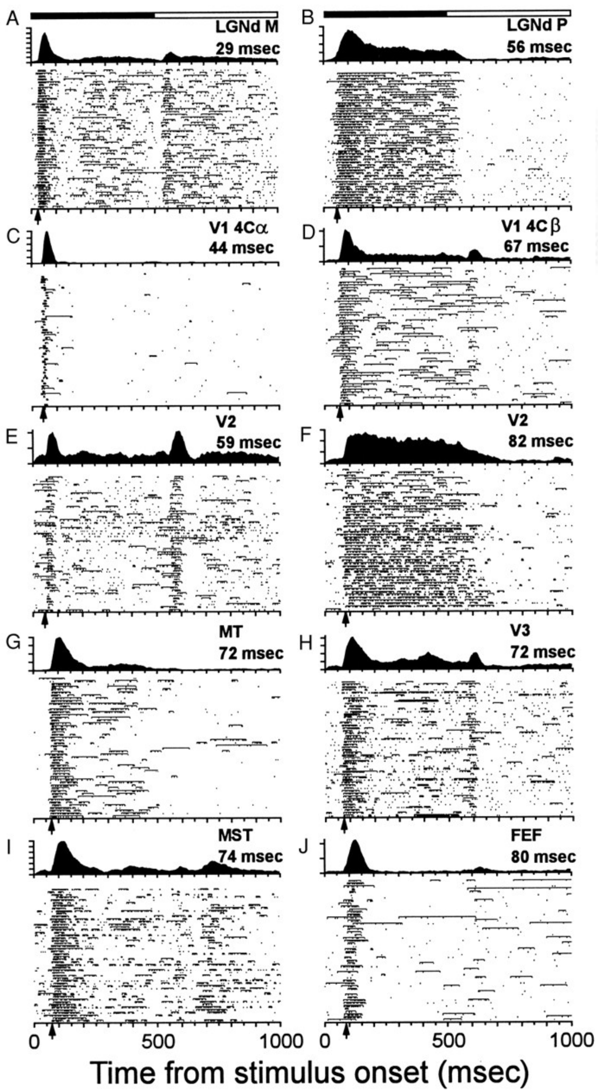
2^{25} possible images

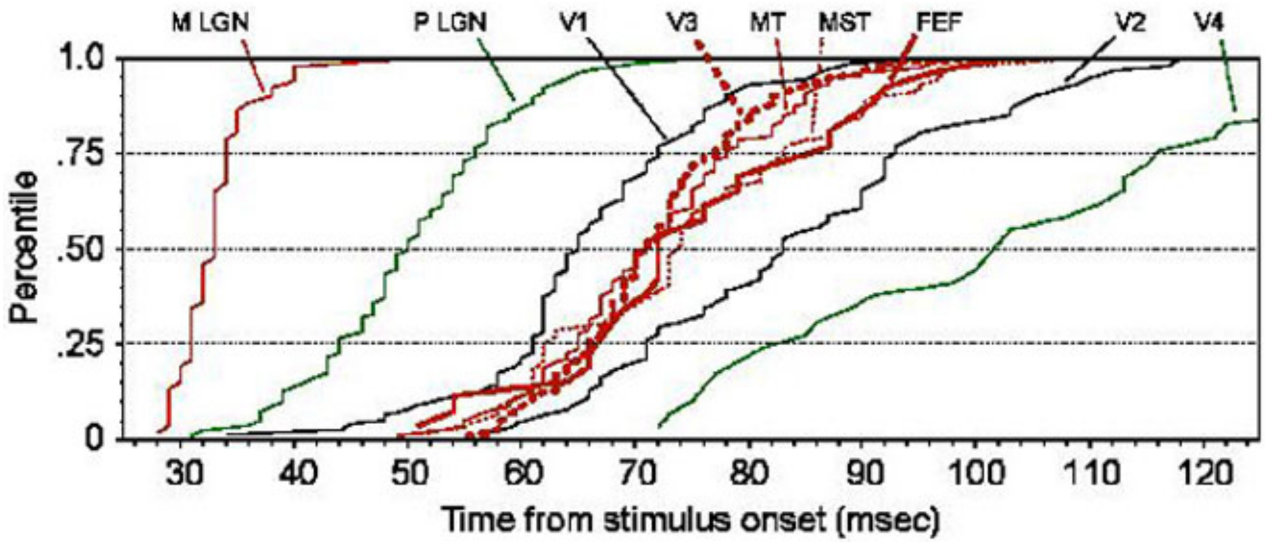
256^{25} possible images



Exhaustive exploration of the high dimensional image space is not possible with current techniques

Response latency increases along the visual hierarchy



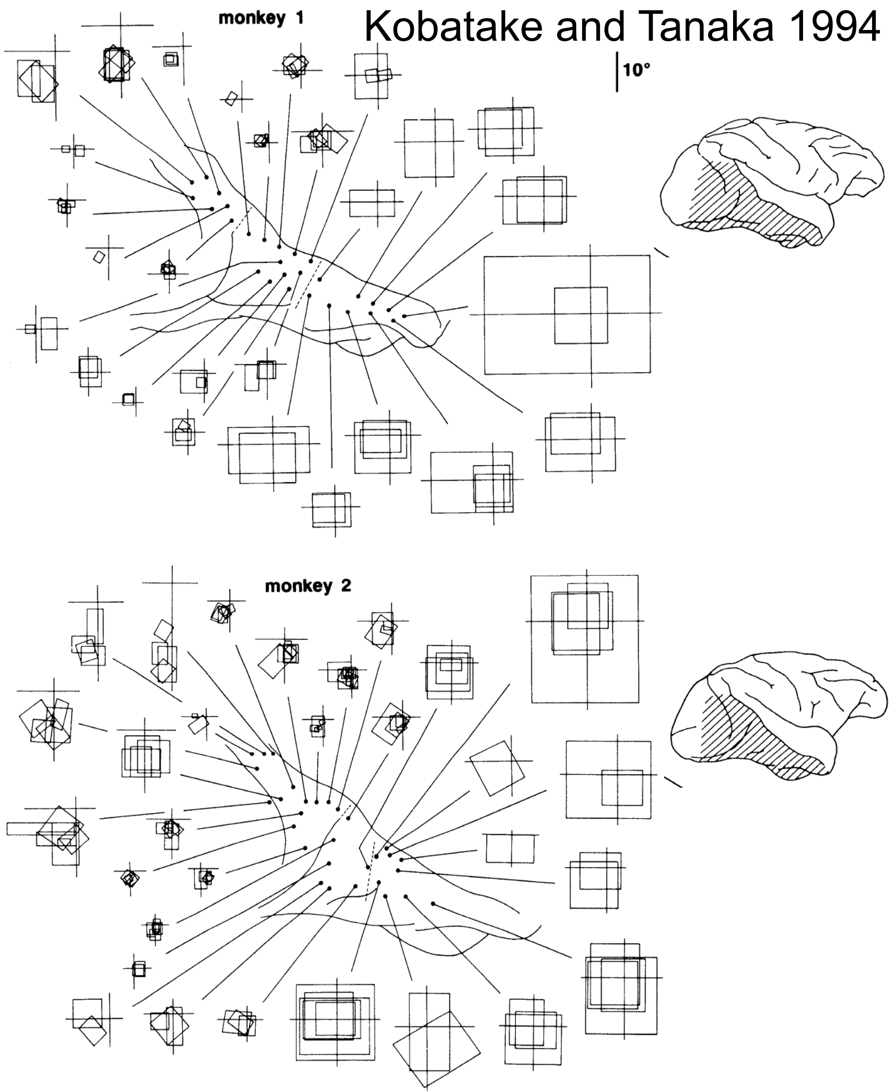


Area	Mean (ms)	S.D. (ms)
LGNd M layer	33	3.8
LGNd P layer	50	8.7
V1	66	10.7
V2	82	21.1
V4	104	23.4
V3	72	8.6
MT	72	10.3
MST	74	16.1
FEF	75	13

Each additional processing step takes ~15 ms

Schmolesky et al 1998

Receptive field size increases along the ventral visual stream



Kobatake and Tanaka 1994

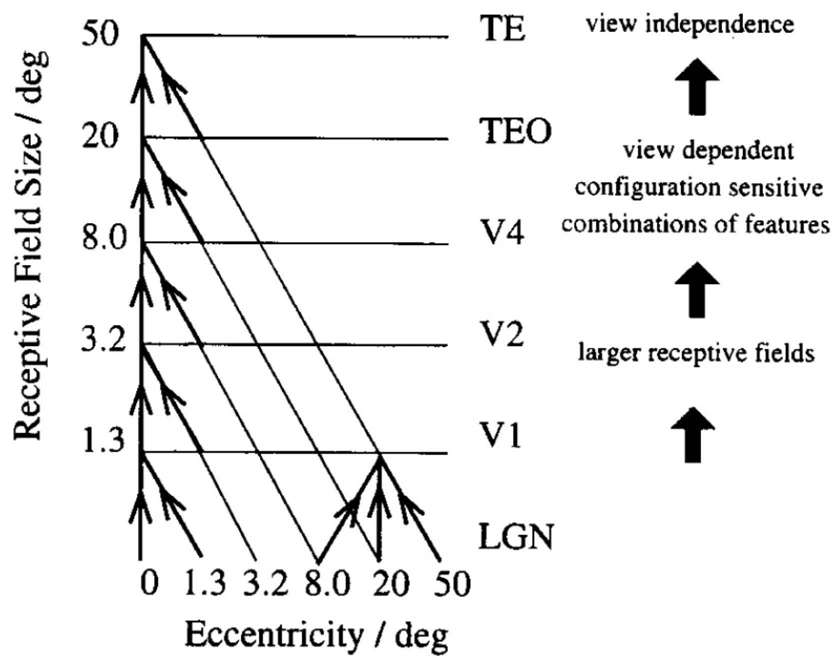
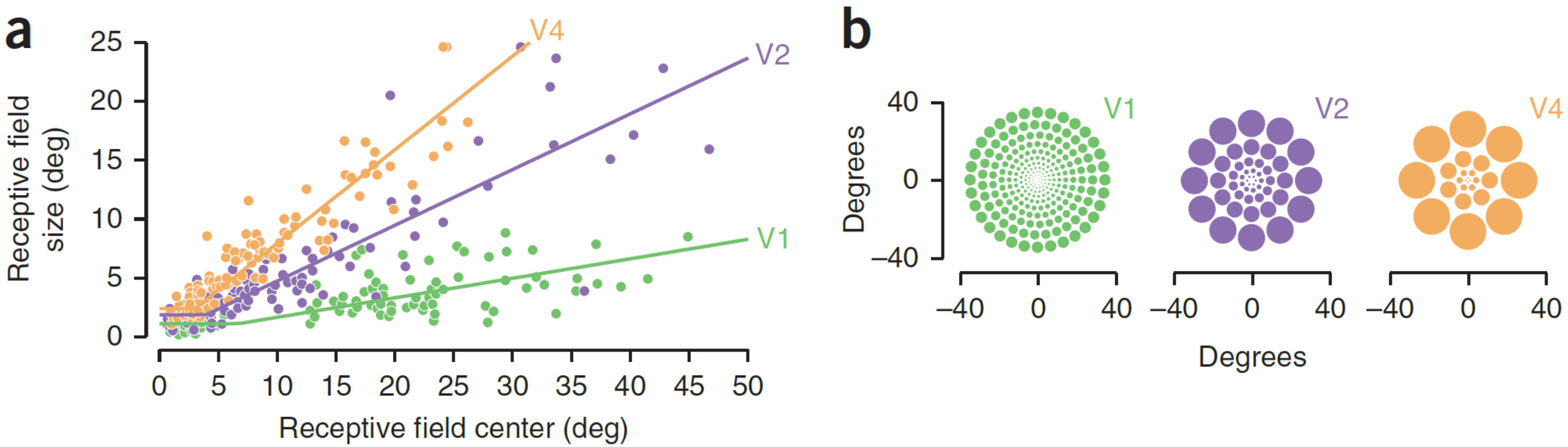


Fig. 2. Schematic diagram showing convergence achieved by the forward projections in the visual system, and the types of representation that may be built by competitive networks operating at each stage of the system from the primary visual cortex (V1) to the inferior temporal visual cortex (area TE) (see text). Area TEO forms the posterior inferior temporal cortex. The receptive fields in the inferior temporal visual cortex (e.g. in the TE areas) cross the vertical midline (not shown). Abbreviation: LGN, lateral geniculate nucleus.

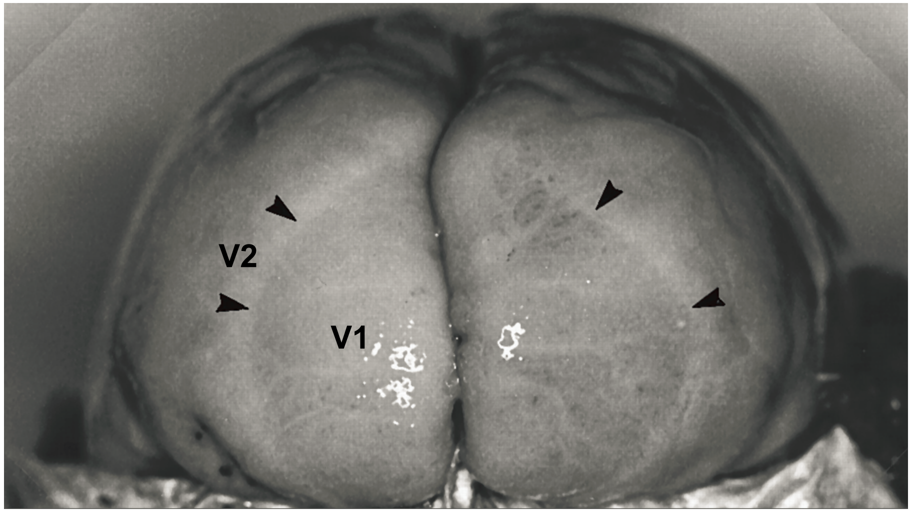
Wallis and Rolls 1997

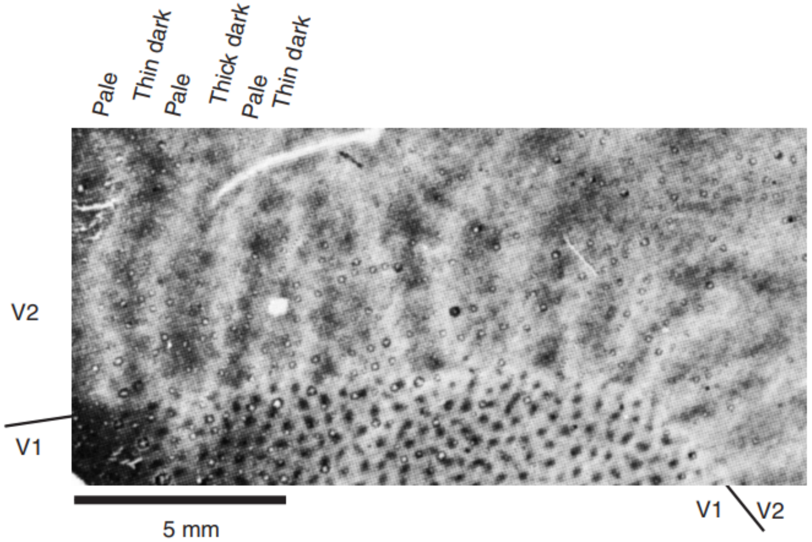
Receptive field size increases along the ventral visual stream



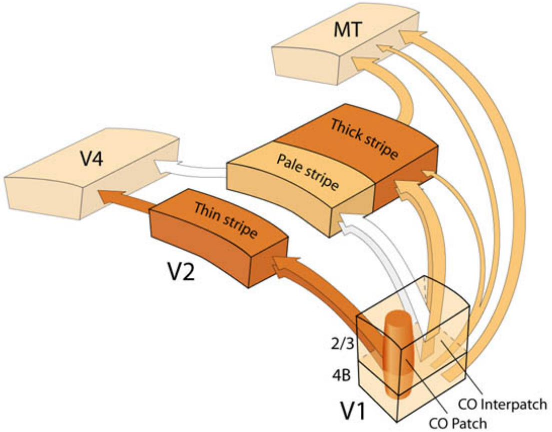
Freeman and Simoncelli 2013

Visual area V2

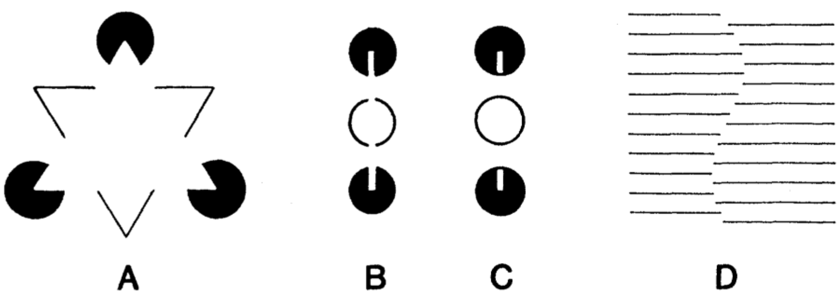


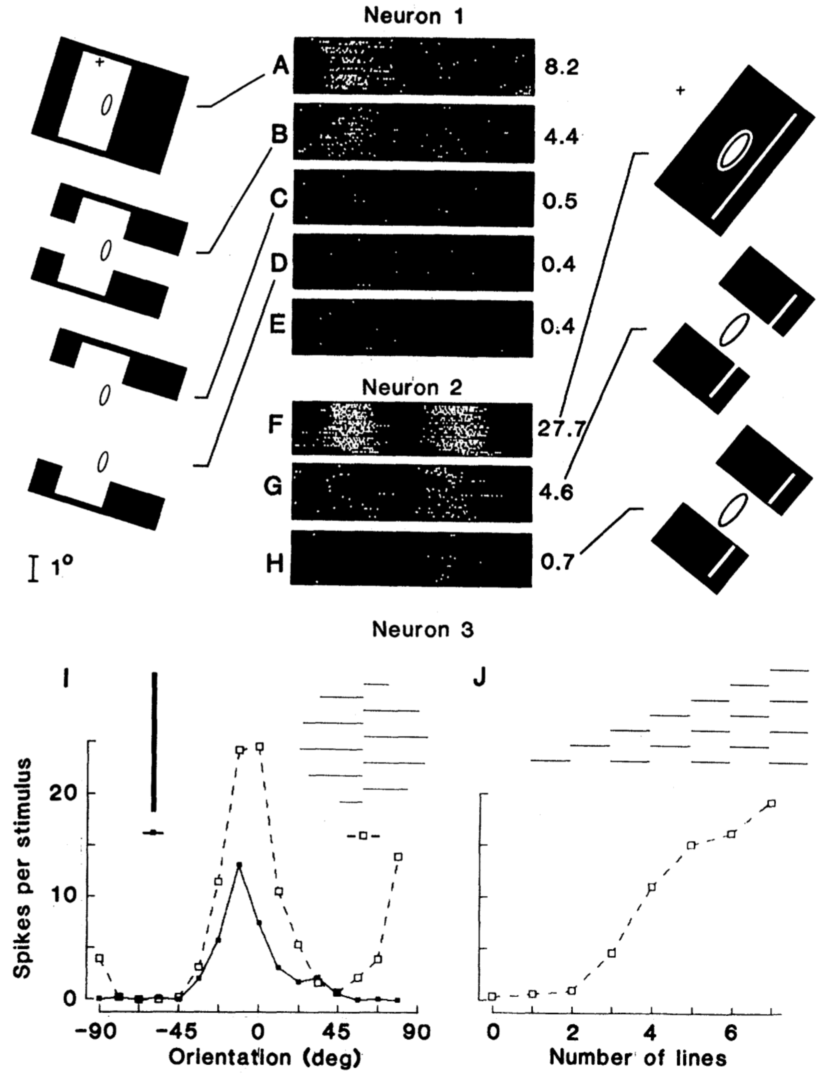


- Illusory Contours
- Binocular disparity
- Border Ownership
- …



Responses to illusory contours in area V2

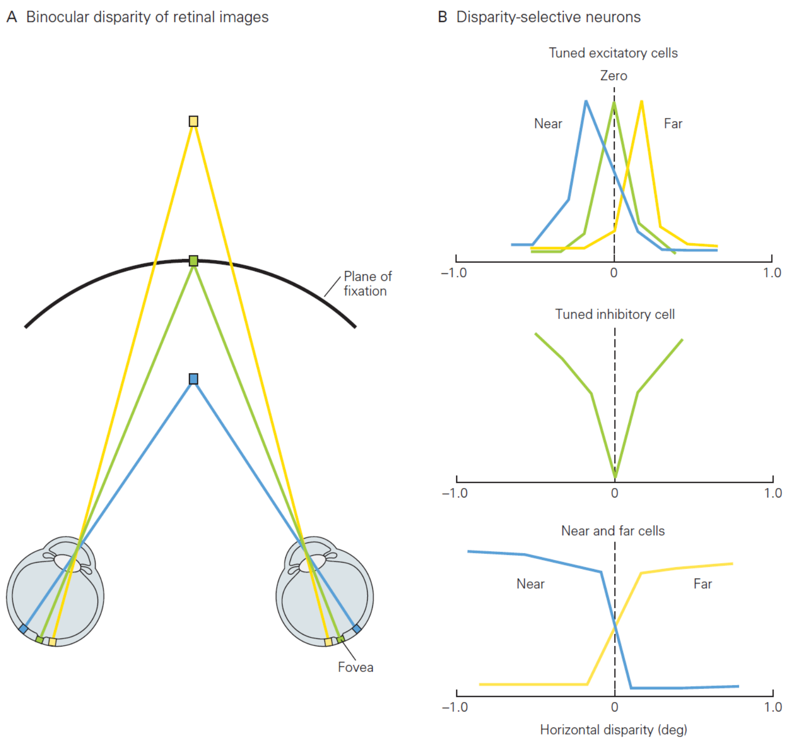




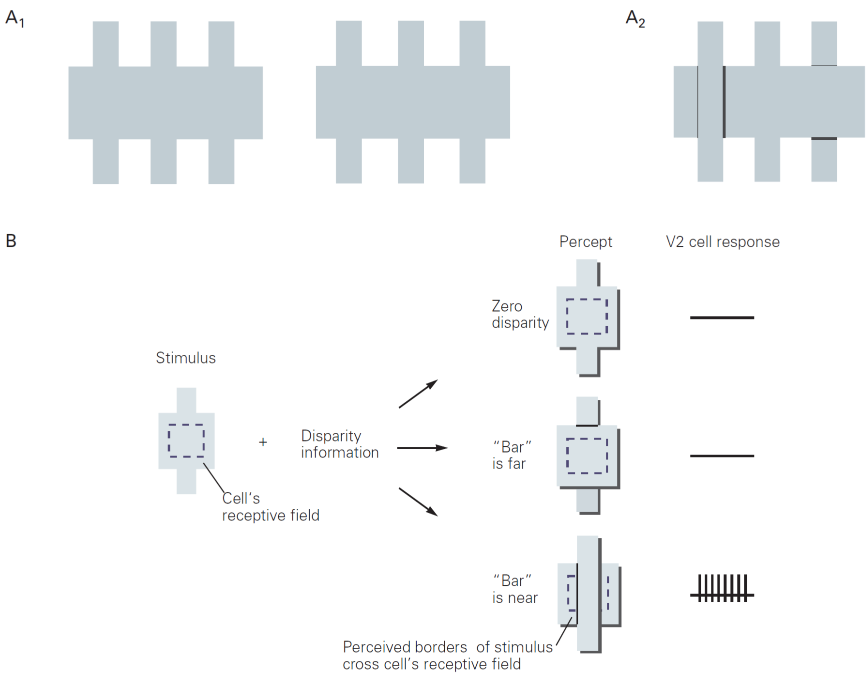
von der Heydt, R., Peterhans, E., & Baumgartner, G. (1984). Science, 224, 1260-1262.

Binocular disparity in V2

Depth cues influence object segmentation



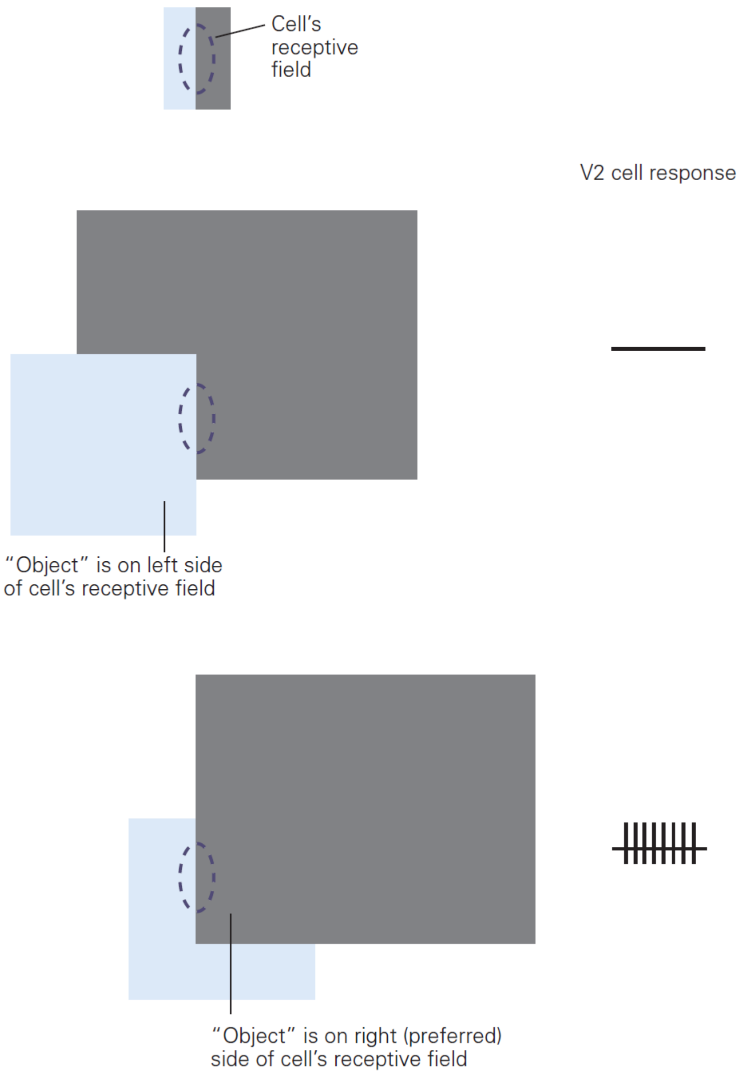
V1



V2

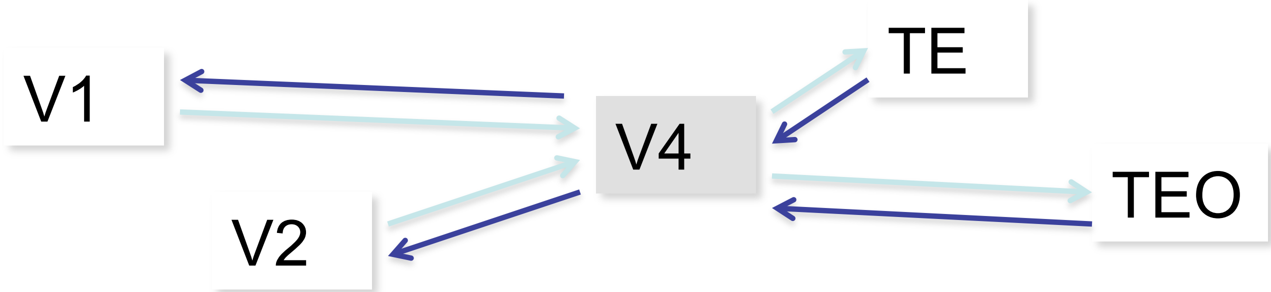
Kandel et al., *Principles of Neuroscience*, 5th ed.

Border ownership in V2



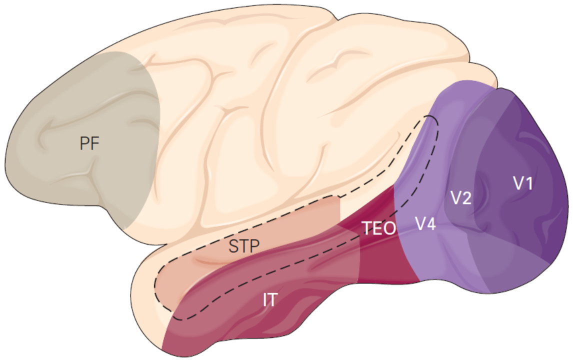
Kandel et al., *Principles of Neuroscience*, 5th ed.

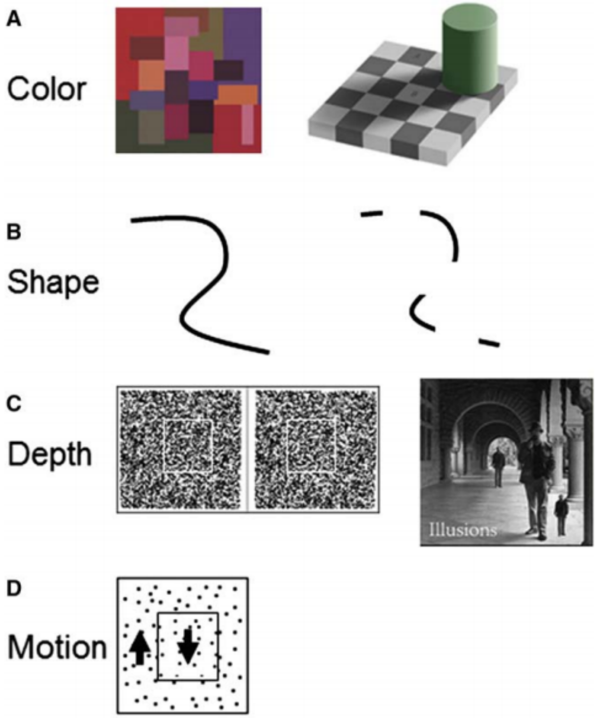
Visual area V4



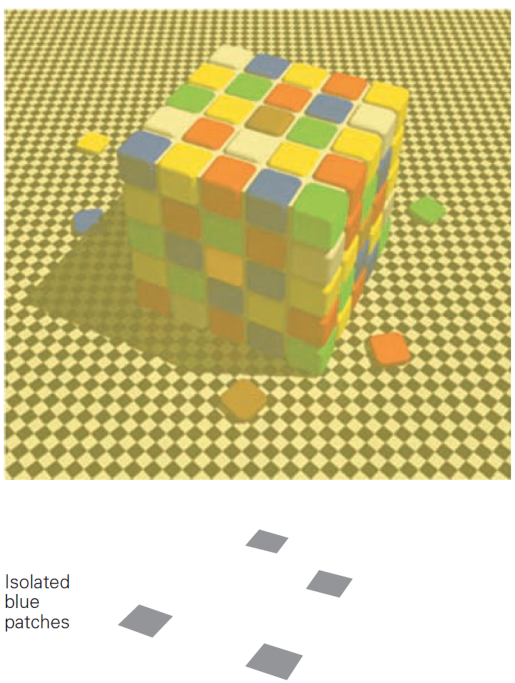
V4 lesions:

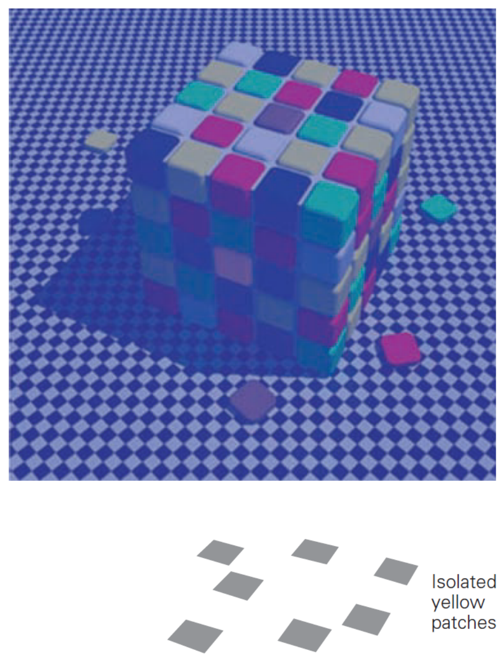
- moderate impairment in simple 2D shape discrimination
- Large deficit in 3D object recognition
- Loss of color constancy
- Deficits in the ability to detect less salient objects

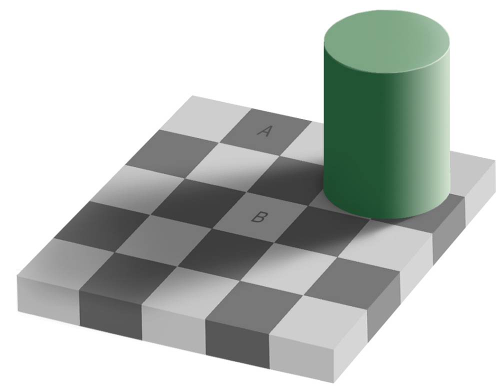




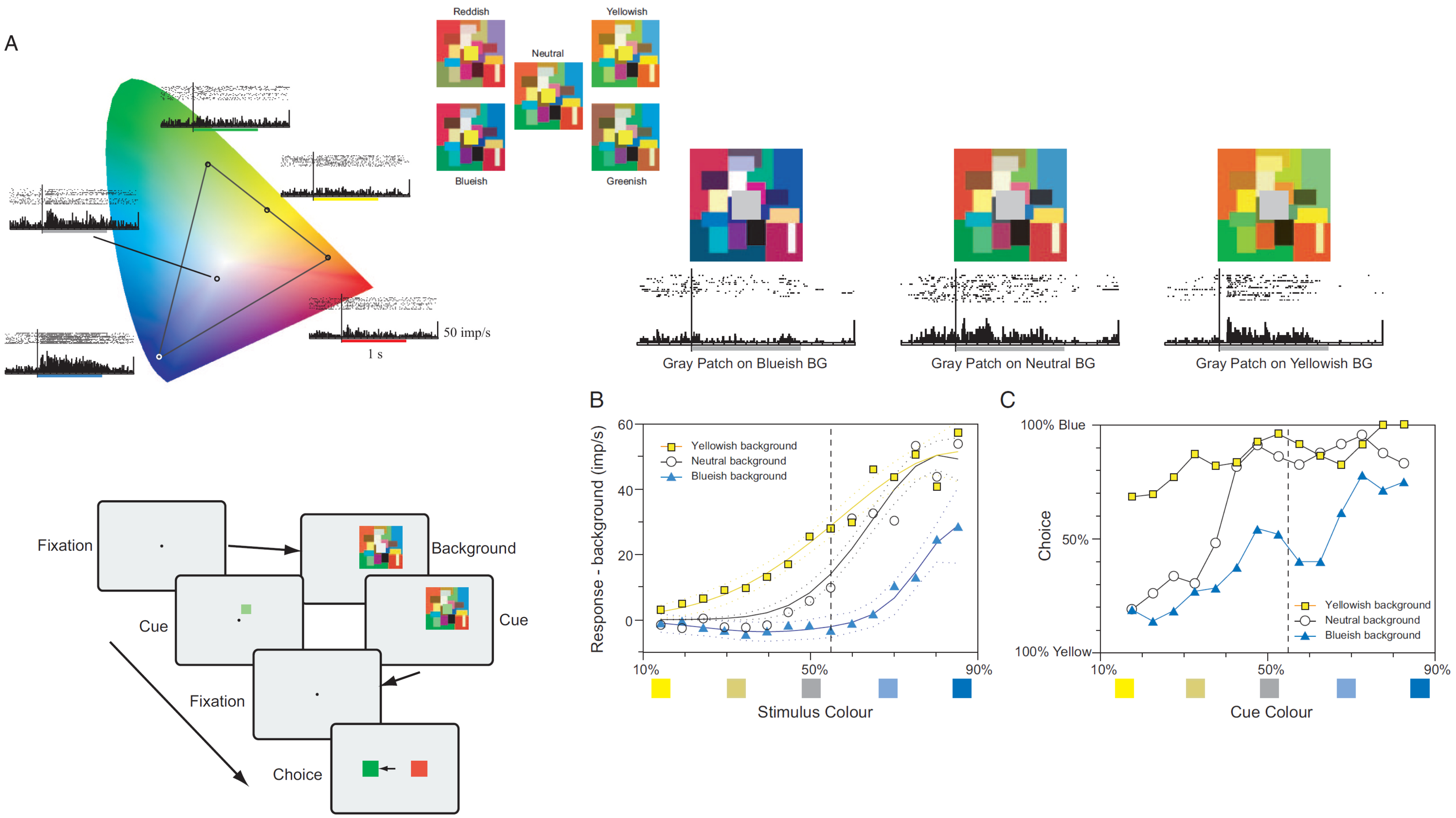
Neurons in V4 show color selectivity





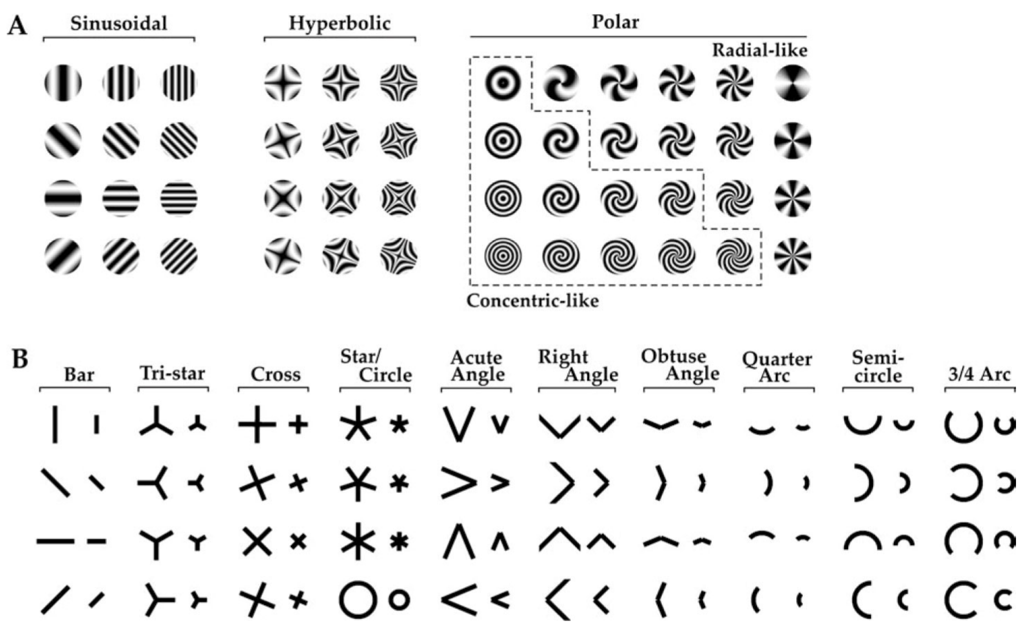


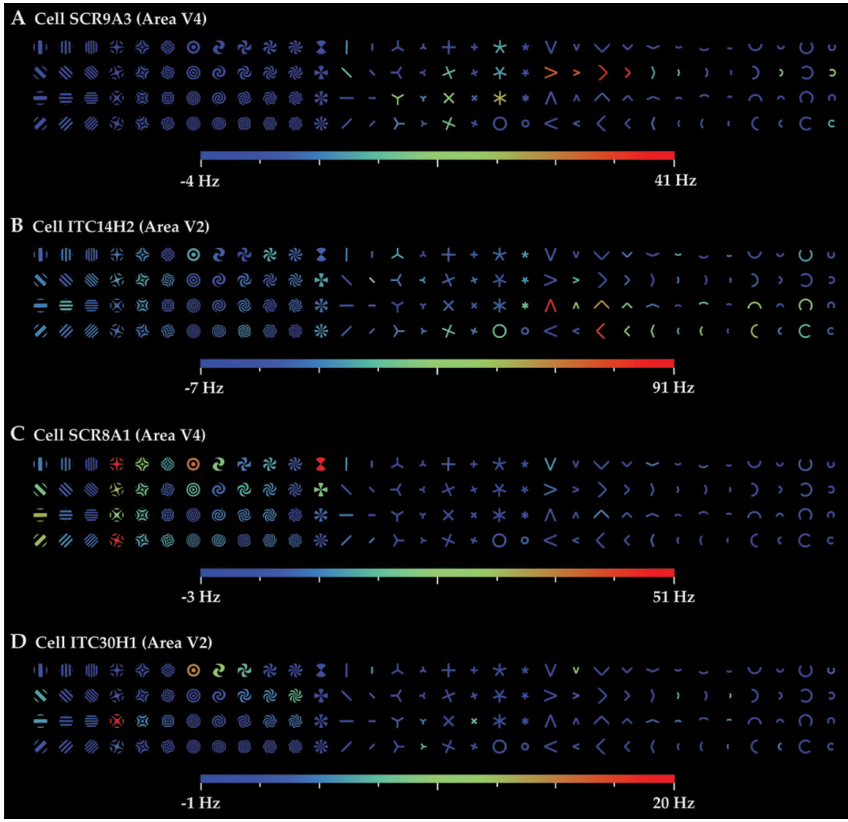
Neurons in V4 show color selectivity



Kusunoki M, Moutoussis K, Zeki S (2006) Effect of background colors on the tuning of color-selective cells in monkey area V4. J Neurophysiol 95:3047-3059.

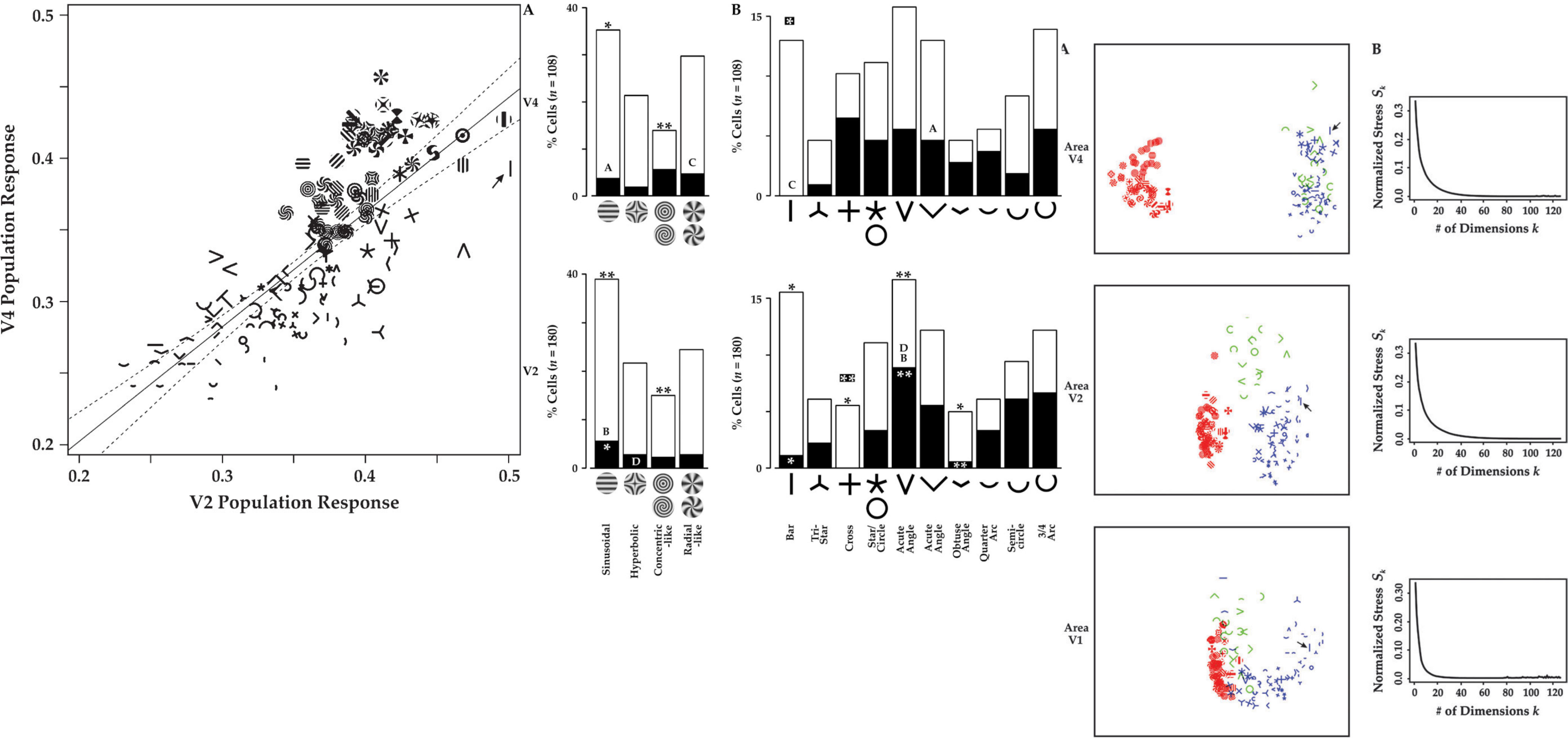
Probing the responses of V2 and V4 neurons





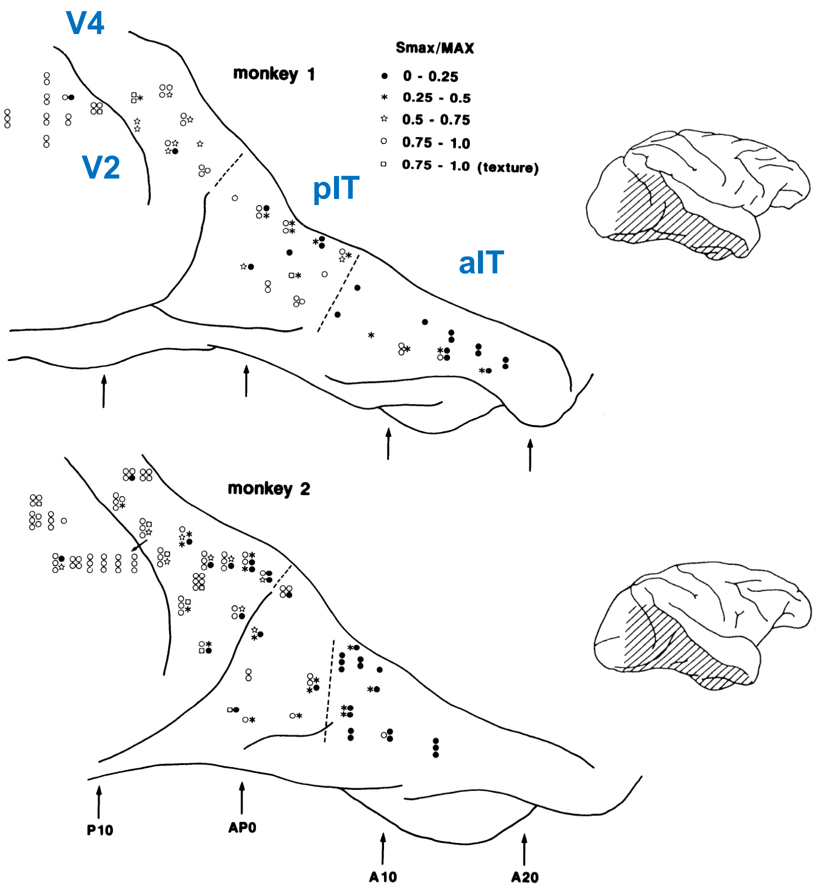
Hegde, J., & Van Essen, D. C. (2007). A comparative study of shape representation in macaque visual areas V2 and v4. Cereb Cortex, 17(5), 1100-1116.

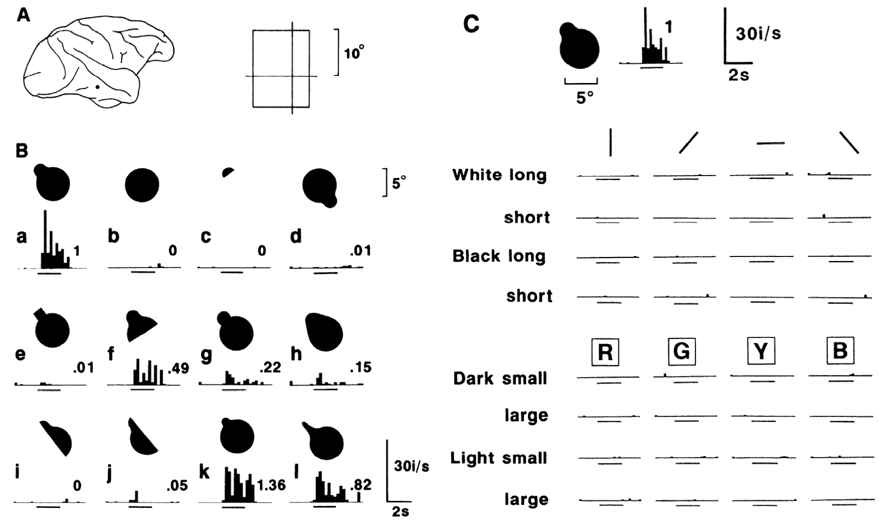
Varied responses along the ventral visual stream

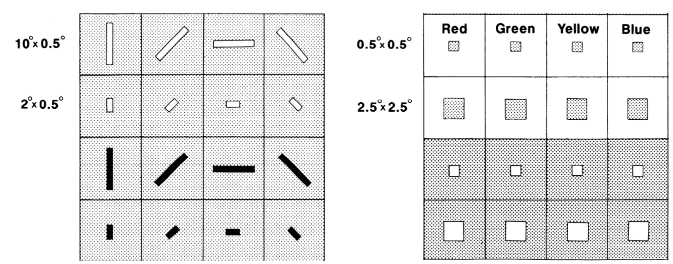


Hegde, J., & Van Essen, D. C. (2007). A comparative study of shape representation in macaque visual areas V2 and v4. Cereb Cortex, 17(5), 1100-1116.

Increase in "complexity" of feature preferences along the ventral visual stream

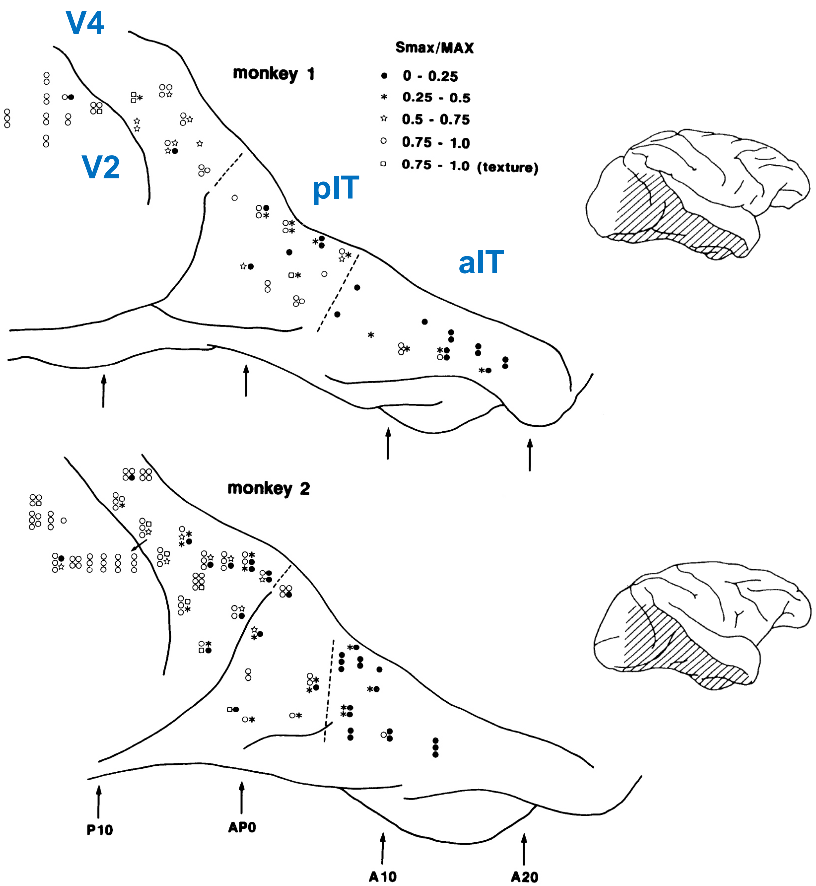


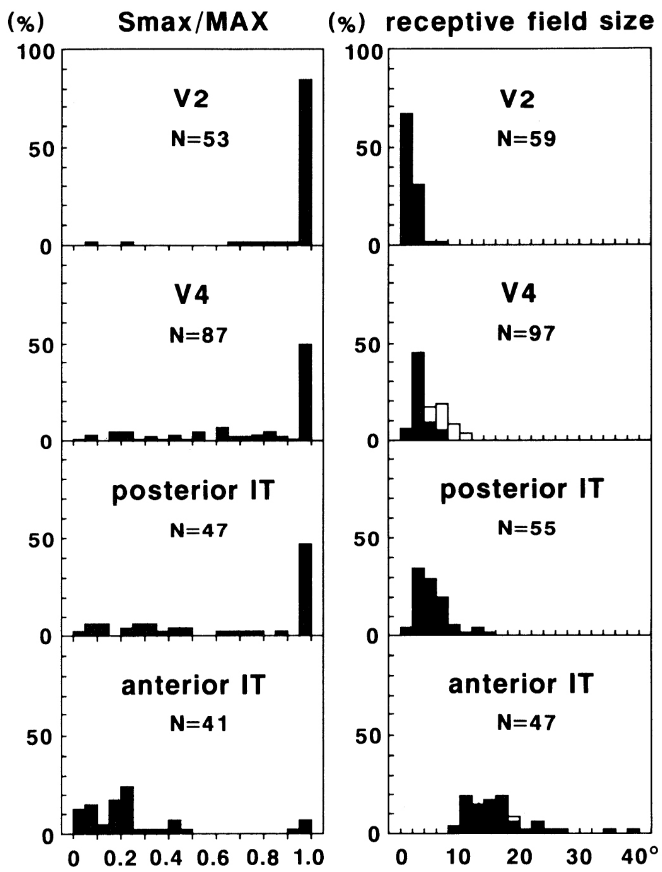




Kobatake E, Tanaka K (1994) Neuronal selectivities to complex object features in the ventral visual pathway of the macaque cerebral cortex. J Neurophysiol 71:856-867.

Increase in "complexity" of feature preferences along the ventral visual stream

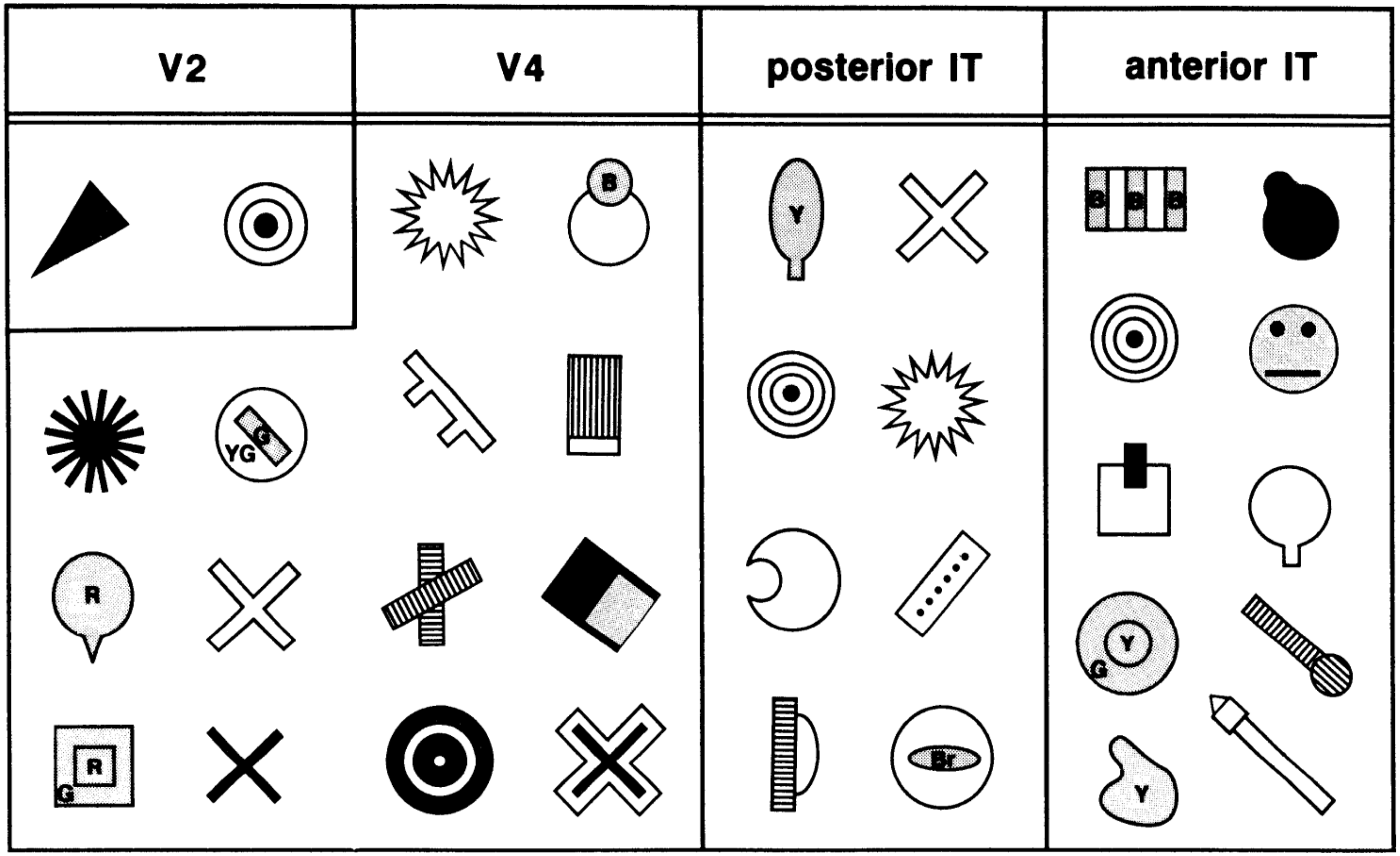




Smax = maximum response to "simple stimulus"
MAX = max response to all stimuli
Smax/MAX = 1 → "simple responses"
Smax/MAX = 0 → "complex responses"

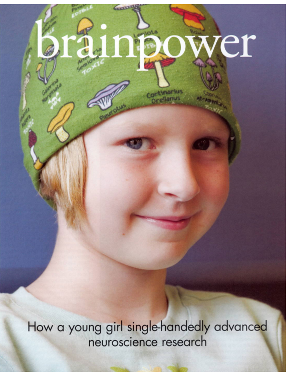
Kobatake E, Tanaka K (1994) Neuronal selectivities to complex object features in the ventral visual pathway of the macaque cerebral cortex. J Neurophysiol 71:856-867.

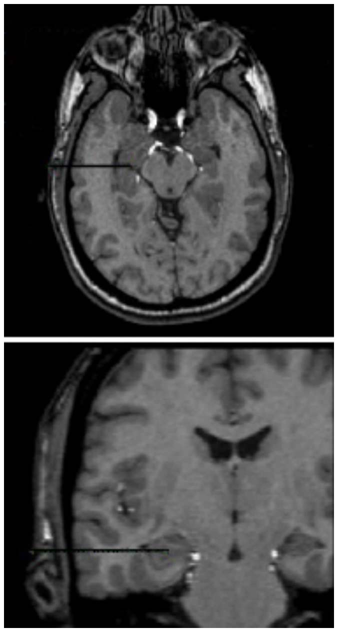
Increase in "complexity" of feature preferences along the ventral visual stream

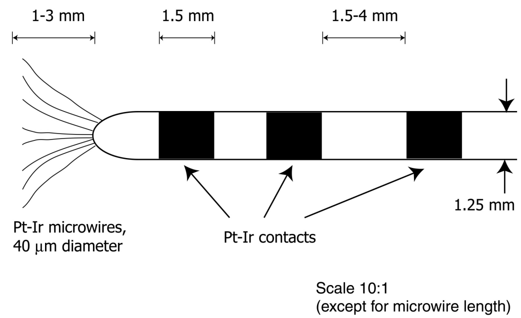


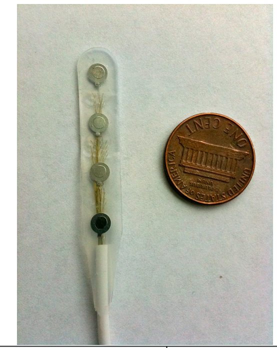
Kobatake E, Tanaka K (1994) Neuronal selectivities to complex object features in the ventral visual pathway of the macaque cerebral cortex. J Neurophysiol 71:856-867.

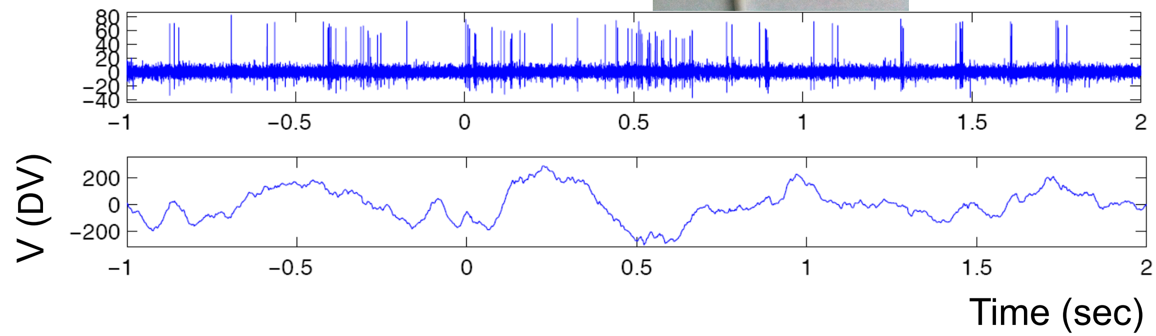
Neurophysiological recordings in the human brain









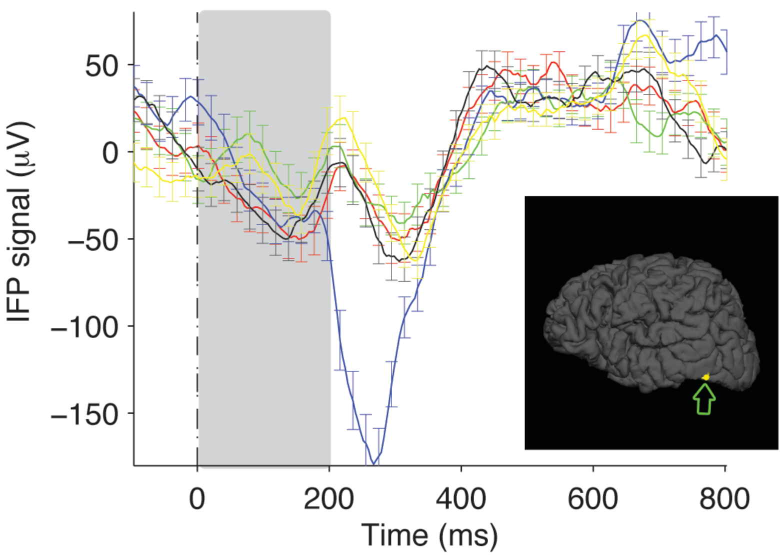


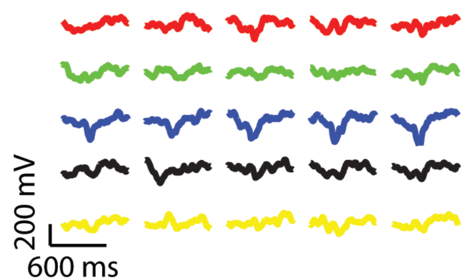
- Patients with pharmacologically intractable epilepsy
- Multiple electrodes implanted to localize seizure focus
- Targets typically include the temporal lobe (inferior temporal cortex, fusiform gyrus), medial temporal lobe (hippocampus, entorhinal cortex, amygdala and parahippocampal gyrus)
- Patients stay in the hospital for about 7-10 days

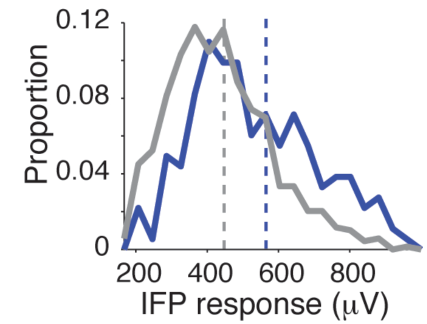
Fast decoding of object information in human visual cortex

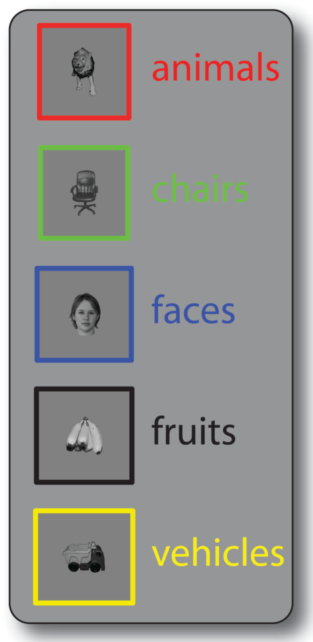
Theory 1: Top-down influences and long recurrent feedback connections (> 200 ms)

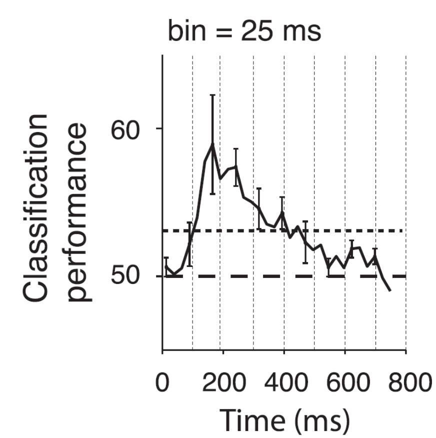
Theory 2: Bottom-up approach and largely dependent on feedforward processing (< 200 ms)





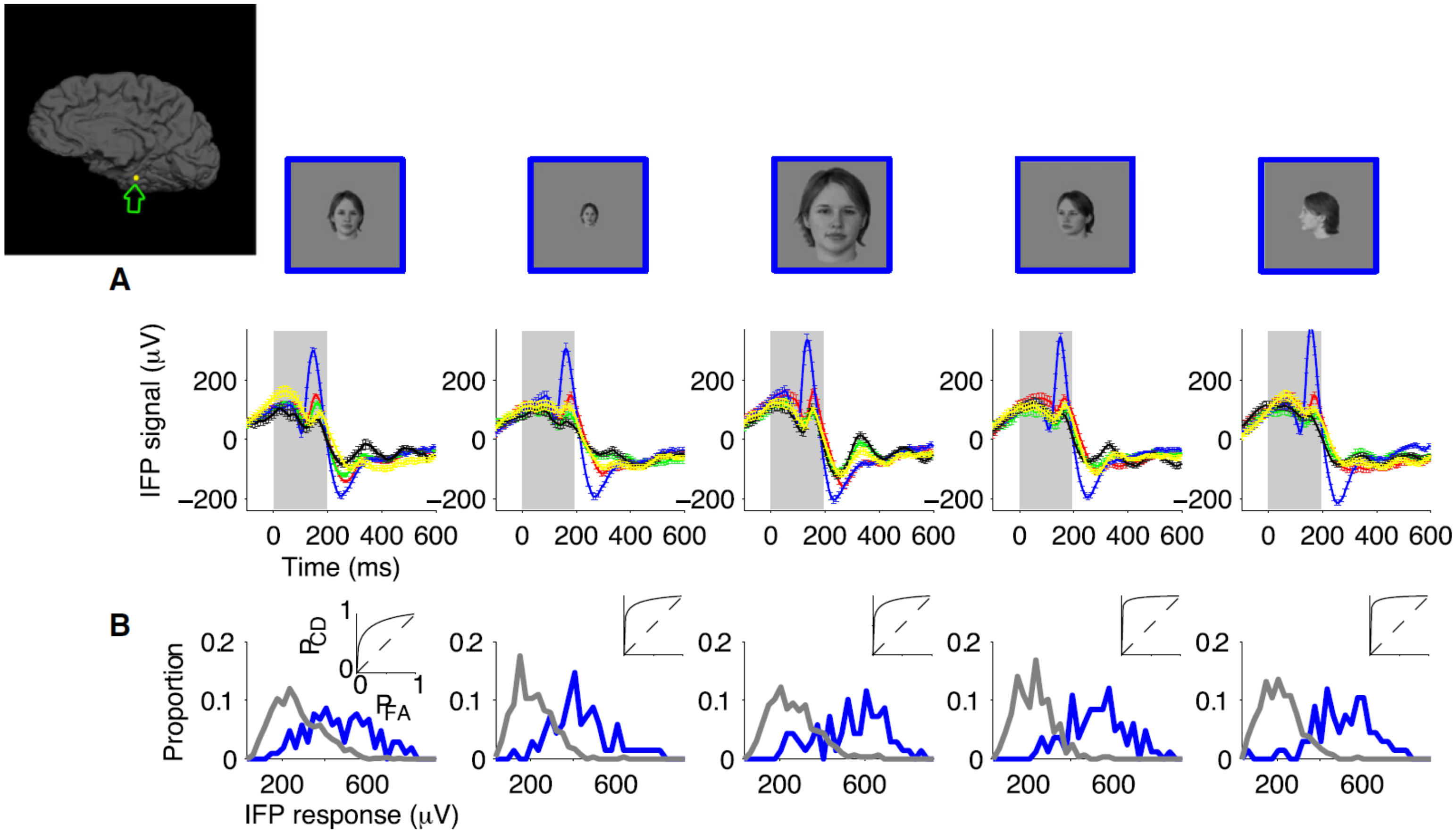






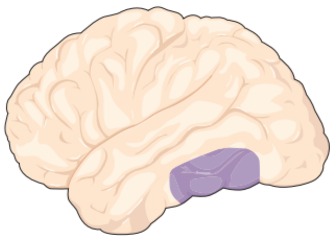
Liu et al. Neuron 2009

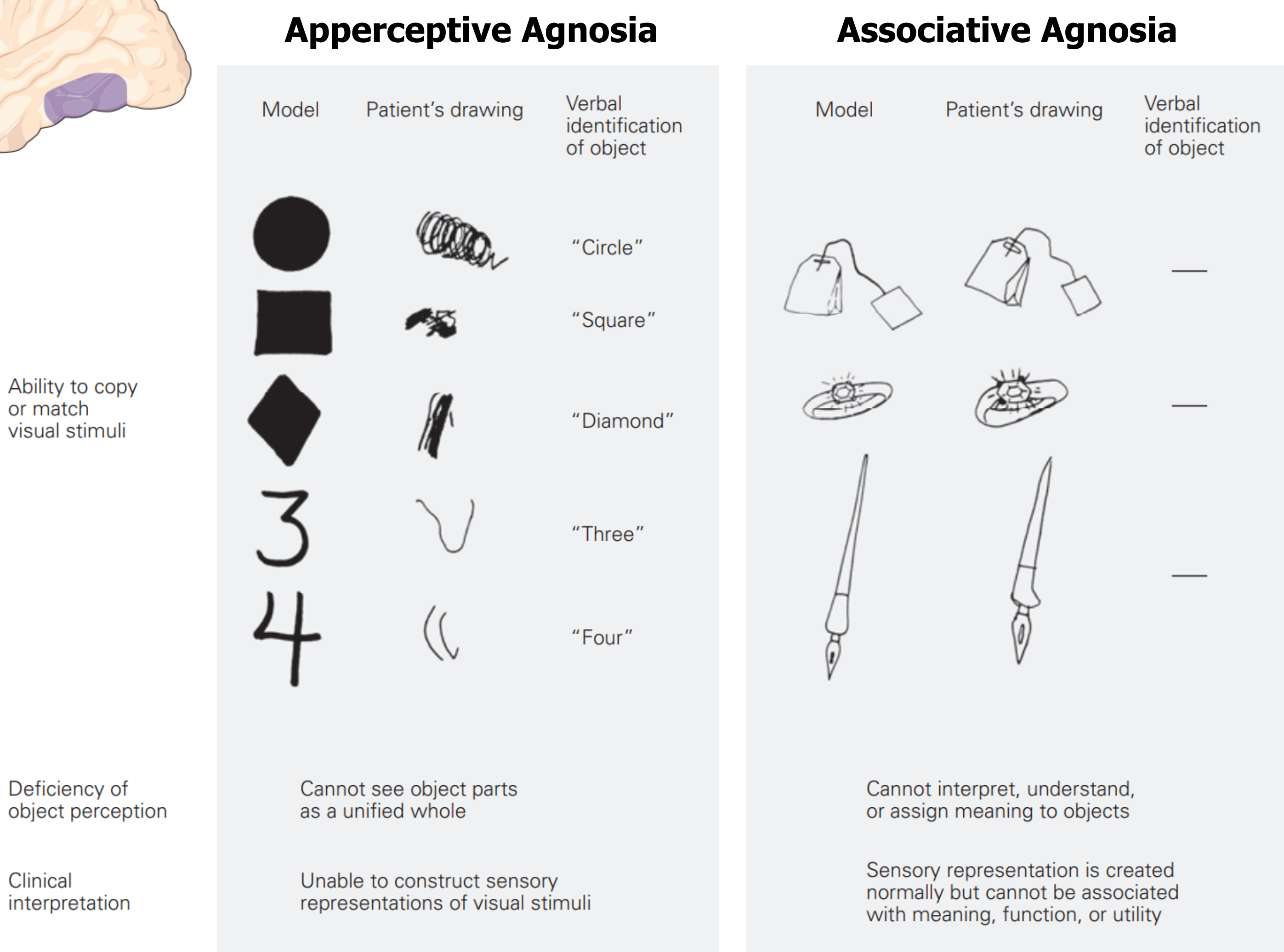
Fast decoding of object information in human visual cortex

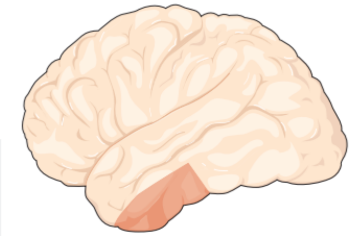


Liu et al. Neuron 2009

Neuropsychological evidence for object recognition in IT







Kandel et al., *Principles of Neuroscience*, 5th ed.

Further reading

- Kandel ER, Schwartz JH, Jessell TM, Siegelbaum SA, Hudspeth AJ 2013. Principles of Neural Science, 5th ed. McGraw-Hill, New York.
- Connor, C. E., Brincat, S. L., & Pasupathy, A. (2007). Transformation of shape information in the ventral pathway. Curr Opin Neurobiol, 17(2), 140-147.

<u>Original articles cited in class (see lecture notes for complete list)</u>

- Hubel, D. and T. Wiesel (1959). "Receptive fields of single neurons in the cat's striate cortex." Journal of Physiology (London) 148: 574-591.
- Desimone, R., et al. (1984). "Stimulus-selective properties of inferior temporal neurons in the macaque." Journal of Neuroscience 4(8): 2051-2062.
- Felleman, D. J. and D. C. Van Essen (1991). "Distributed hierarchical processing in the primate cerebral cortex." Cereb Cortex 1: 1-47.
- Schmolesky, M., et al. (1998). "Signal timing across the macaque visual system." Journal of Neurophysiology 79(6): 3272-3278.
- Wallis, G. and E. T. Rolls (1997). "Invariant face and object recognition in the visual system." PROGRESS IN NEUROBIOLOGY 51(2): 167-194.
- Hegde, J., & Van Essen, D. C. (2007). A comparative study of shape representation in macaque visual areas v2 and v4. Cereb Cortex, 17(5), 1100-1116.
- von der Heydt, R., Peterhans, E., & Baumgartner, G. (1984). Illusory contours and cortical neuron responses. Science, 224, 1260-1262.
- Luck, S. J., Chelazzi, L., Hillyard, S. A., & Desimone, R. (1997). Neural mechanisms of spatial selective attention in areas V1, V2, and V4 of macaque visual cortex. J Neurophysiol, 77(1), 24-42.
- David, S. V., Hayden, B. Y., & Gallant, J. L. (2006). Spectral receptive field properties explain shape selectivity in area V4. J Neurophysiol, 96(6), 3492-3505.
- Kusunoki M, Moutoussis K, Zeki S (2006) Effect of background colors on the tuning of color-selective cells in monkey area V4. J Neurophysiol 95:3047-3059
- Liu H, Agam Y, Madsen J, Kreiman G. (2009) Timing, timing, timing: Fast decoding of object inforrmation from intracranial field potentials in human visual cortex. Neuron 62:281-290
- Freeman, J. and E. P. Simoncelli (2011). "Metamers of the ventral stream." Nat Neurosci 14(9): 1195-1201.
- Kobatake, E. and K. Tanaka (1994). "Neuronal selectivities to complex object features in the ventral visual pathway of the macaque cerebral cortex." J Neurophysiol 71(3): 856-867

Reading assignment

(1) Write a critical comment on the paper

What was right?

What was wrong?

Is the interpretation justified?

Are the methods correct?

Are all the controls there?

Are there any confounding factors

(2) What would be a follow up study based on this paper?

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