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

Web site: http://tinyurl.com/visionclass

→ Class notes, Class slides, Readings Assignments

Location: Biolabs 2062

Time: Mondays 03:00 – 05:00

Lectures:

Faculty: Gabriel Kreiman and invited guests

TA: Emma Giles

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Office Hours: After Class. Mondays 5pm, or by appointment

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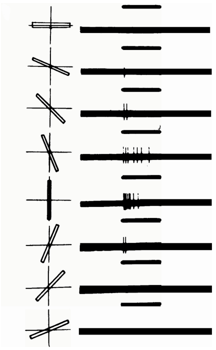
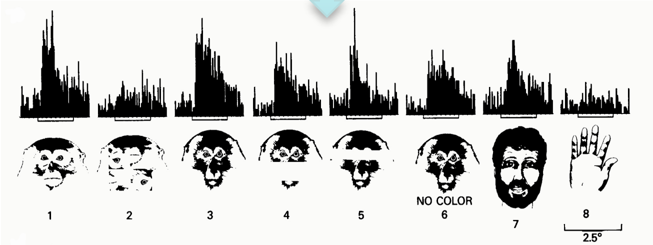
Class 1 [09/10/2018]. Introduction to pattern recognition [Kreiman]
Class 2 [09/17/2018]. Why is vision difficult? Natural image statistics. The retina. [Kreiman]
Class 3 [09/24/2018]. Lesions and neurological studies [Kreiman].
Class 4 [10/01/2018]. Psychophysics of visual object recognition [Sarit Szpiro]
October 8: University Holiday
Class 5 [10/15/2018]. Primary visual cortex [Hartmann]
Class 6 [10/22/2018]. Adventures into *terra incognita* [Frederico Azevedo]
Class 7 [10/29/2018]. High-level visual cognition [Diego Mendoza-Haliday]
Class 8 [11/05/2018]. Correlation and causality. Electrical stimulation in visual cortex [Kreiman]
Class 9 [11/12/2018]. Visual consciousness [Kreiman]
Class 10 [11/19/2018]. Computational models of neurons and neural networks. [Kreiman]
Class 11 [11/26/2018]. Computer vision. Artificial Intelligence in Visual Cognition [Bill Lotter]
Class 12 [12/03/2018]. The operating system for vision. [Xavier Boix]
FINAL EXAM, PAPER DUE 12/13/2018. No extensions.

How do we go from oriented lines to complex shapes?



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

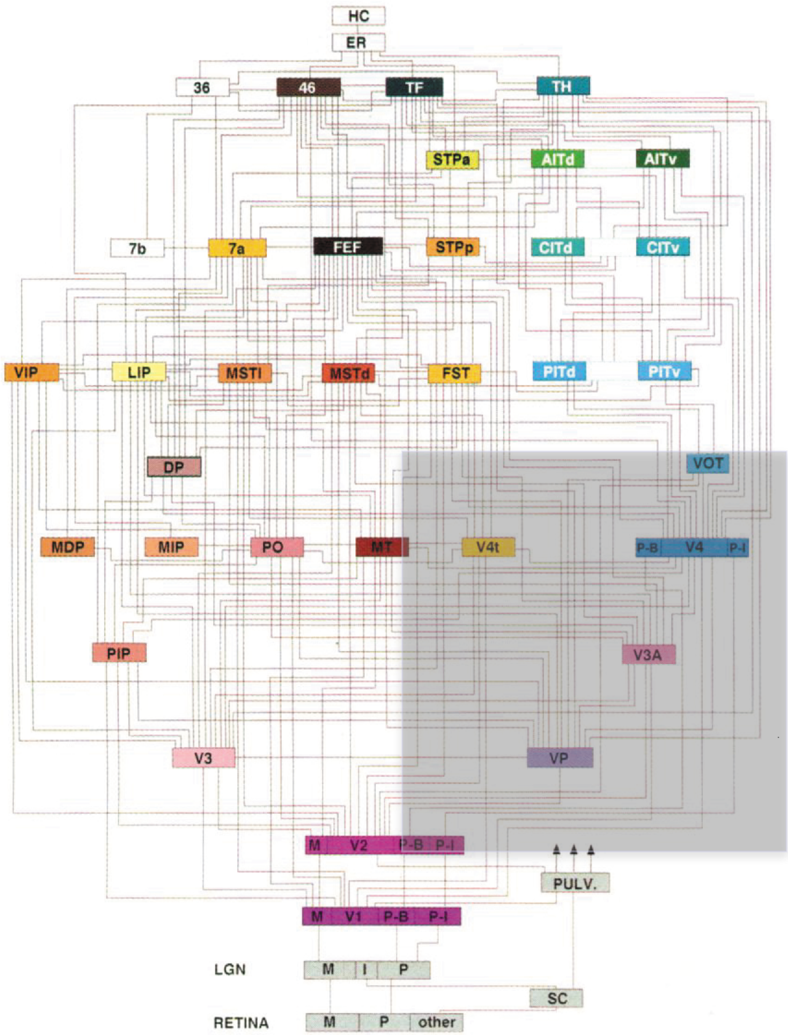
?

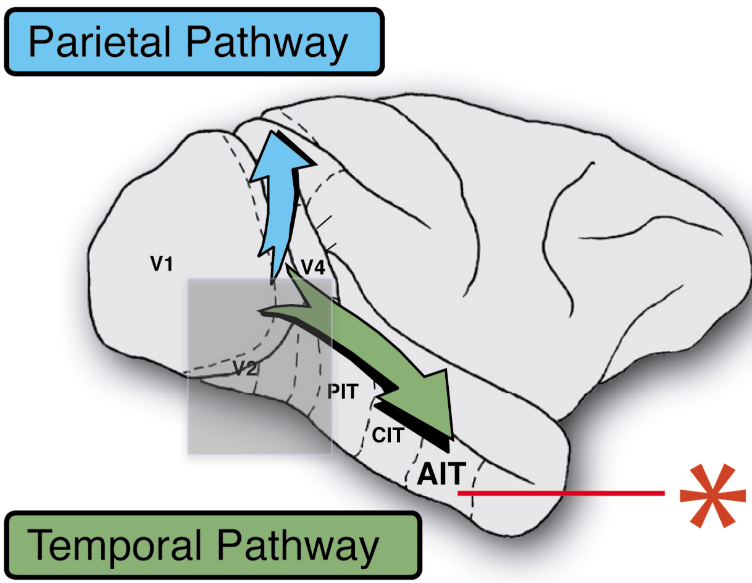


Desimone *et al* (1984) *J. Neurosci. 4:*2051-2062

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

Adventures into *terra incognita*



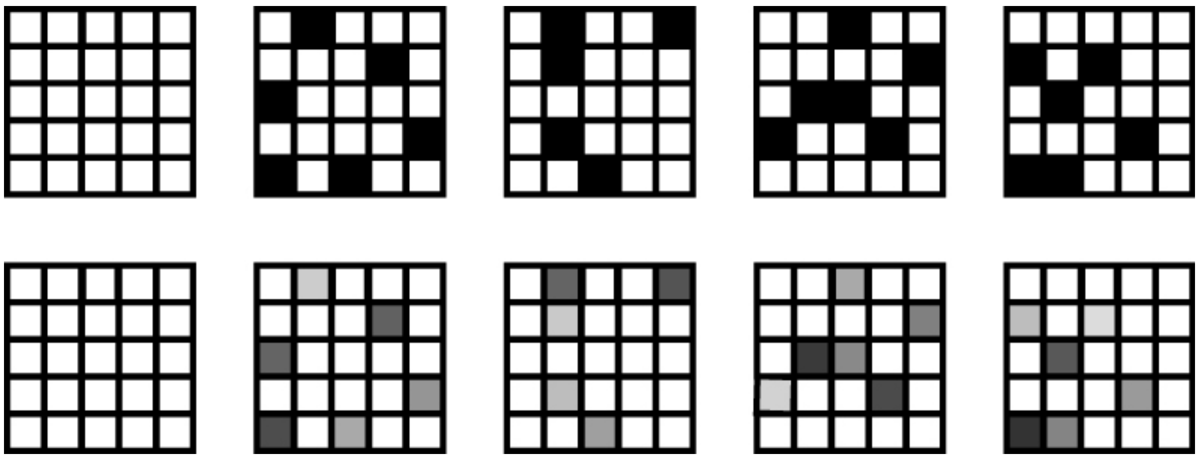


Felleman and Van Essen. *Cerebral Cortex* 1991

The curse of dimensionality

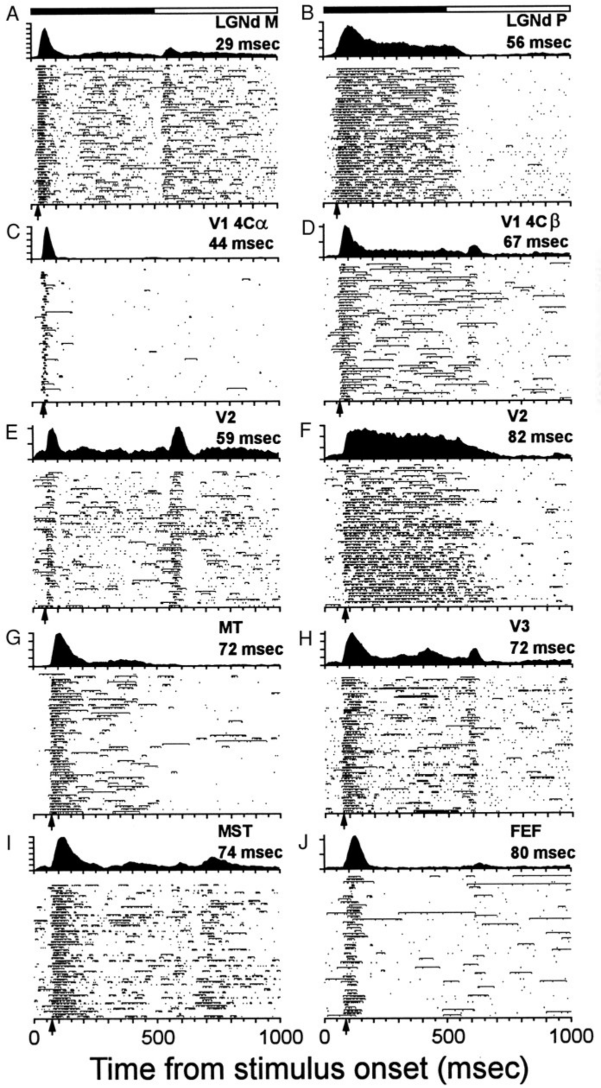
2^{25} possible images

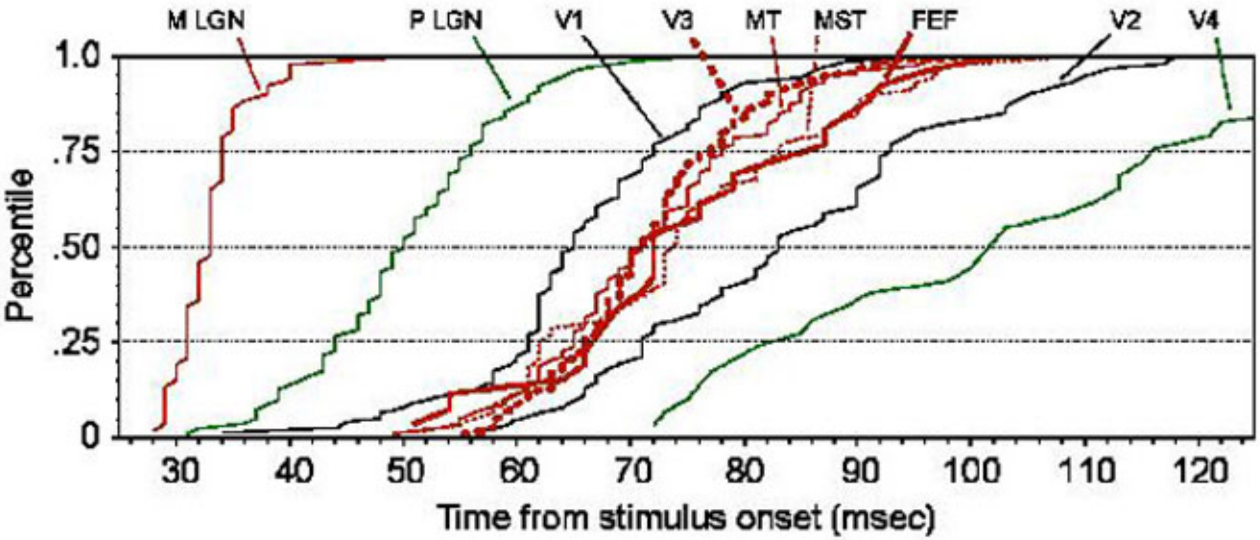
256^{25} possible images



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

Response latency increases along the visual hierarchy

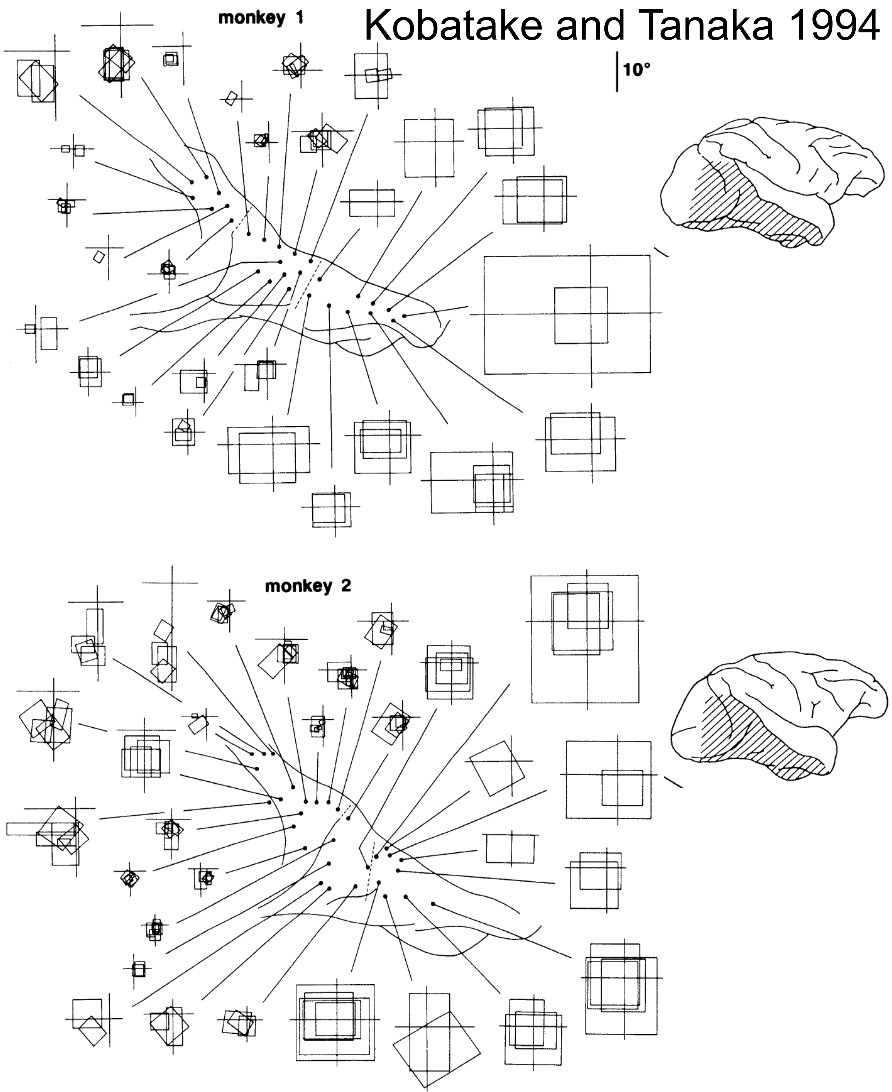




Each additional processing step takes ~15 ms

Schmolesky et al 1998

Receptive field size increases along the ventral visual stream



Kobatake and Tanaka 1994

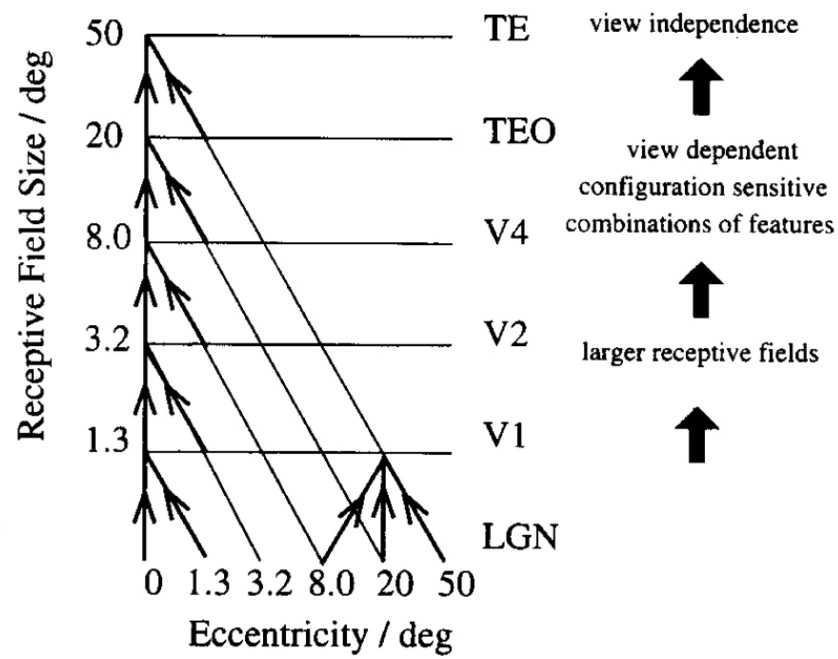
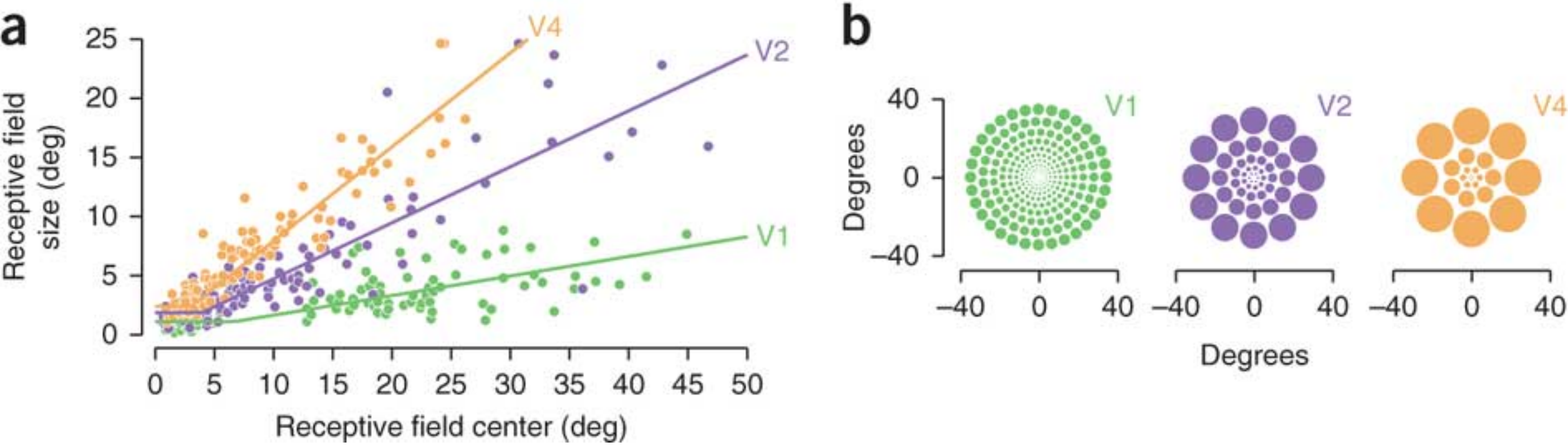


Fig. 2. Schematic diagram showing convergence achieved by the forward projections in the visual system, and the types of representation that may be built by competitive networks operating at each stage of the system from the primary visual cortex (V1) to the inferior temporal visual cortex (area TE) (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.

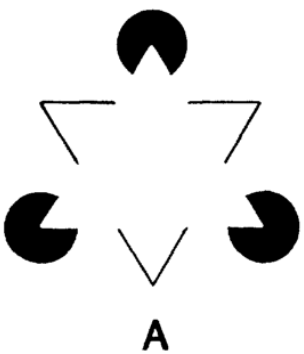
Wallis and Rolls 1997

Receptive field size increases along the ventral visual stream



Freeman and Simoncelli 2013

Responses to illusory contours in area V2



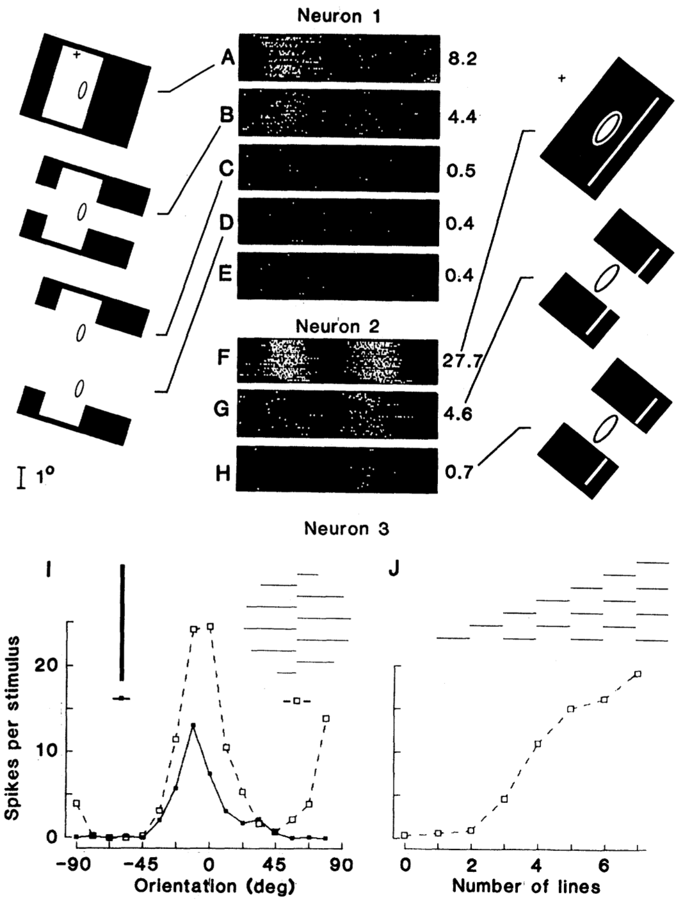
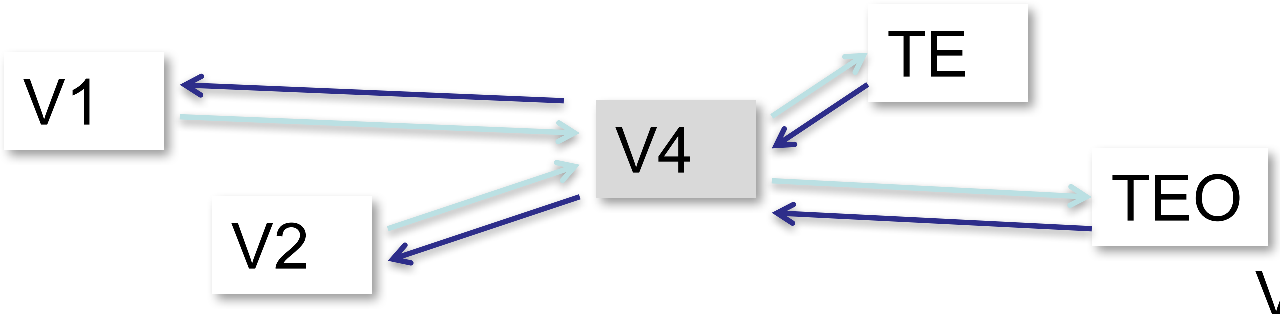


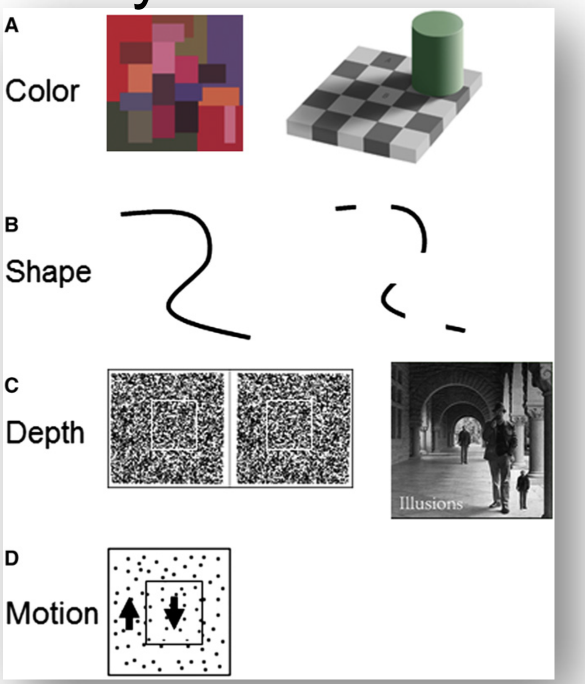
Fig. 2. Responses of neurons in area 18 of the monkey visual cortex to edges, bars, and stimuli producing illusory contours. The stimuli (insets) (*10*) were moved back and forth across the receptive fields (neuron 1, 1° at 1 Hz; neurons 2 and 3, 2° at 1 Hz). Each was presented 8 (I), 16 (J), or 24 (A to H) times; blocks of eight repetitions were alternated in pseudorandom order. For neurons 1 and 2, the response fields (the regions in the visual field where the neurons could be activated by a bar or edge) are represented by ellipses, and the fixation point is marked by crosses in A and F; the responses are represented by rows of dots; mean numbers of spikes per stimulus cycle are indicated on the right. Neuron 1, which responded to the lower right edge of the light bar (A), was activated also when only the illusory contour passed over its response field (B). Either half of the stimulus failed to evoke a response (C and D); (E) spontaneous activity. Neuron 2 responded to a narrow bar (F) and, less strongly, to the illusory bar stimulus (G). When the ends of the ''bar'' were intersected by thin lines, however, the response was nearly abolished (H). In neuron 3, the border between two abutting gratings elicited a strong response. The orientation tuning curves show corresponding peaks for bar and illusory contour (I). When the lines inducing the contour were reduced in number to less than three, the response disappeared (J); compare the lines

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

Visual area V4



V4 implicated in many visual functions



V4 lessions:

- 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

COLOR-SELECTIVE CEL

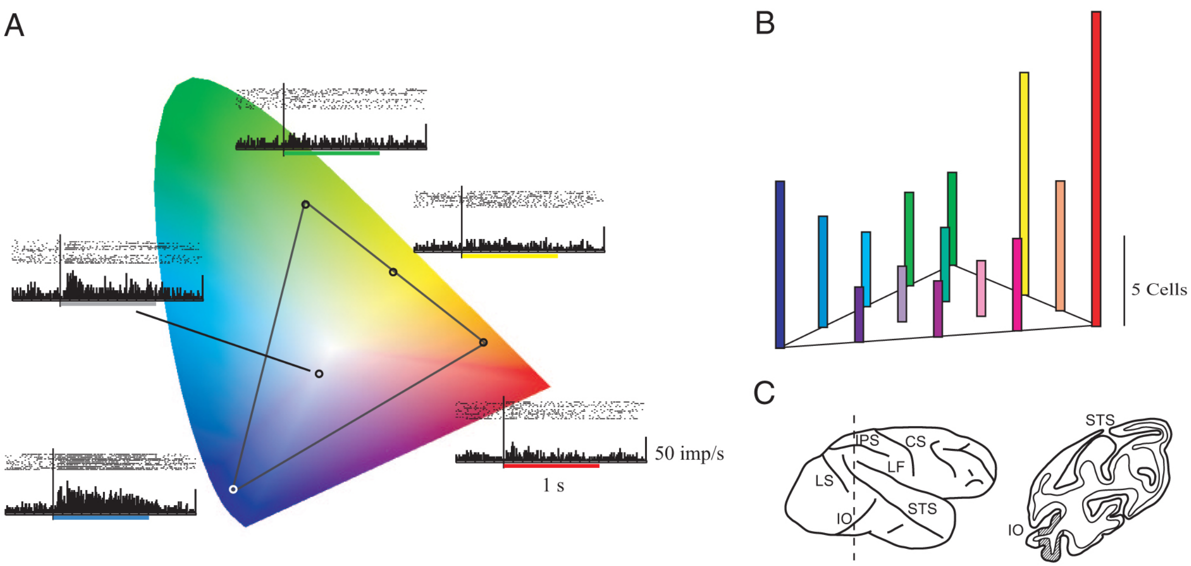
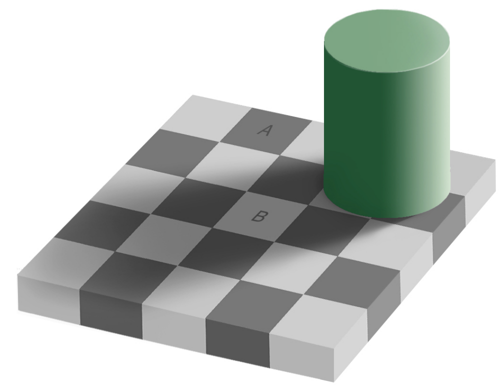
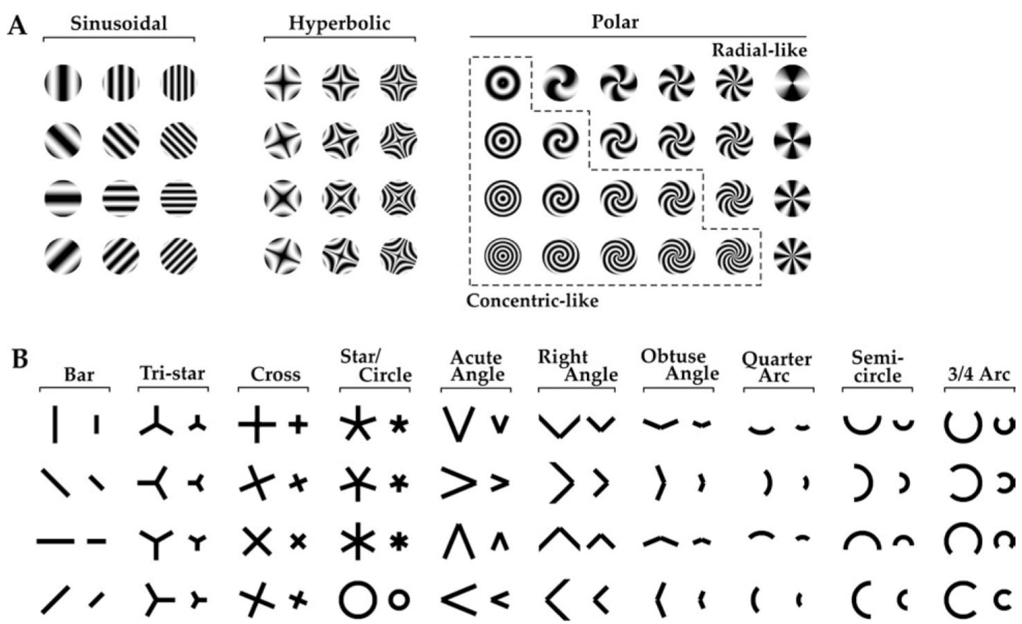


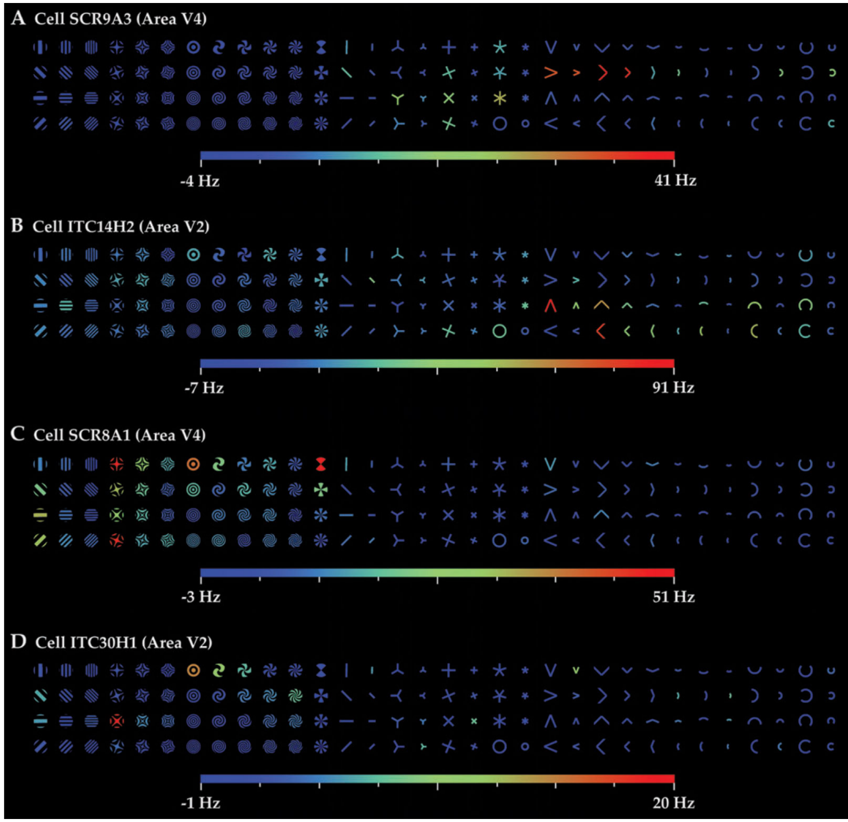
FIG. 2. *A*: example of the responses of a neuron in area V4 to patches of different isoluminant colors presented against a gray background. Spike rasters and response histograms are plotted with reference to the CIE chromaticity diagram. The bar under each histogram shows the duration of stimulus presentation (1 s). The neuron responded best to the blue stimulus. *B*: histogram showing the distribution of spectral preferences of all the V4 neurons recorded in these experiments. *C*: schematic representation of the part of the brain from which recordings were made. The dashed line on the lateral view of the monkey brain shows the approximate position of the coronal section (*right*). ▨, spectrally tuned neurons.



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.

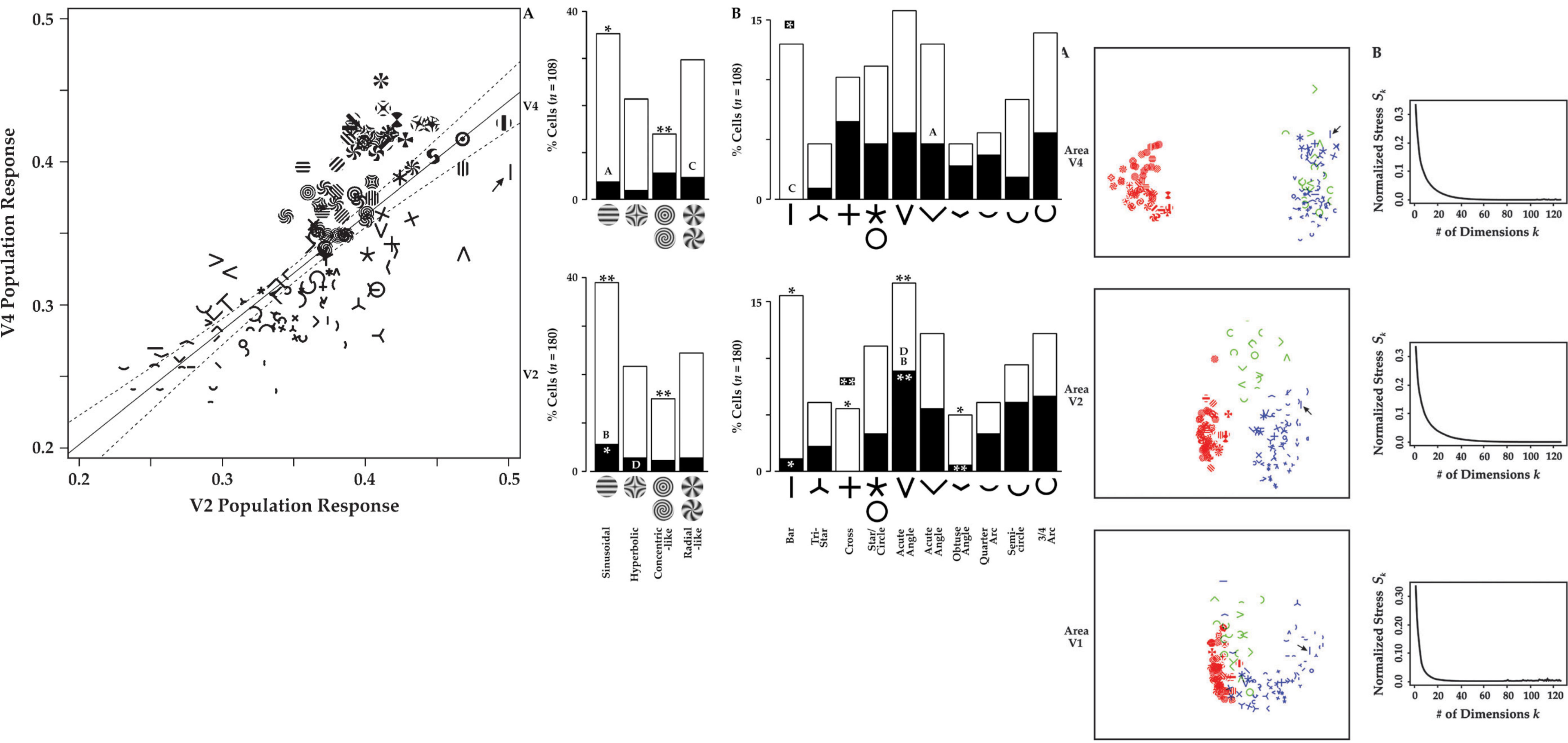
Probing the responses of V2 and V4 neurons





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.

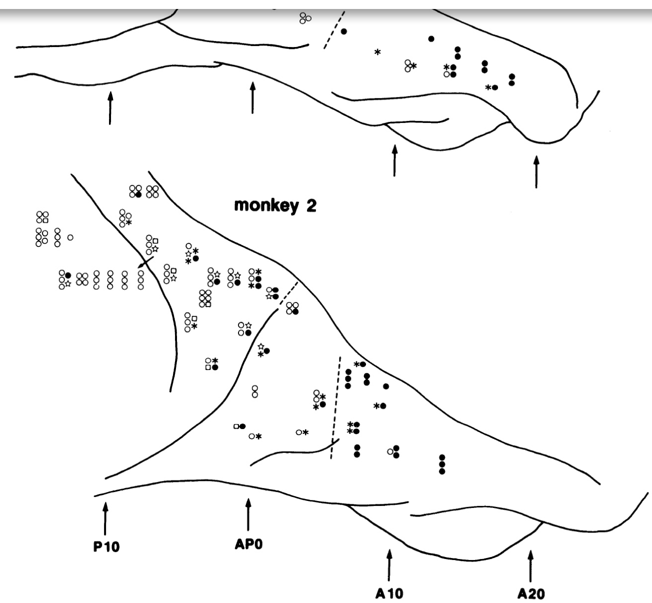
Varied responses along the ventral visual stream



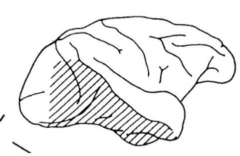
Hegde, J., & Van Essen, D. C. (2007). A comparative study of shape representation in macaque visual areas v2 and v4. Cereb Cortex, 17(5), 1100-1116.

Increase in “complexity” of feature preferences along the ventral visual stream

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



to complex features. To quantify the distinctiveness of the selectivity to complex features, we calculated the ratio of the maximum of the responses to simple stimuli to the maximum of the responses to all the stimuli (S_{max}/MAX). A smaller ratio represents more distinctive selectivity. Cells are indicated by 4 different symbols according to the ratio as shown at the *top right corner.* Among the cells with a ratio >0.75, those that responded to some simple textures but not to bars or spots are indicated by open squares. Broken lines: the border between anterior part of inferotemporal cortex (anterior IT) and posterior part of inferotemporal cortex (posterior IT) and that between posterior IT and V4. Cells recorded from a single penetration are grouped together. The 5 V4 cells recorded from the medial bank of the lunate sulcus (in monkey 2) are shifted to the prelunate gyrus (indicated by an arrow). The V2 cells were recorded from the lateral bank of the lunate sulcus. The depicted regions are the same as those of Fig. 1.



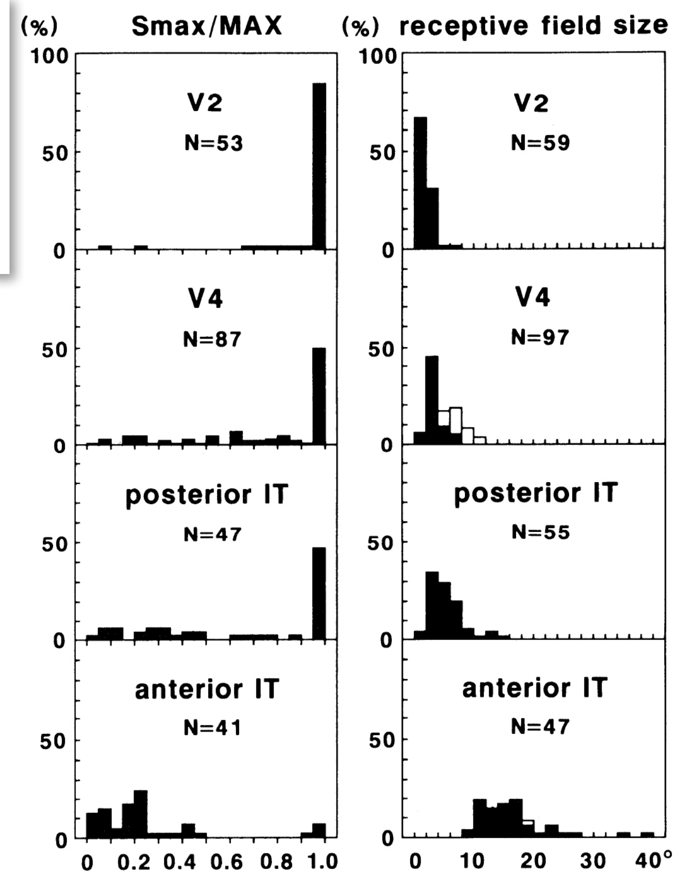
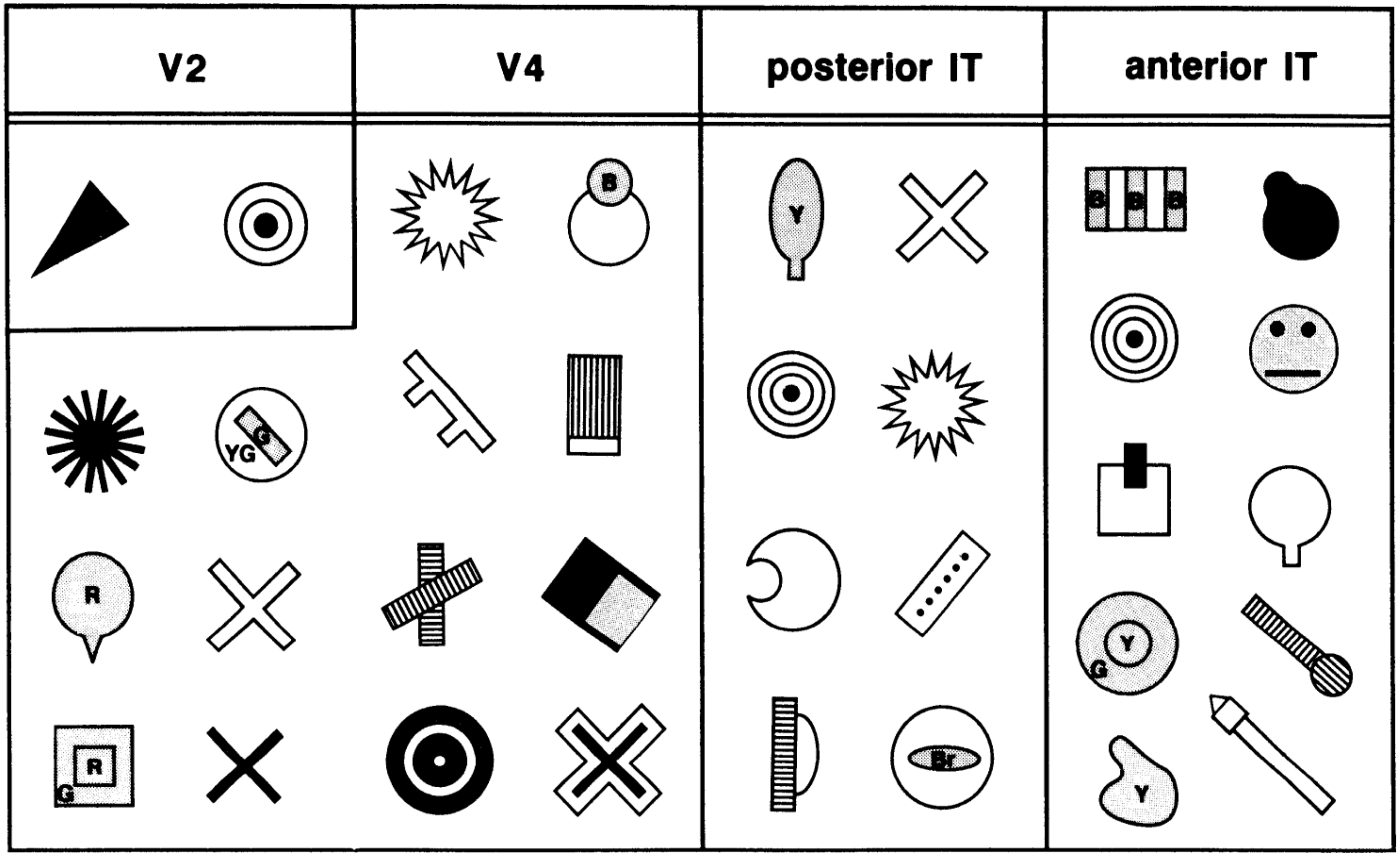


FIG. 10. Distribution histograms of the ratio of S_{max}/MAX and the size of the receptive field in the 4 regions. The size of the receptive field is given by the square root of the area of the receptive field. See METHODS for the method of determining the border of the receptive field and the method of calculation for the area. Filled areas in *right histograms*: cells having

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.

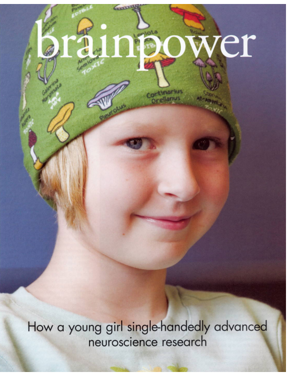
Smax/MAX = 1 → “simple responses”
Smax/MAX = 0 → “complex responses”

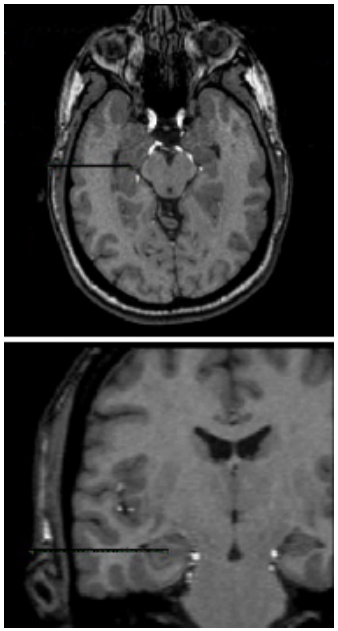
Increase in “complexity” of feature preferences along the ventral visual stream

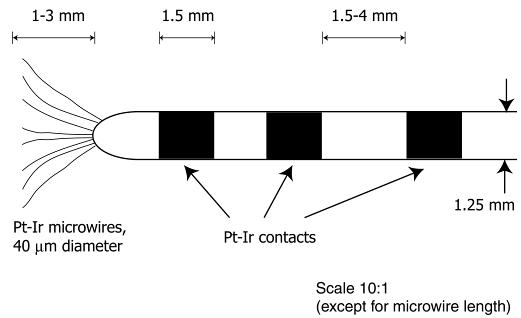


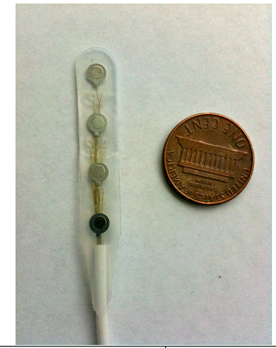
Kobatake E, Tanaka K (1994) Neuronal selectivities to complex object features in the ventral visual pathway of the macaque cerebral cortex. J Neurophysiol 71:856-867.

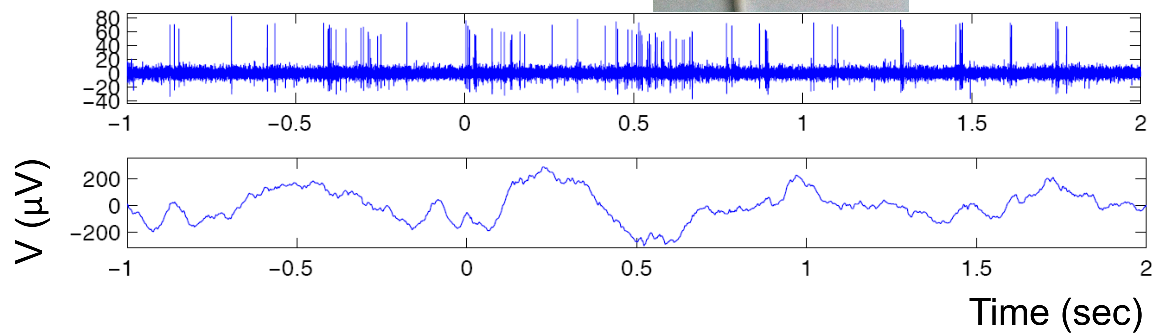
Neurophysiological recordings in the human brain





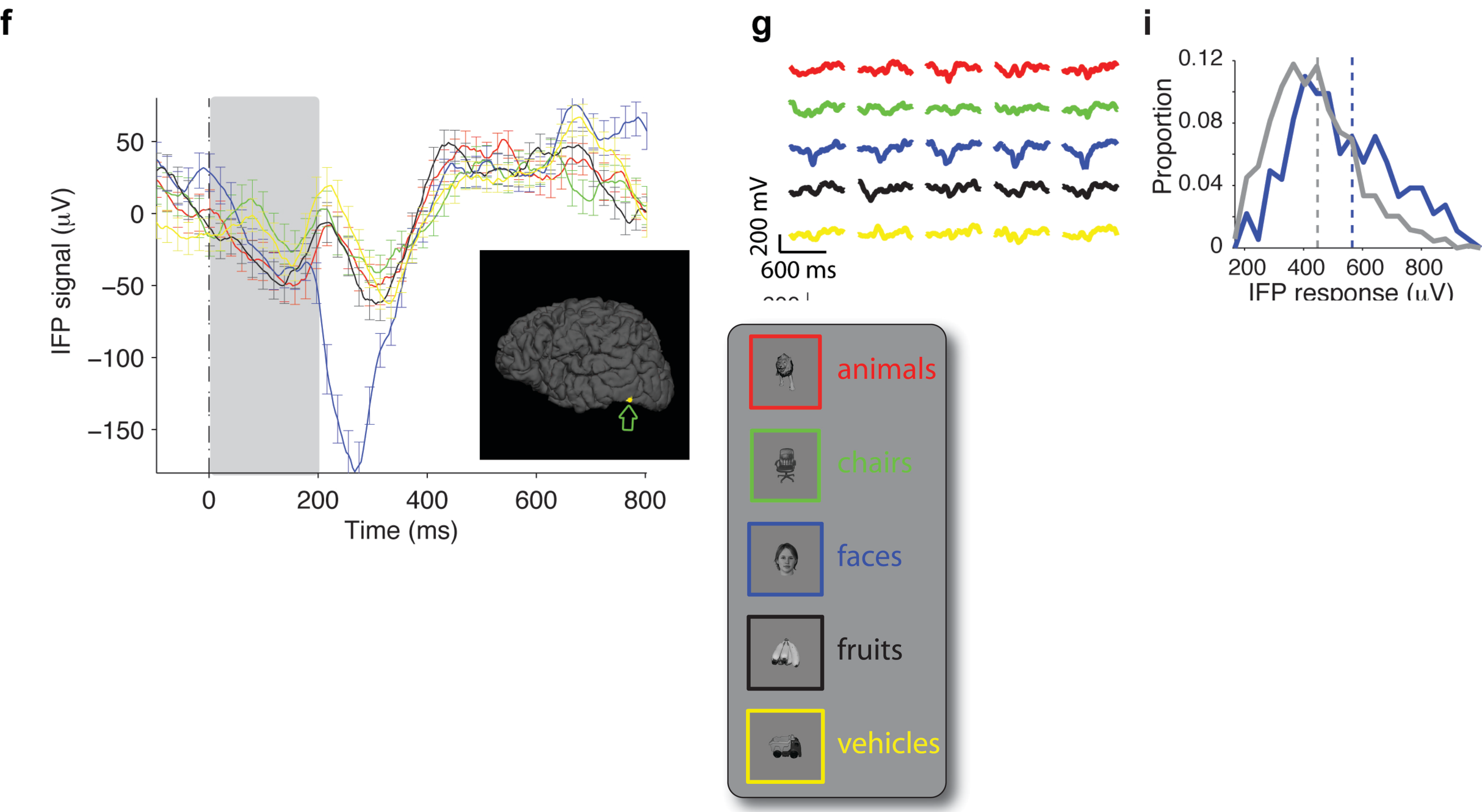






- Patients with pharmacologically intractable epilepsy
- Multiple electrodes implanted to localize seizure focus
- Targets typically include the temporal lobe (inferior temporal cortex, fusiform gyrus), medial temporal lobe (hippocampus, entorhinal cortex, amygdala and parahippocampal gyrus)
- Patients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

Shape selectivity in human extrastriate visual cortex

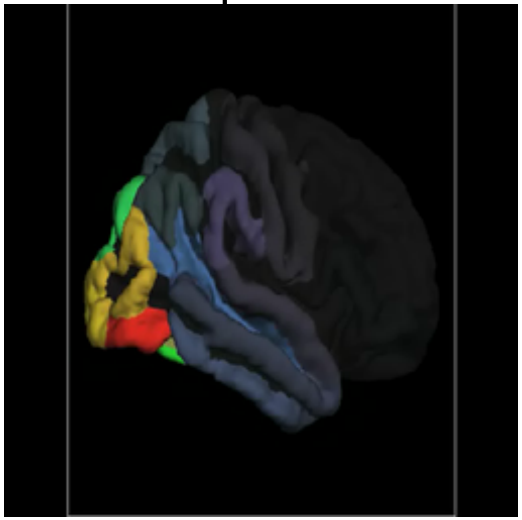


Liu et al. Neuron 2009

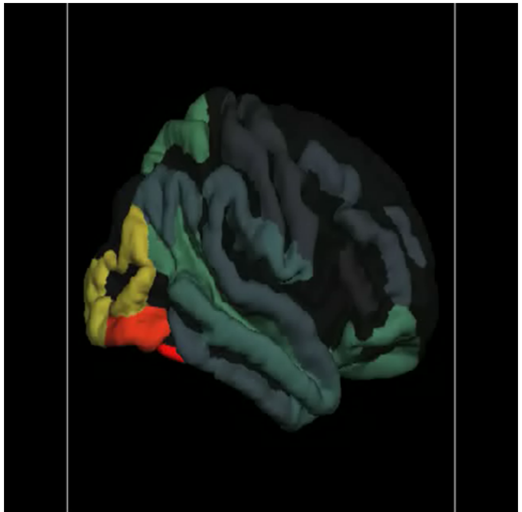
Visual shape selectivity is largely focused along the ventral visual stream

2205 electrodes
27 subjects

Responsive



Selective



Jed Singer

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