# Visual Object Recognition
# Computational Models and Neurophysiological Mechanisms
Neuro 130/230. Harvard College/GSAS 78454

**What fraction of human cortex is devoted to processing visual information? Take a guess.**

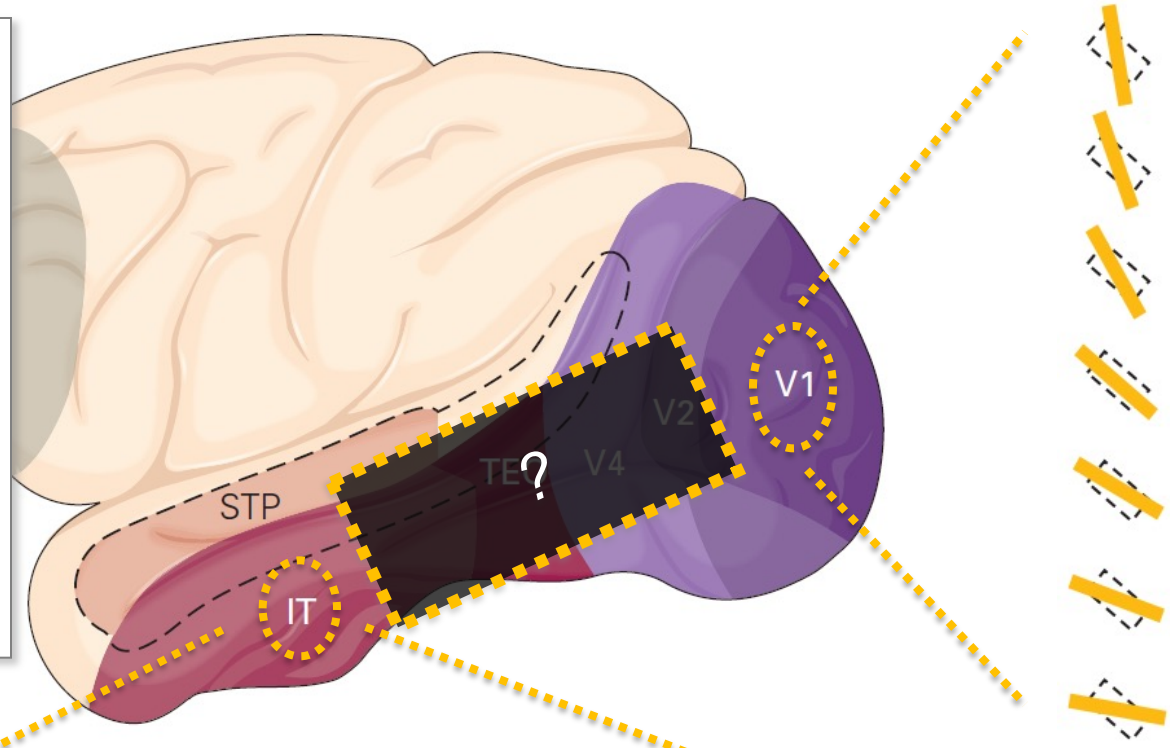
# Visual Object Recognition
# Computational Models and Neurophysiological Mechanisms
Neurobiology 230. Harvard College/GSAS 78454

Class 1 [09/01/2021]. Introduction to Vision
Note: no class on 09/06/2021
Class 2 [09/13/2021]. Natural image statistics and the retina
Class 3 [09/20/2021]. The Phenomenology of Vision
Class 4 [09/27/2021]. Learning from Lesions
Class 5 [10/04/2021]. Primary Visual Cortex
Note: no class on 10/11/2021
**Class 6 [10/18/2021]. Adventures into *terra incognita***
Class 7 [10/25/2021]. From the Highest Echelons of Visual Processing to Cognition
Class 8 [11/01/2021]. First Steps into in silico vision [Will Xiao]
Class 9 [11/08/2021]. Teaching Computers how to see
Class 10 [11/15/2021]. Computer Vision
Class 11 [11/22/2021]. Connecting Vision to the rest of Cognition
Class 12 [11/29/2021]. Visual Consciousness

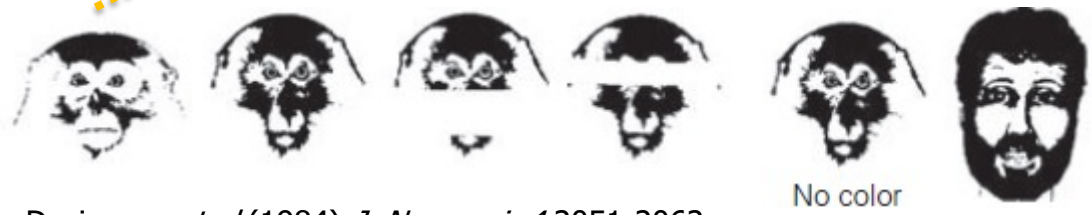
**FINAL EXAM, PAPER DUE 12/14/2021. No extensions.**

# How do we go from oriented lines to complex shapes?

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

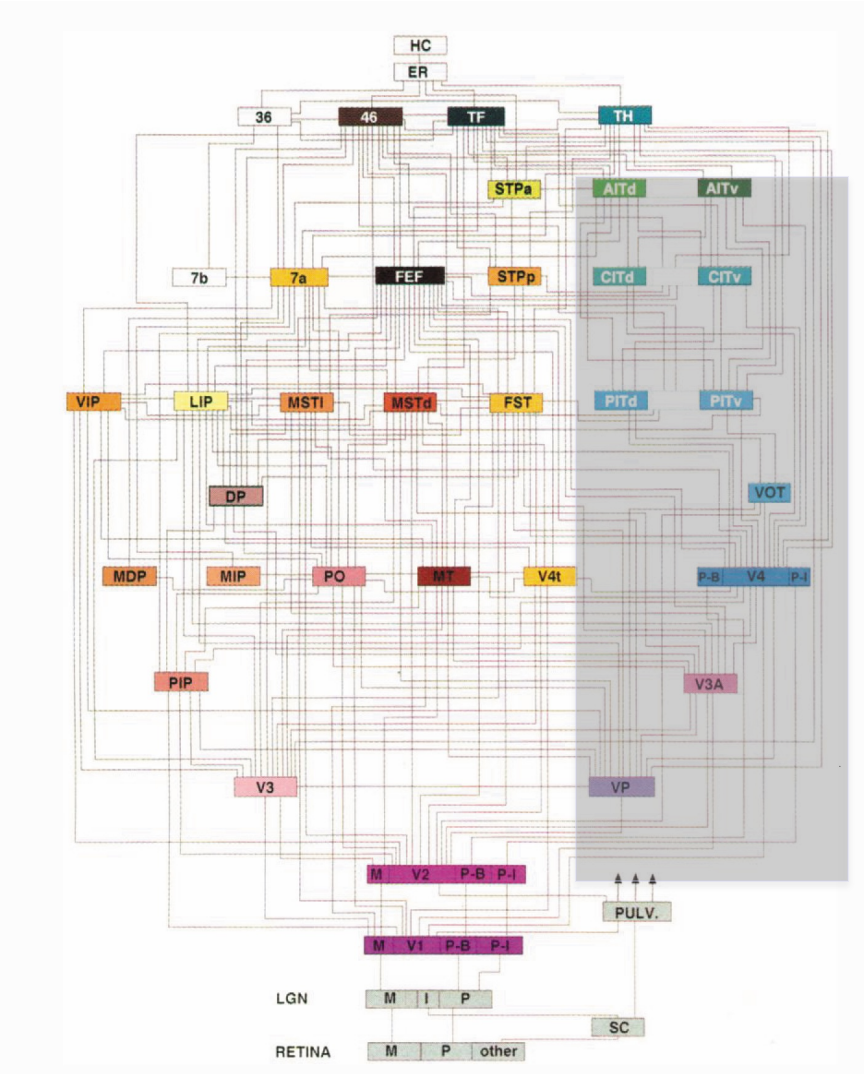


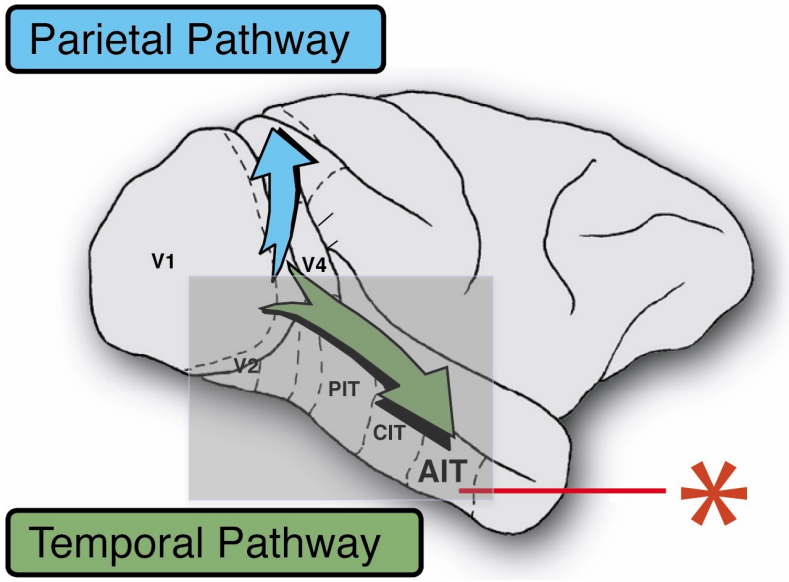

Hubel and Wiesel (1959)
J. Physiol. **148**: 574-591




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

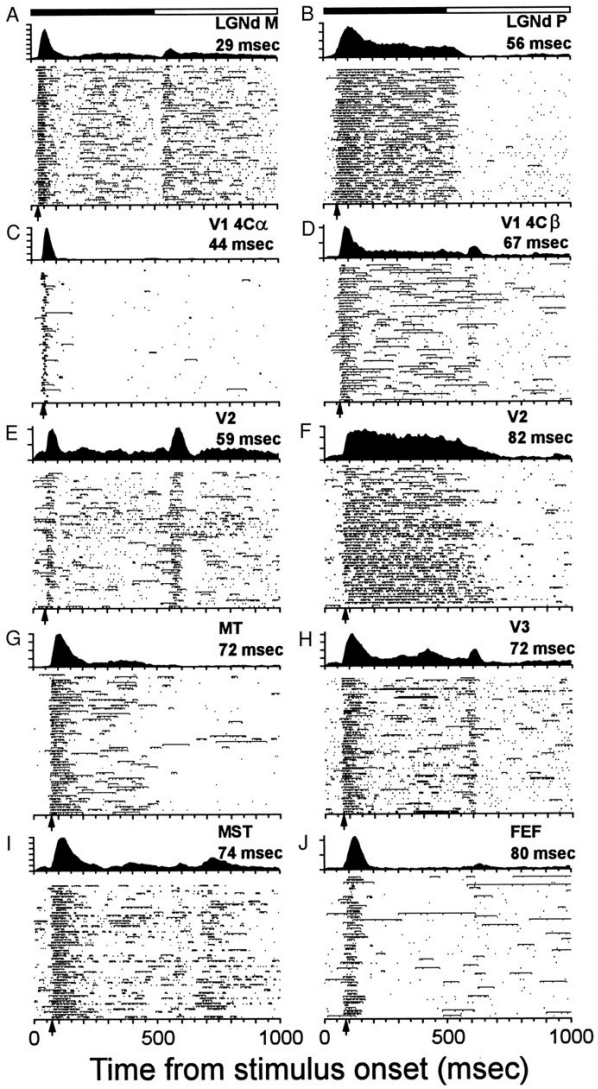
# Adventures into *terra incognita*

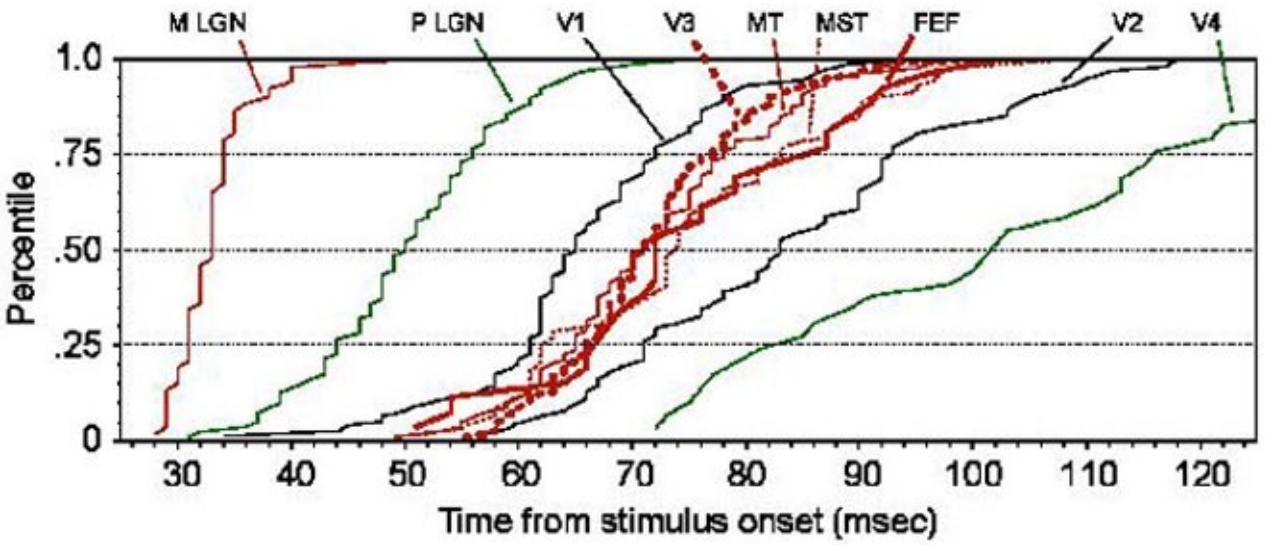



Felleman and Van Essen. *Cerebral Cortex* 1991

# Response latency increases along the visual hierarchy

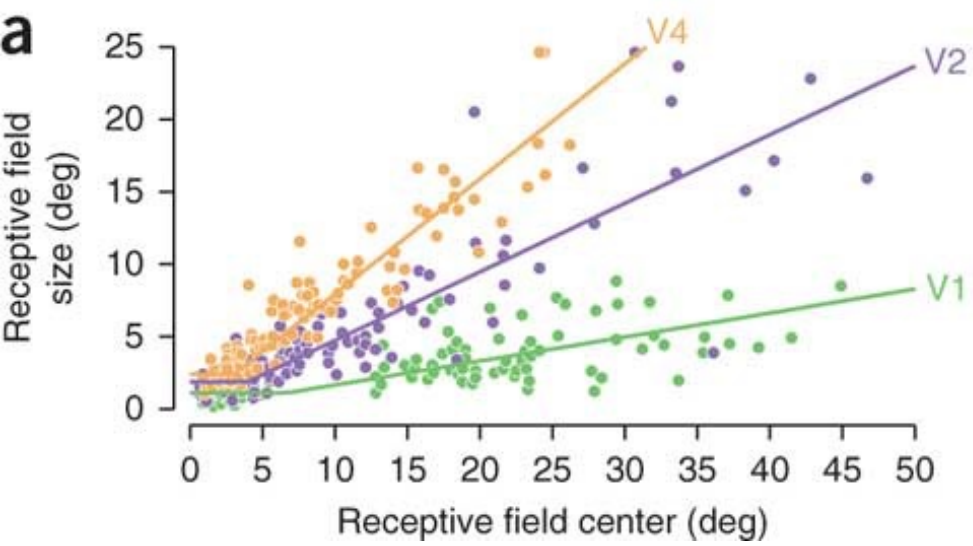


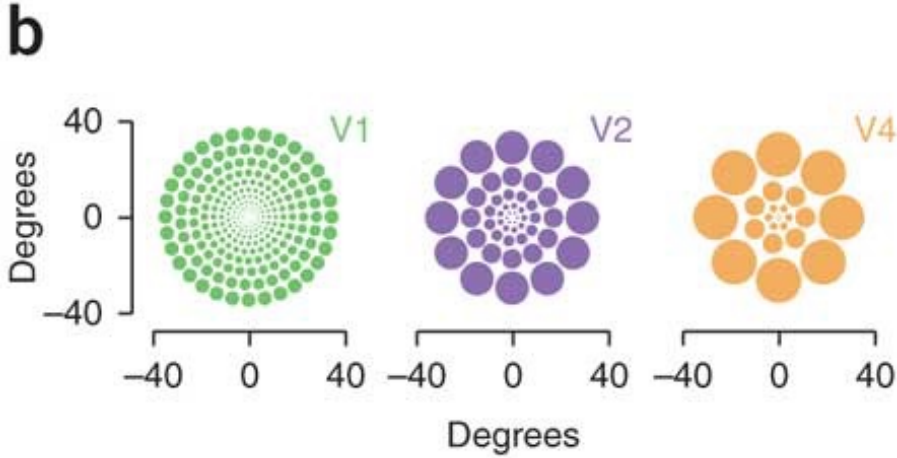




Each additional processing step takes ~15 ms

Schmolesky et al 1998

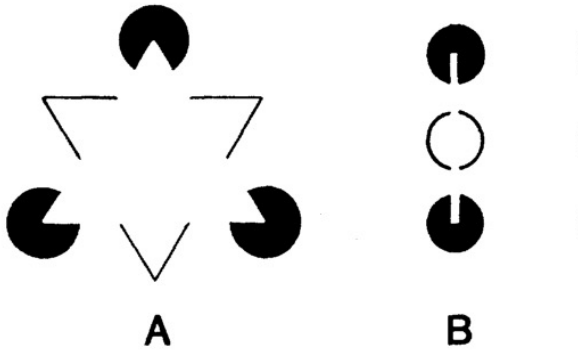
# Receptive field size increases along the ventral visual stream

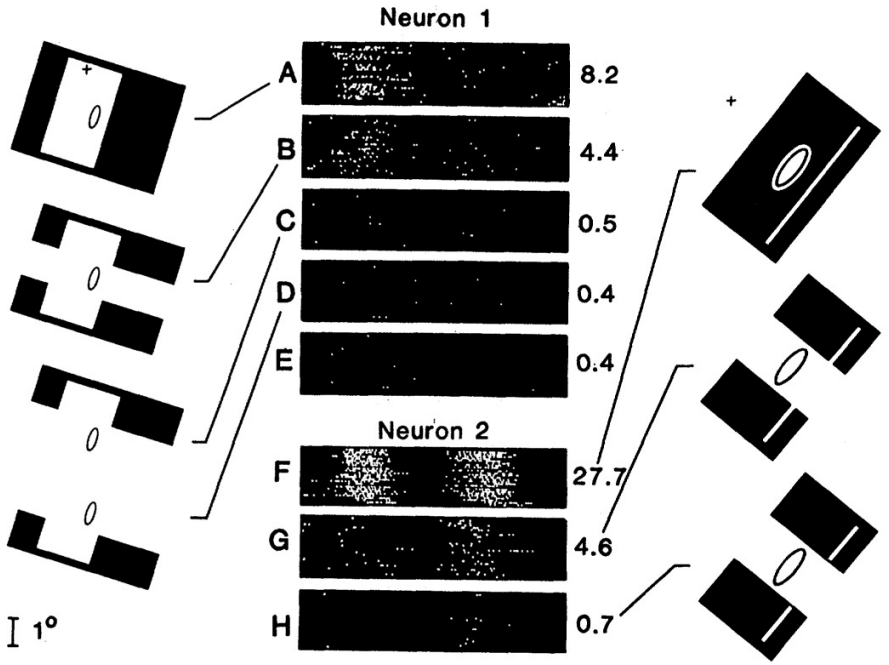



Freeman and Simoncelli 2013

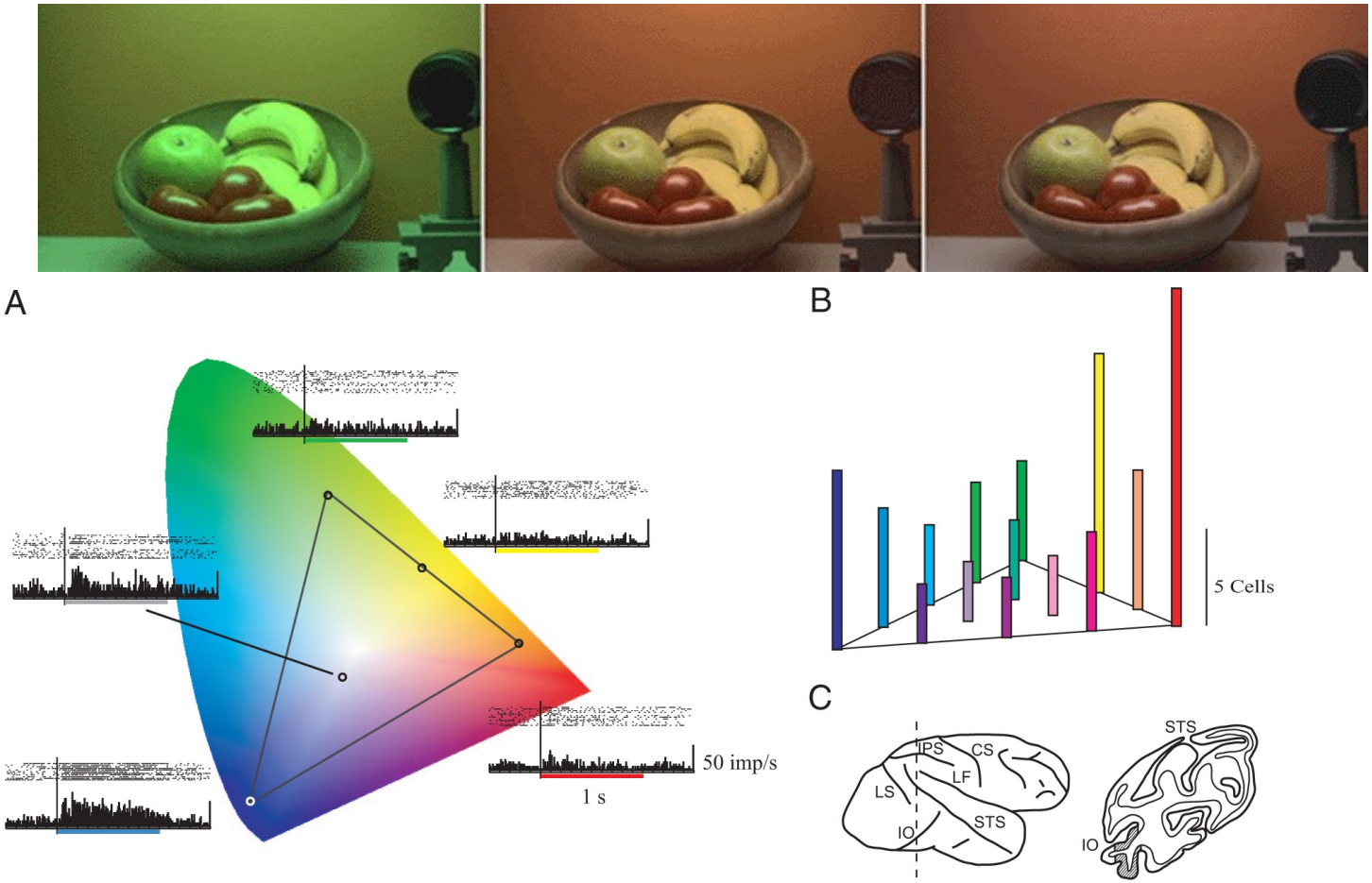
# Responses to illusory contours in area V2



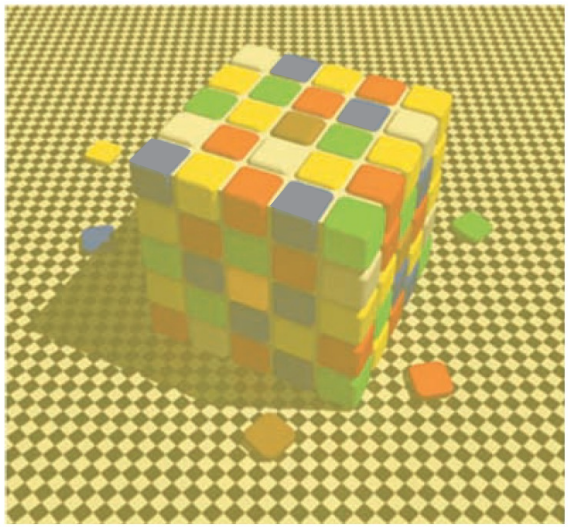

von der Heydt, R., Peterhans, E., & Baumgartner, G. (1984). Science, 224, 1260-1262.

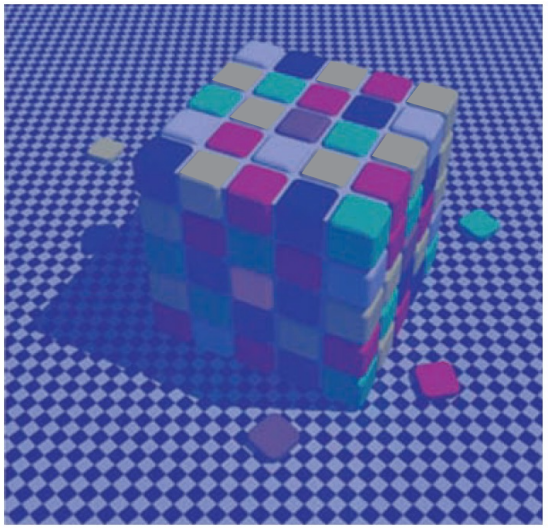
# Neurons in V4 show color selectivity




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.

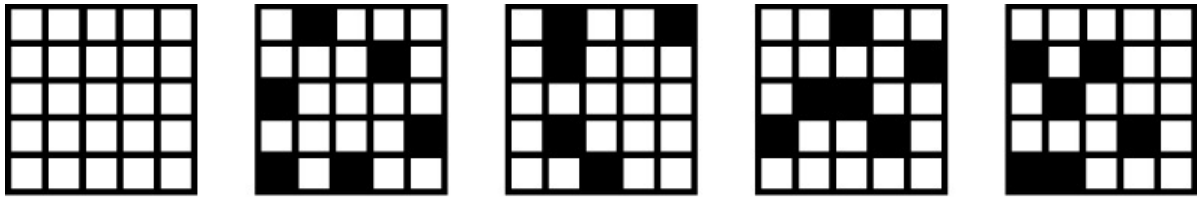
# Color constancy



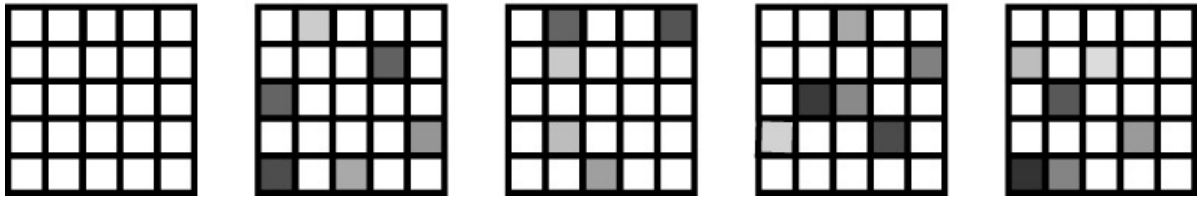


# The curse of dimensionality

$2^{25}$ possible images

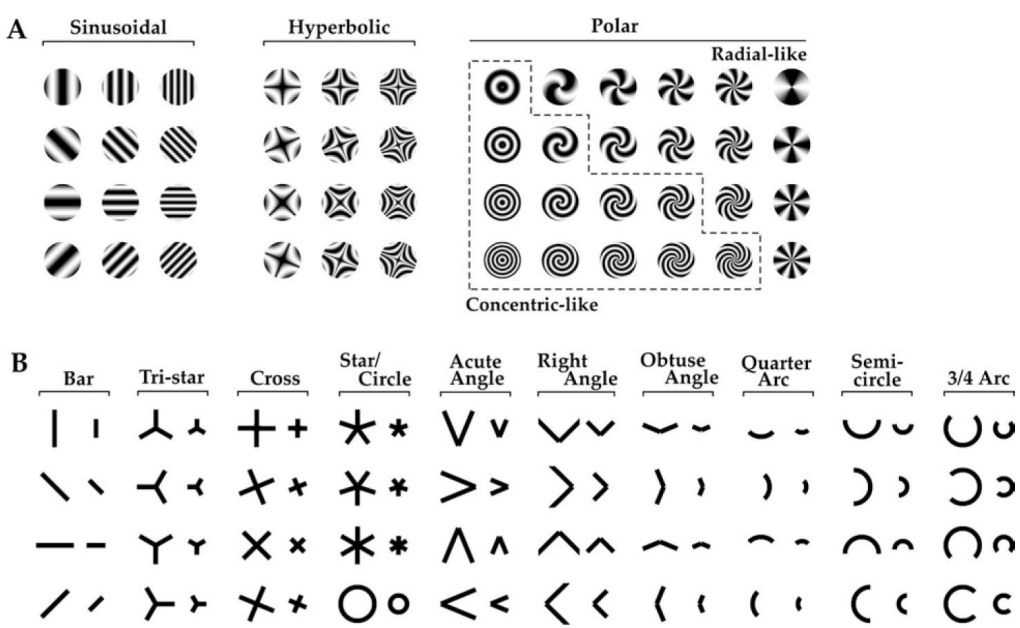


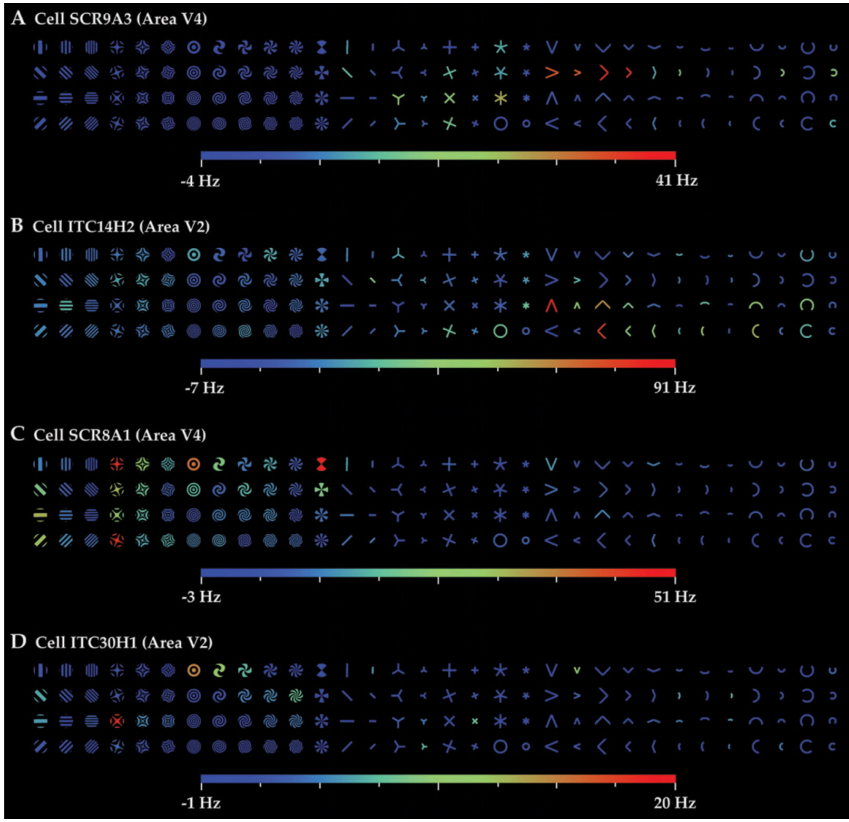
$256^{25}$ possible images



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

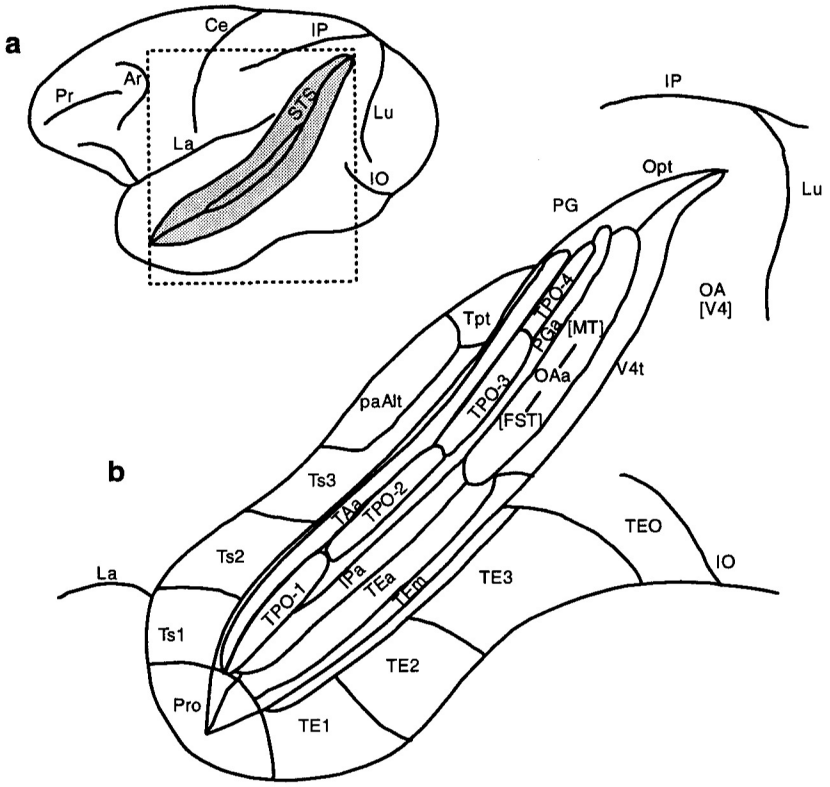
# Probing V2 and V4 neurons



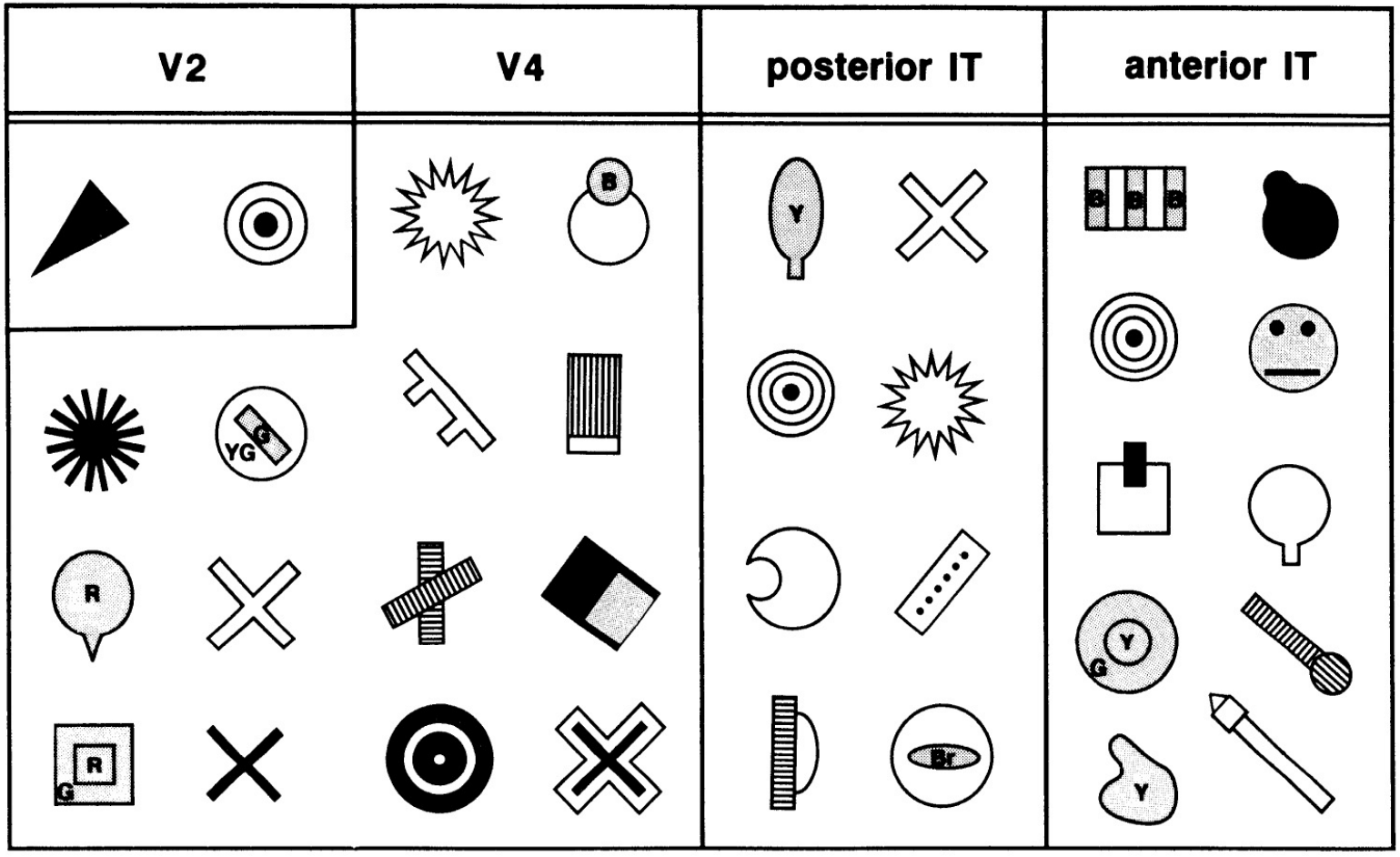

Hegde, J., & Van Essen, D. C. (2007). A comparative study of shape representation in macaque visual areas V2 and v4. Cereb Cortex, 17(5), 1100-1116.

# Inferior temporal cortex is composed of many subareas




Logothetis and Sheinberg. Annual Review of Neuroscience 1996

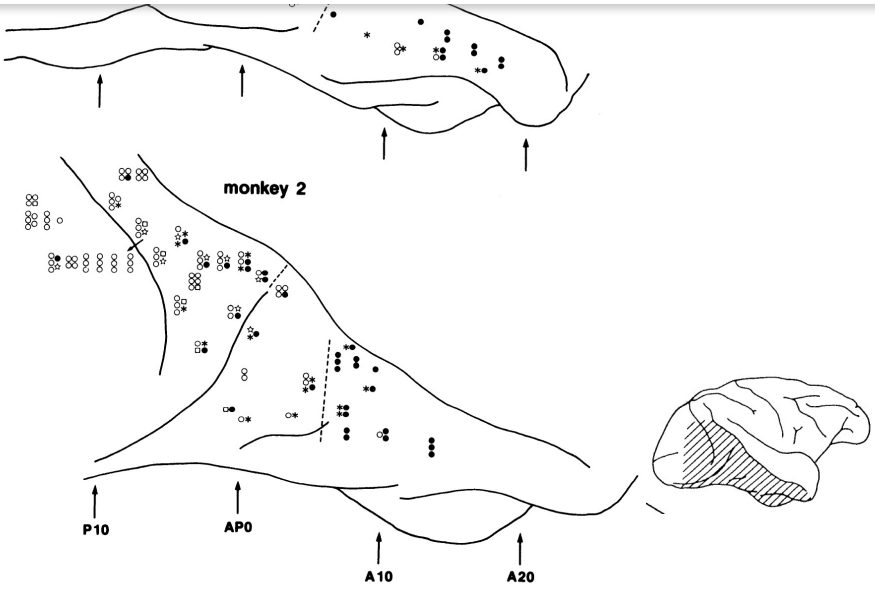
# Increase in "complexity" of feature preferences along the ventral visual stream

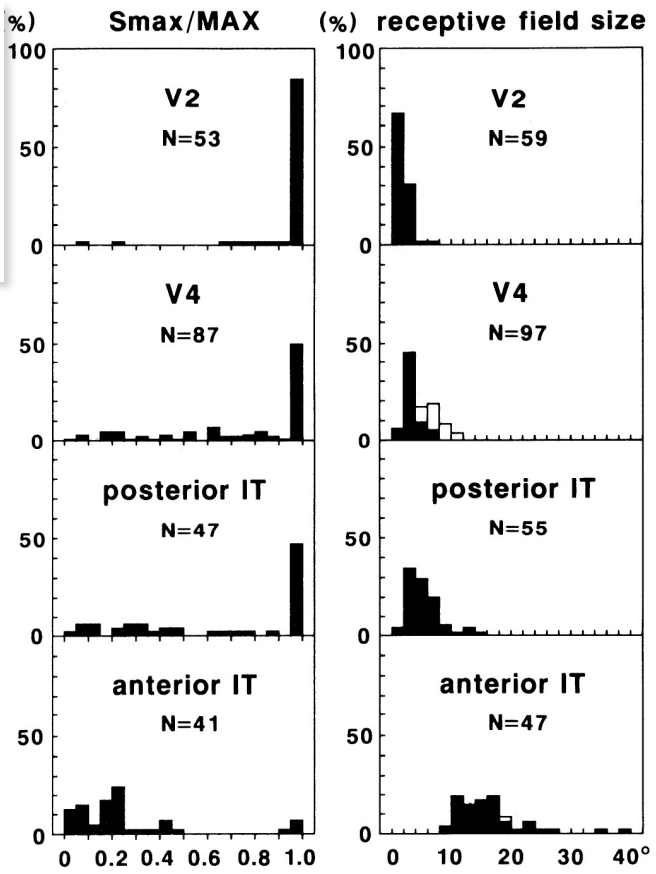



Kobatake E, Tanaka K (1994) Neuronal selectivities to complex object features in the ventral visual pathway of the macaque cerebral cortex. J Neurophysiol 71:856-867.

# 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.

# ITC neurons respond to a large variety of complex shapes

Desimone, Albright, Gross and Bruce


**Selective responses to almost every kind of stimulus tried.**

Kiani, Esteky, Mirpour and Tanaka

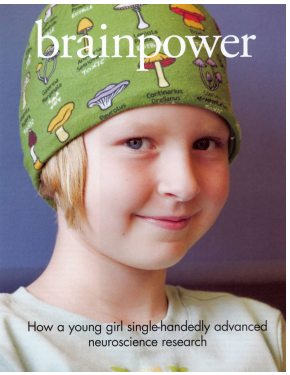
Connor and others

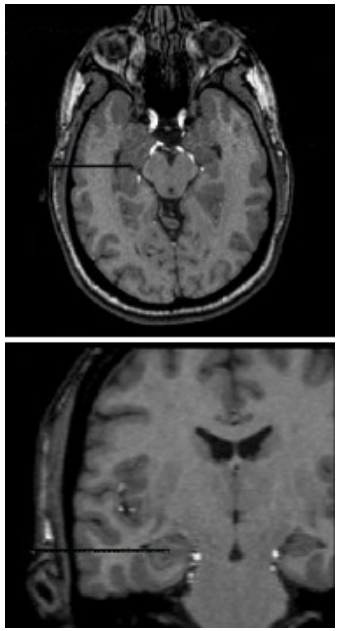
Logothetis, Pauls and Poggio

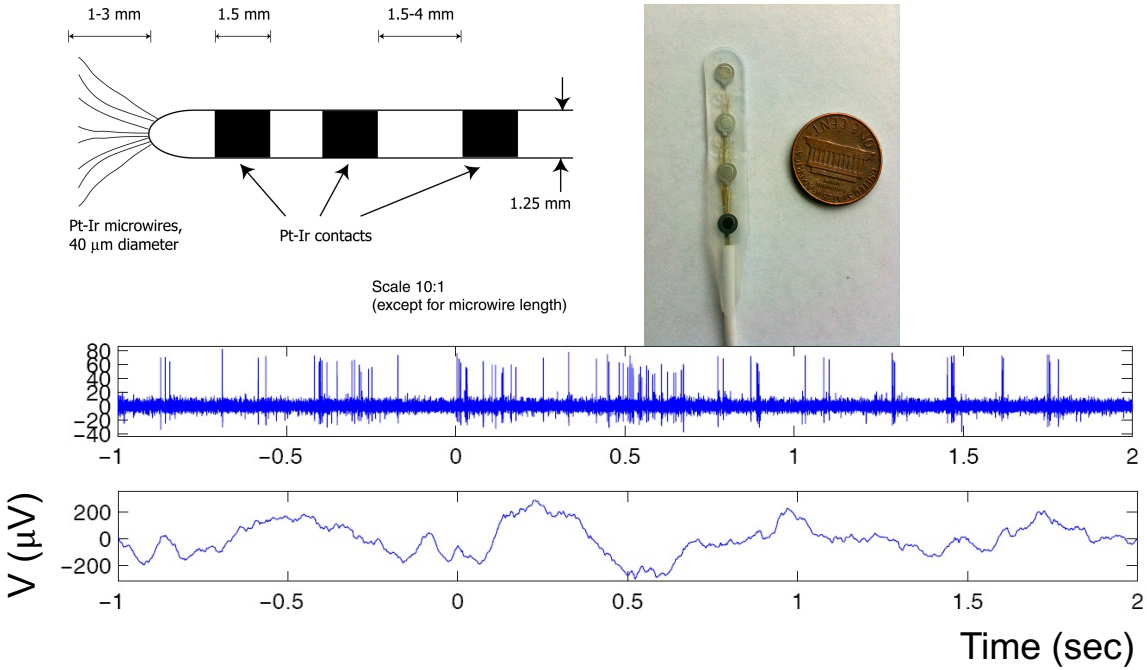
Tanaka, Saito, Fukada and Moriya


Hung, Kreiman, Poggio and DiCarlo

# Neurophysiological recordings in the human brain

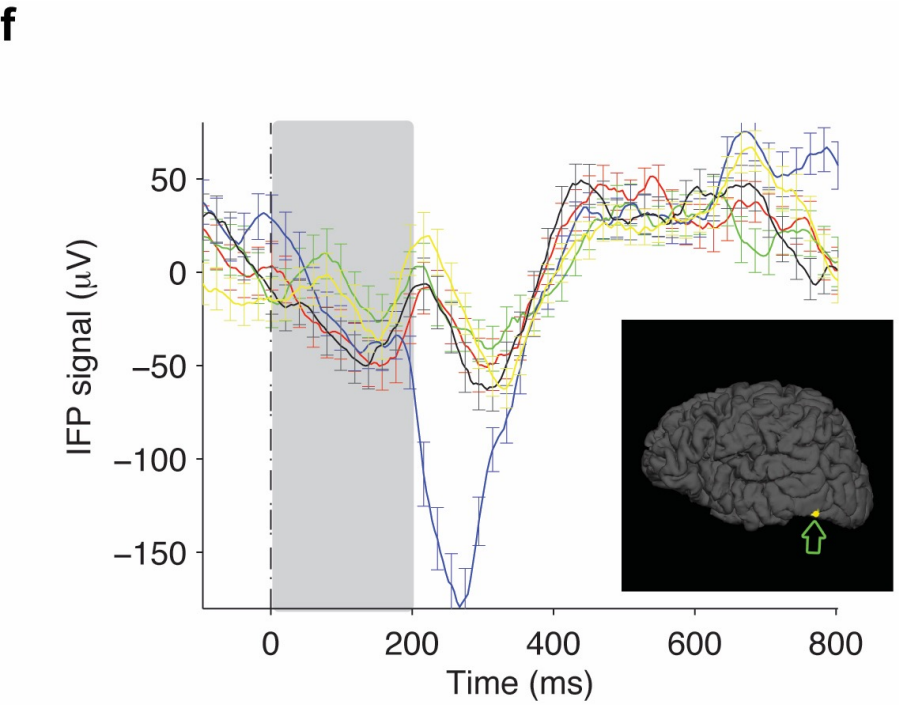


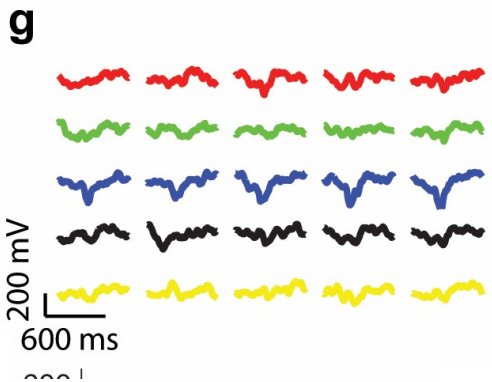



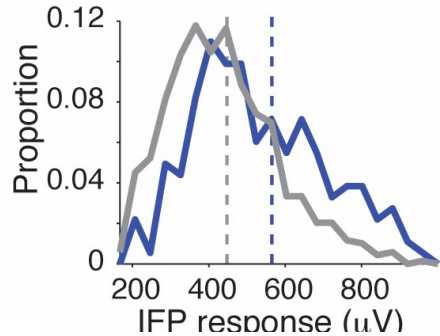


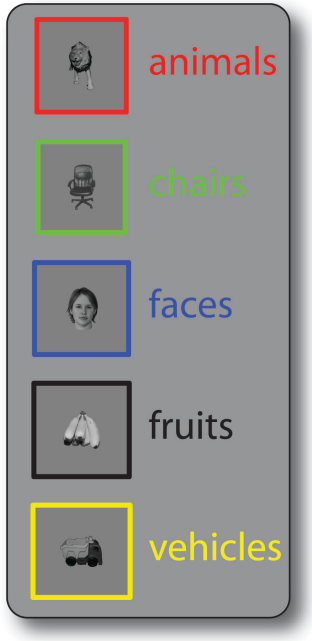

- Patients with pharmacologically intractable epilepsy
- Multiple electrodes implanted to localize seizure focus
- Targets typically include the temporal lobe (inferior temporal cortex, fusiform gyrus), medial temporal lobe (hippocampus, entorhinal cortex, amygdala and parahippocampal gyrus)
- Patients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

# Shape selectivity in human extrastriate visual cortex



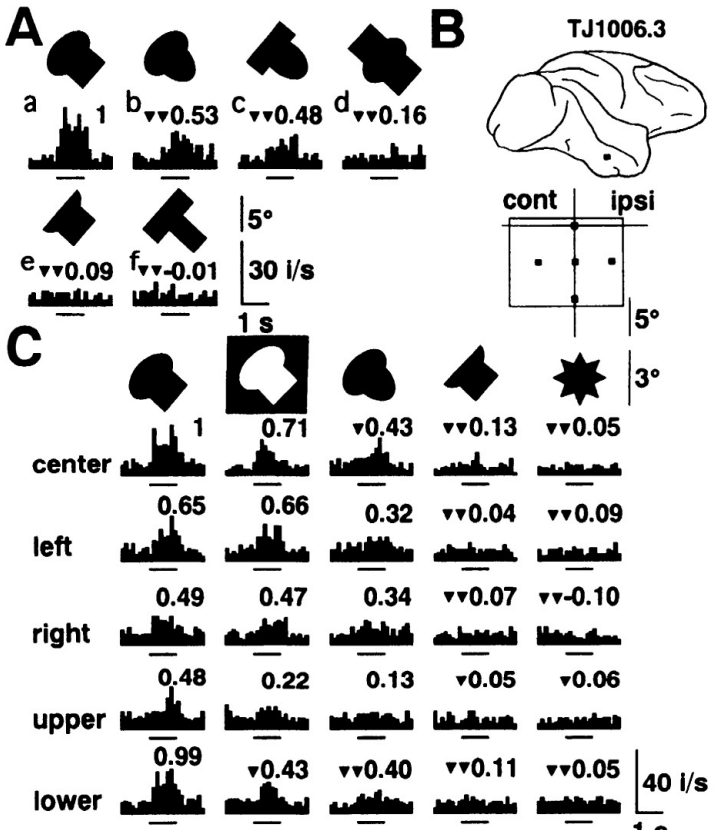



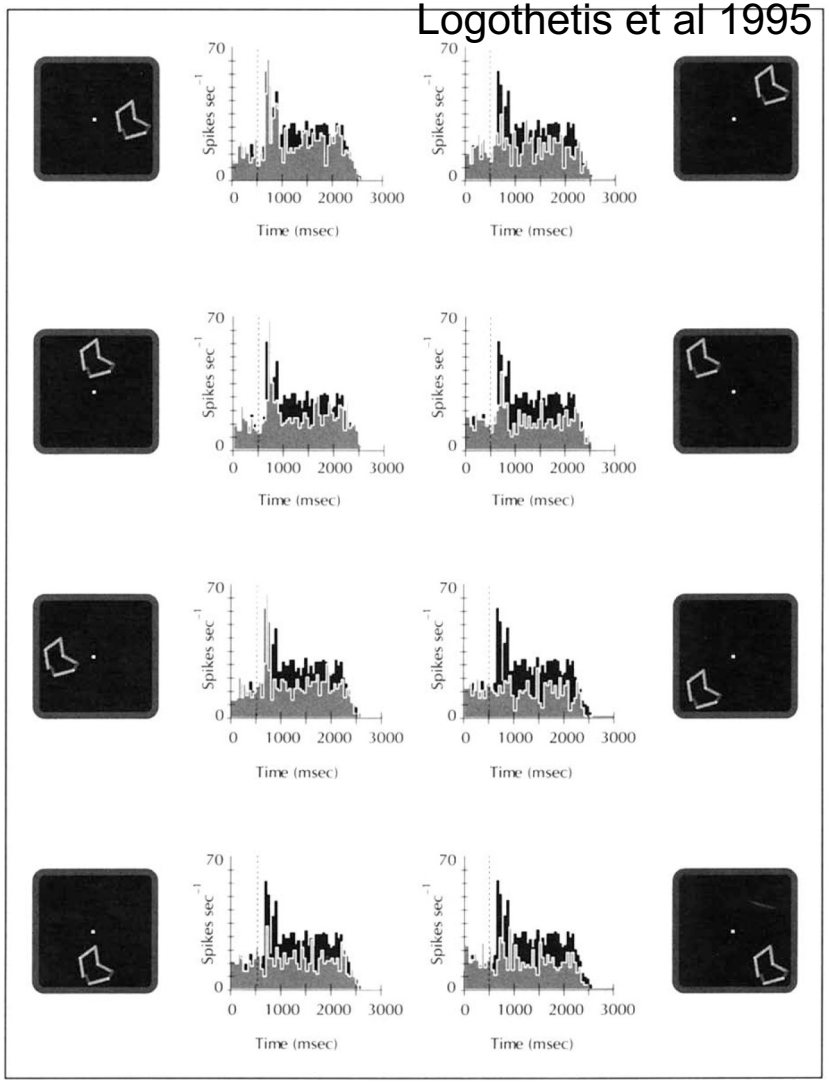

Liu et al. Neuron 2009

# Position invariance in ITC

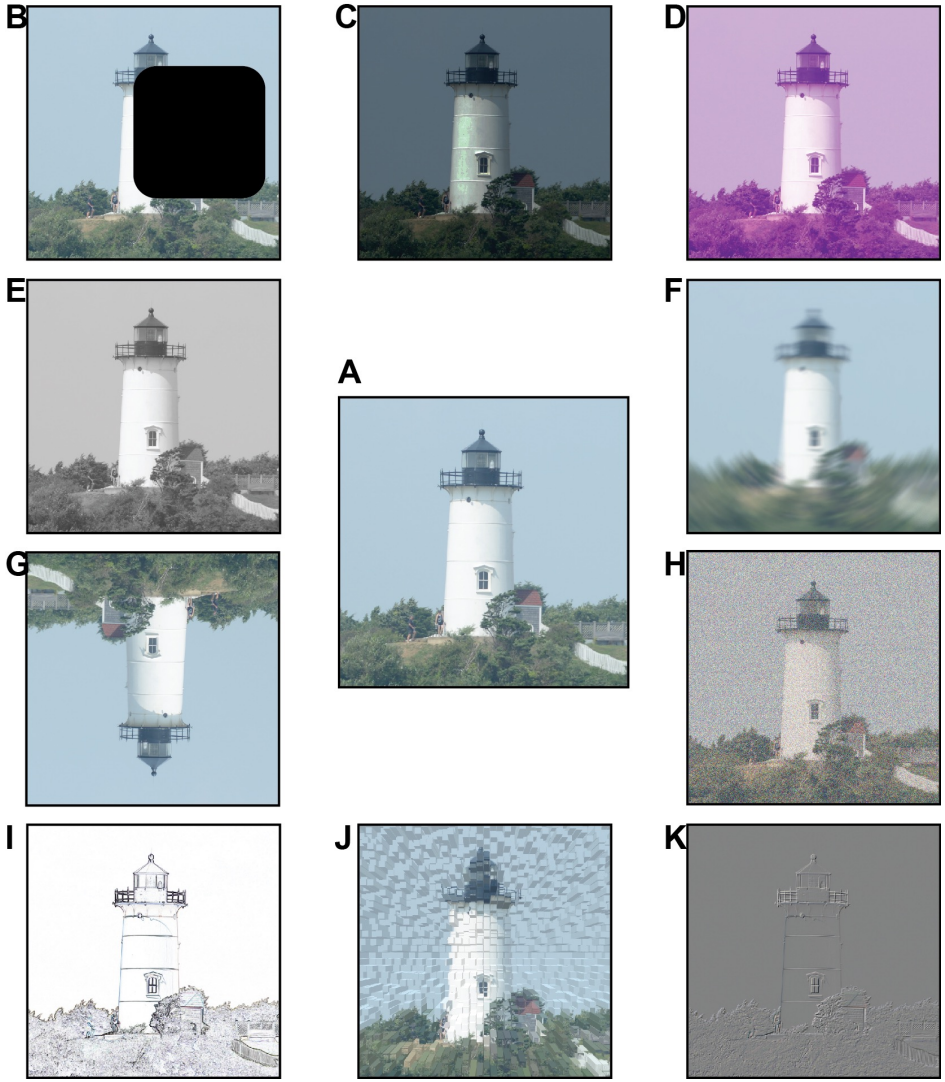



Ito *et al*. J. Neurophys. 1995

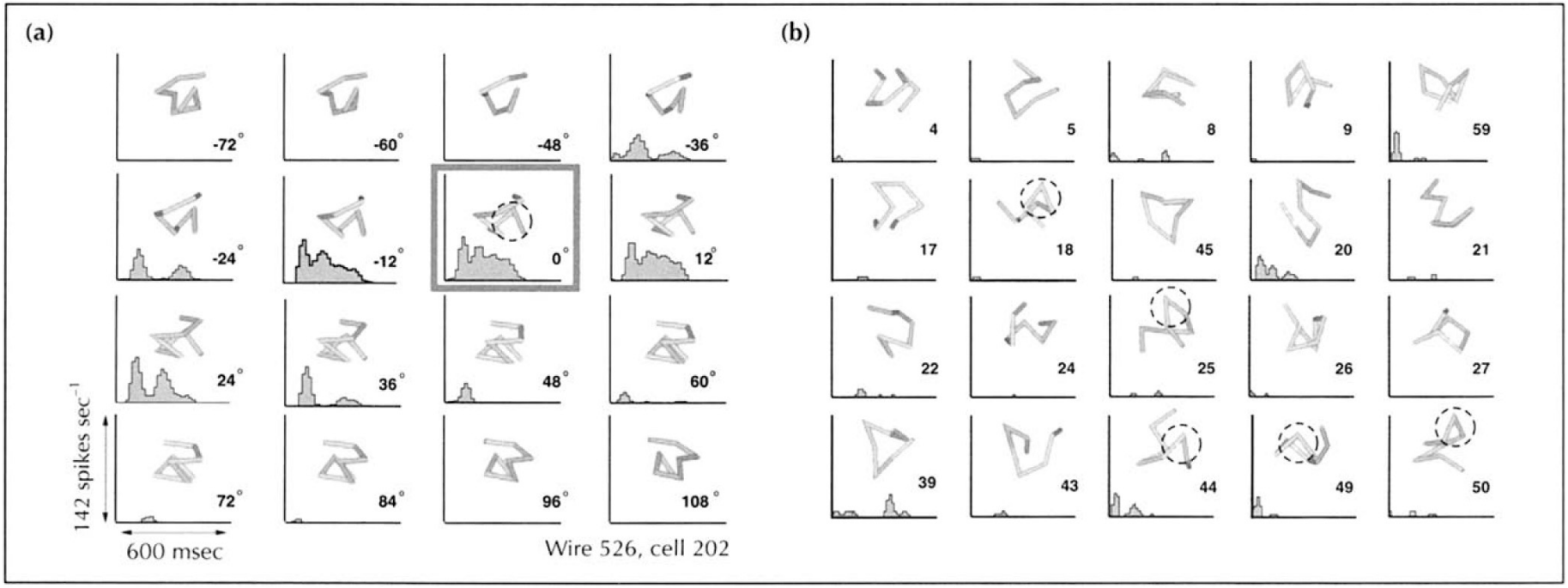
Logothetis et al 1995

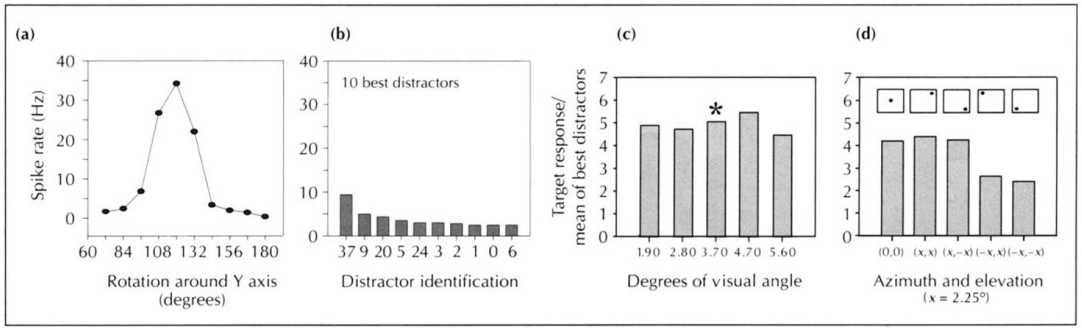


# Tolerance to image transformations



# Tolerance to viewpoint changes




Logothetis et al 1995

# Size invariance in ITC

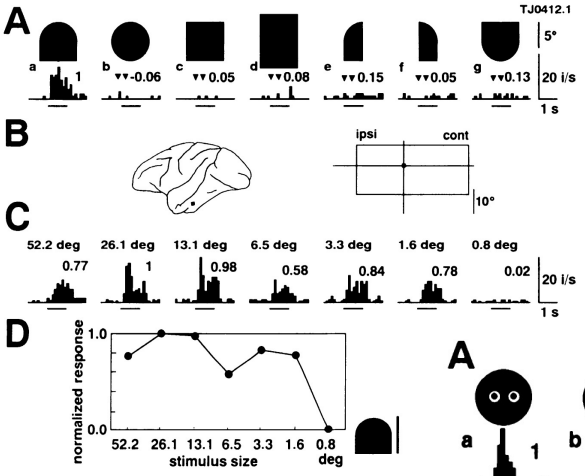



FIG. 4. Example of broadly tuned cells. *A*: optimal stimulus was a dome-shaped structure shown in *a*. *B*: recording site, the receptive field, and site of the stimulus presentation. *C*: responses to different sizes of the optimal stimulus. Comparably strong responses were evoked at a wide range of size (52.2–1.6° in height). *D*: magnitude of the responses normalized by that of the response to the stimulus 26.1° in size.

Ito et al .
J. Neurophys.
1995

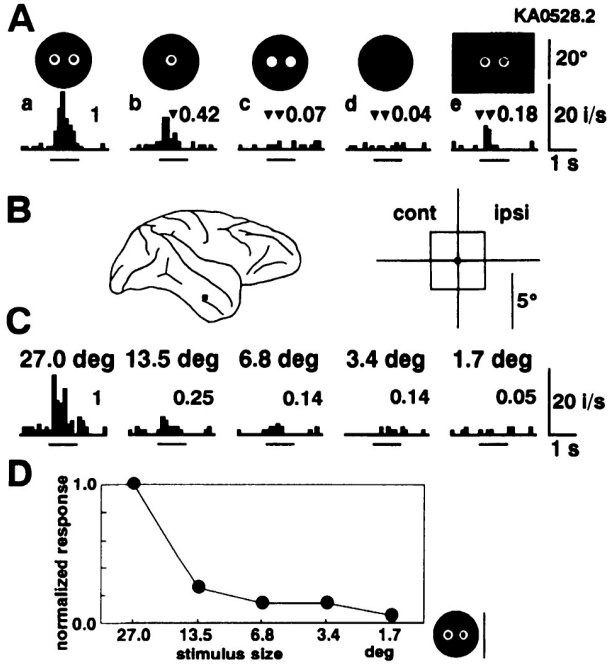
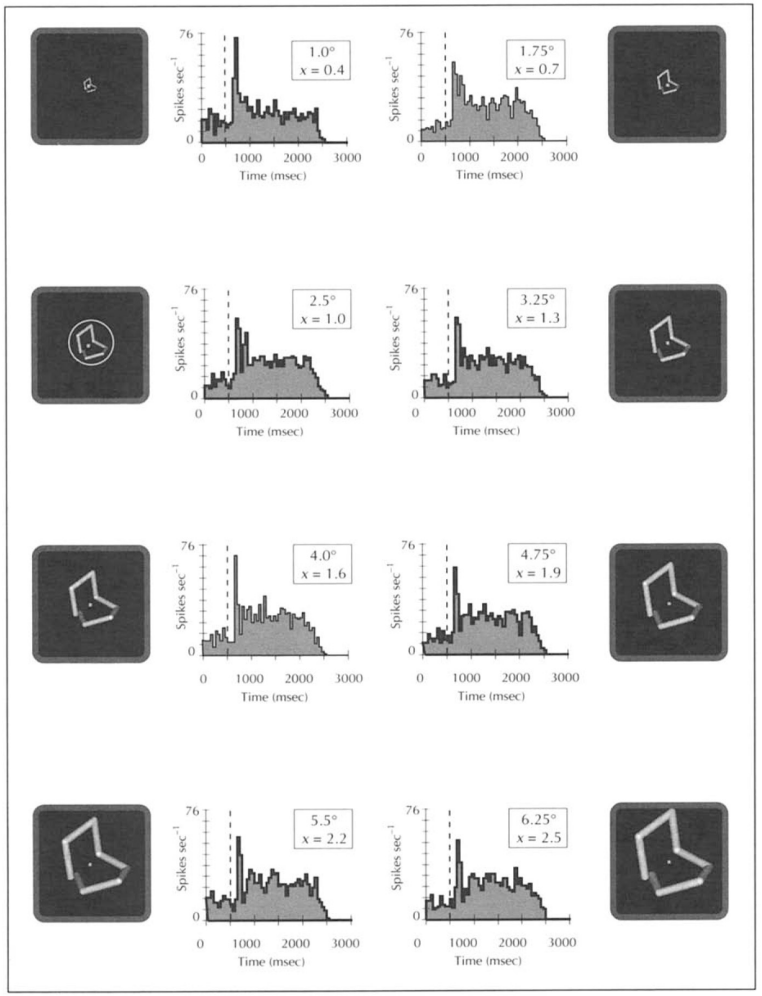
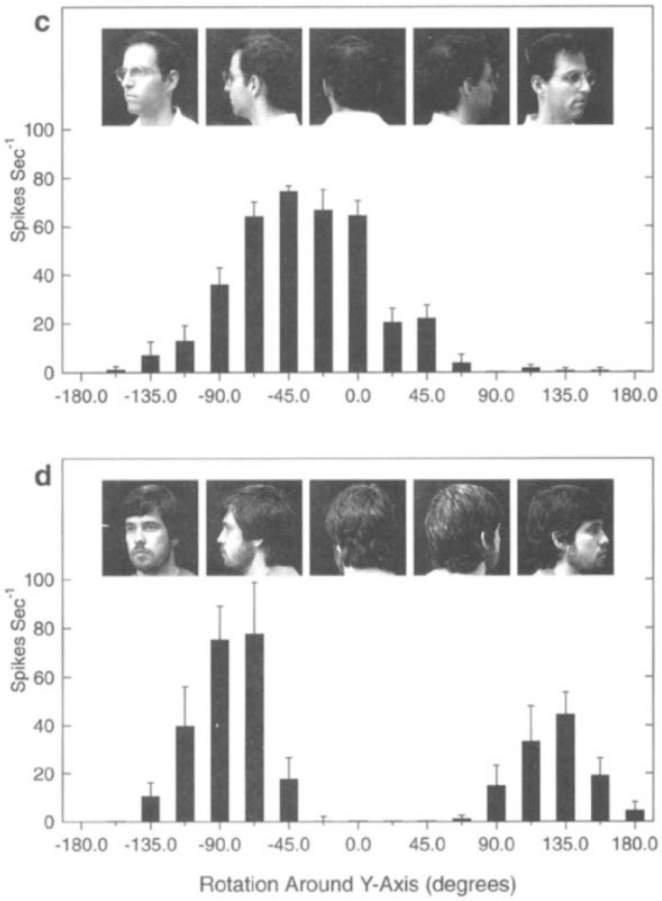



FIG. 5. Example of cells that maximally responded to the largest size of the optimal stimulus. *A*: optimal stimulus of the cell was a pair of white rings on a black base. *B*: recording site, the receptive field, and site of the



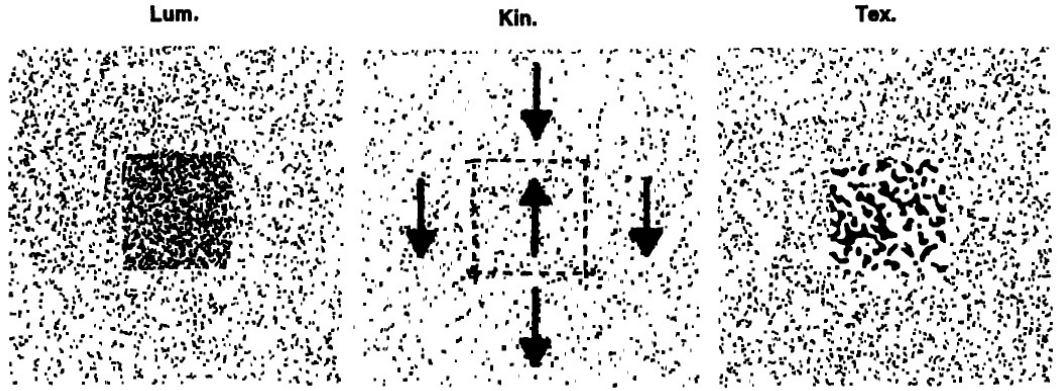

Logothetis et al 1995

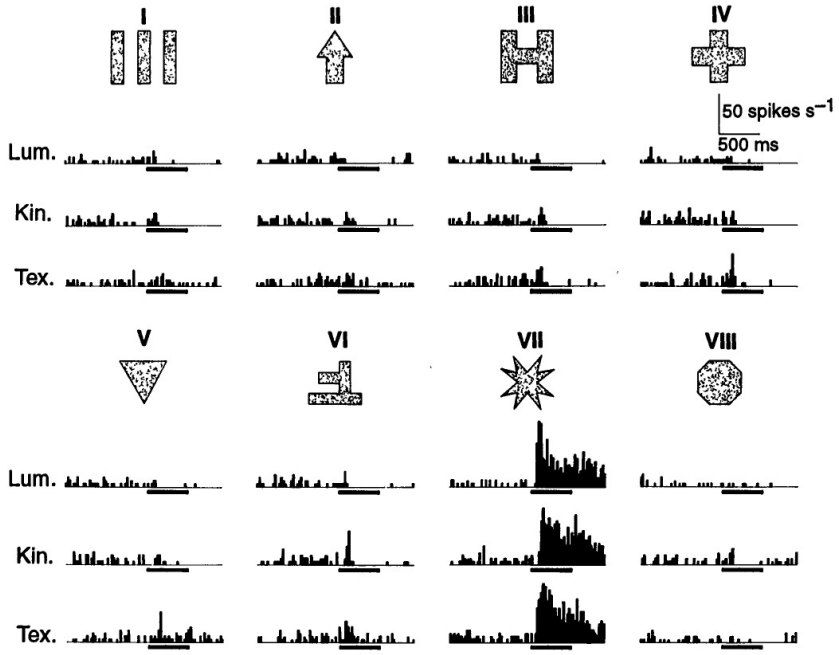
# Rotation invariance in ITC

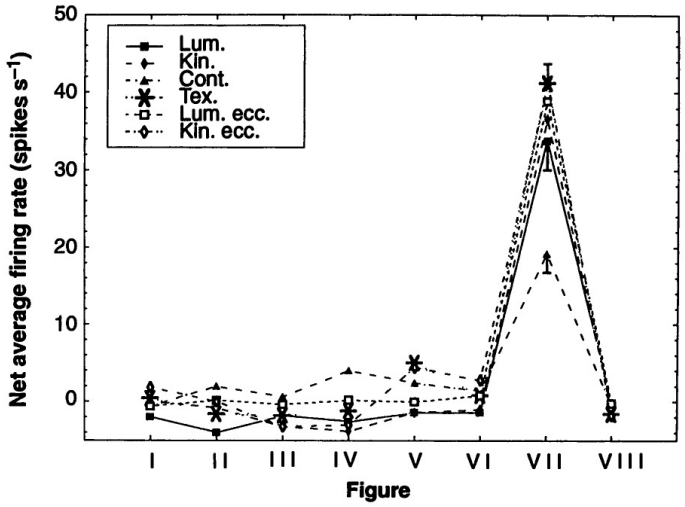



Logothetis and Sheinberg.
Annual Review of Neuroscience 1996

# Cue invariance in the responses of ITC



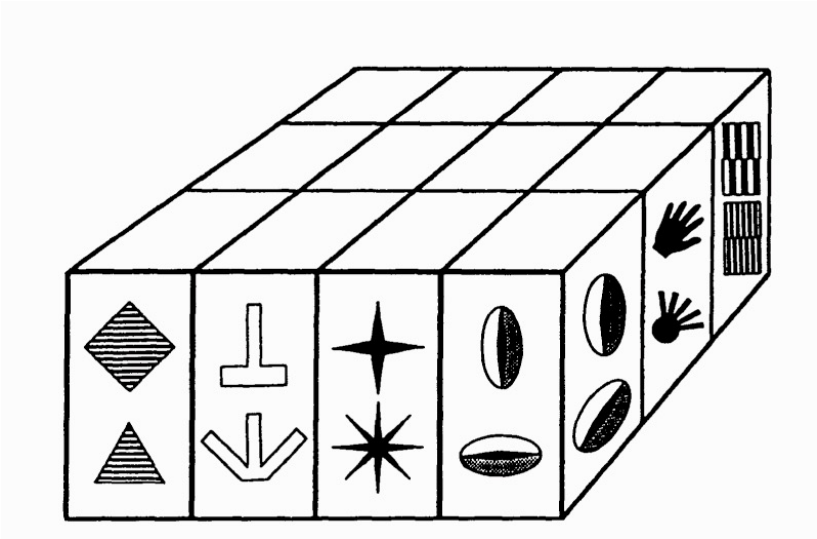



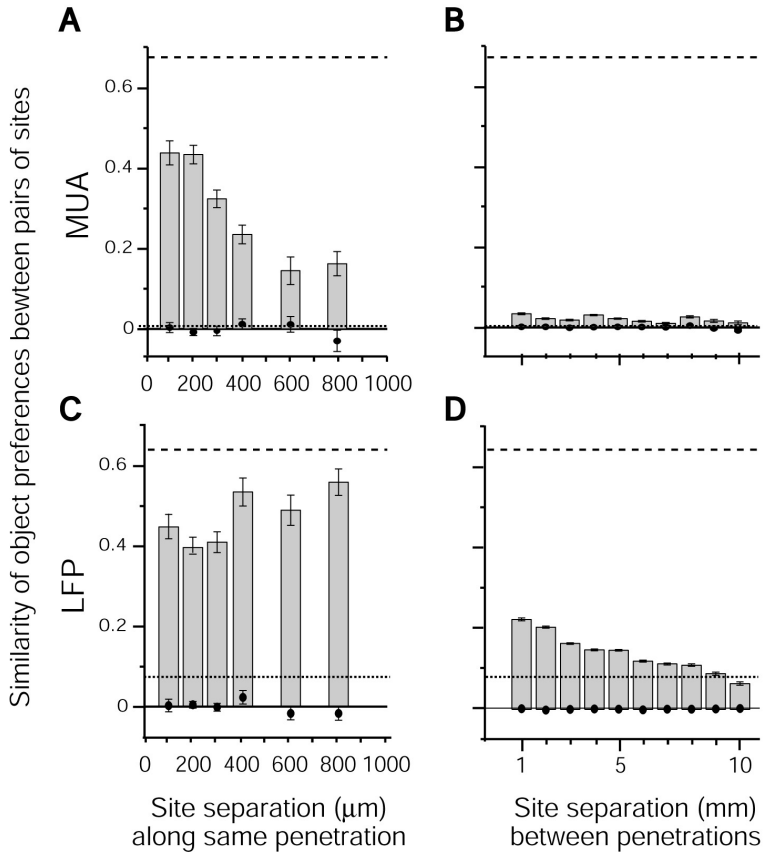

Sary et al Science 1993

# Feature topography in ITC

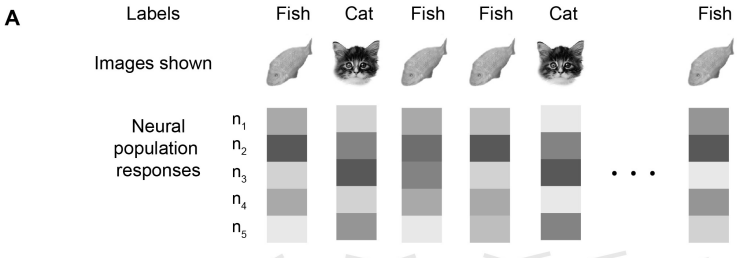
Tanaka. Science 1993



Kreiman et al, Neuron 1996



# Machine learning 101: reading out neural activity



# Summary

- Inferior temporal cortex (ITC) sits at the pinnacle of the visual cortical hierarchy, receiving strong inputs from both ventral and dorsal cortical areas and projecting widely to areas involved in episodic memory formation, decision making, and cognitive control.

- Monkey and human ITC neural responses are selective for a wide range of shapes, including abstract patterns and natural objects like chairs or faces.

- ITC neurons represent an overcomplete dictionary of features, are more concerned with shape rather than semantics,

- ITC neurons show invariance to image transformations.

- The activity of neural populations in ITC in single trials can be used to decode object information with linear classifiers.

# Further reading

- Connor, C. E., Brincat, S. L., & Pasupathy, A. (2007). Transformation of shape information in the ventral pathway. Curr Opin Neurobiol, 17(2), 140-147.

**Original articles cited in class (see lecture notes for complete list)**


- 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