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 03:30 – 05:30

Lectures:

Faculty: Gabriel Kreiman and invited guests

TA: Joseph Olson

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Office Hours: After Class. Mon 05:30-06:30 or by appointment

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Class 1. Sep-12 Introduction to pattern recognition. Why is vision difficult? Visual input. Natural image statistics. The retina. [Kreiman]

Class 2. Sep-19 Lesion studies in animal models. Neurological studies of cortical visual deficits in humans. [Kreiman]

Class 3. Sep-26 Psychophysics of visual object recognition [Joseph Olson]

Class 4. Oct-03 Introduction to the thalamus and primary visual cortex [Camille Gomez-Laberge]

Oct-10 *Columbus Day. No class.*

Class 5. Oct-17 Adventures into *terra incognita*. Neurophysiology beyond V1 [Jiye Kim]

Class 6. Oct-24 First steps into inferior temporal cortex [Carlos Ponce]

Class 7. Oct-31 From the highest echelons of visual processing to cognition [Leyla Isik]

Class 8. Nov-07 Correlation and causality. Electrical stimulation in visual cortex.

Class 9. Nov-14 Theoretical neuroscience. Computational models of neurons and neural networks. [Bill Lotter]

Class 10. Nov-21 Computer vision. Towards artificial intelligence systems for cognition [David Cox]

Class 11. Nov-28 Computational models of visual object recognition. [Kreiman]

Class 12. Dec-05 **[Extra class]** Towards understanding subjective visual perception. Visual consciousness.

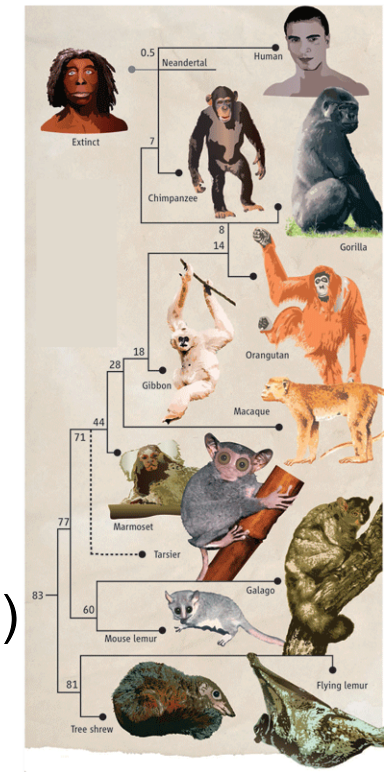
We can extract a large amount of information from a brief glimpse of a complex image

Who is there?
What is there?
Where are they?
What are they doing?
What is their relationship?
What happened before and what will happen next?

Visual recognition is instantiated by the most powerful computational device on Earth

Why visual recognition?
Evolution

Trilobites,
circa 500 million years ago



- Navigation
- Recognizing danger
- Recognizing food
- Social interactions
- Recognizing far away signals (cf. tactile & auditory senses)
- High speeds (cf. olfactory signals)
- (Reading/Symbols)

Why visual recognition?
Applications

- Face recognition
- Pedestrian recognition
- Robot navigation
- Clinical applications)
- Security
- Intelligent image understanding

A Turing test for vision: Can machines (be taught to) see the world the way we do?

Alan Turing, 1950. Computing Machinery and Intelligence. “Can machines think?”

Key aspects of visual recognition

1. Selectivity (e.g. different faces)

2. Invariance (scale, position, illumination, contrast, etc)

3. Speed (Potter & Levy 1969, Thorpe *et al* 1996)

4. Large capacity (Standing 1973, Shepard 1967)

Key aspects of visual recognition
Selectivity

Selectivity: discriminating among many (similar) objects

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Key aspects of visual recognition
Invariance

Invariance: recognizing an object in spite of changes in scale, position, illumination, contrast, viewpoint, cue, clutter, background, etc

Key aspects of visual recognition
Speed

10 frames/sec

Potter & Levy 1969

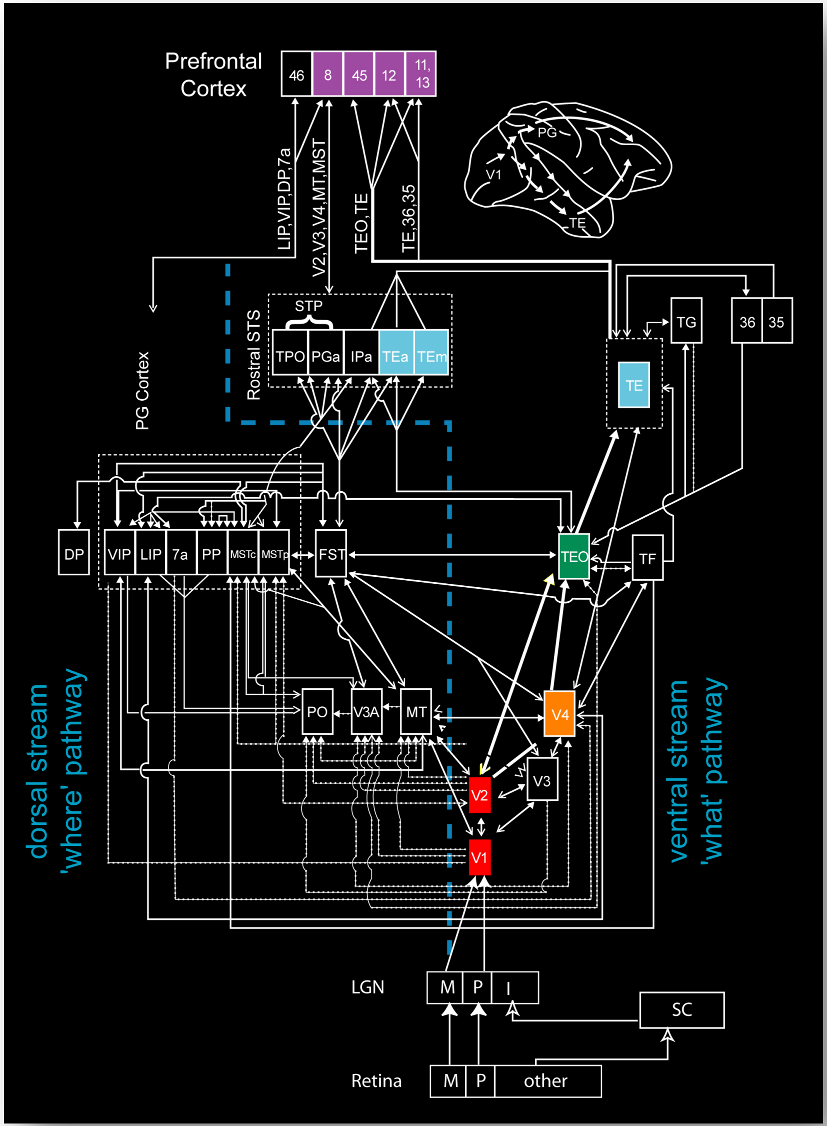
Thorpe et al 1996

Key aspects of visual recognition
Capacity

- Standing L (1973) Learning 10,000 pictures.
- Shepard RN (1987) Toward a universal law of generalization for psychological science.
- Biederman I (1987) Recognition-by-components: A theory of human image understanding.

Chinese: ~2000 characters

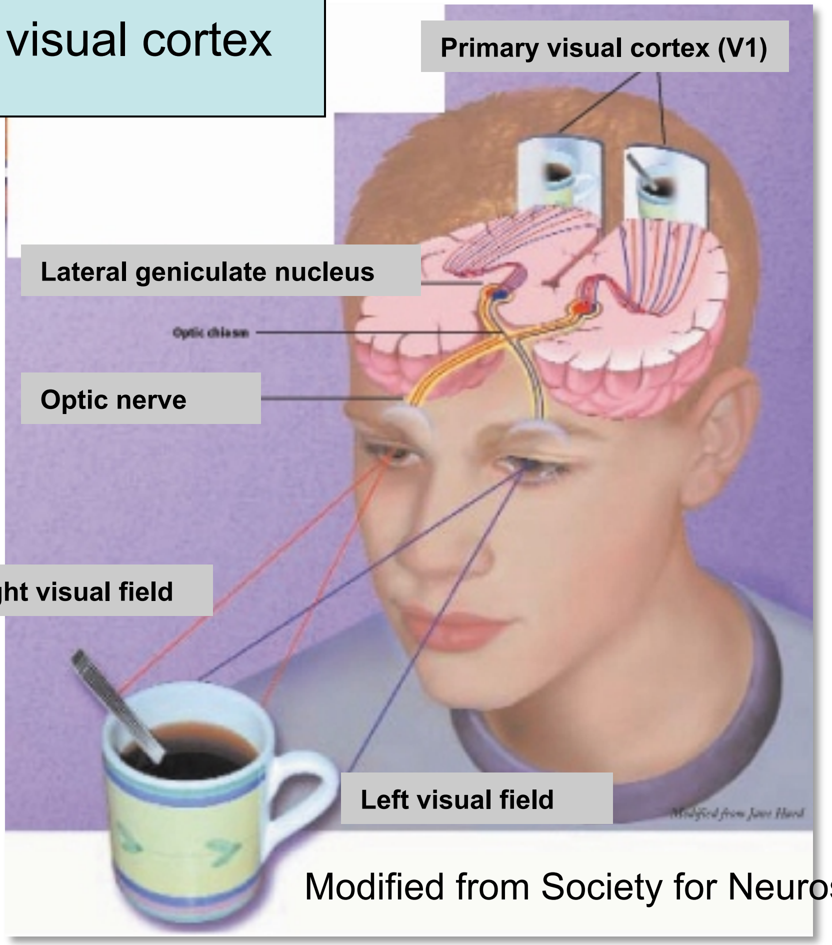
Visual system circuitry



Felleman and Van Essen. *Cerebral Cortex* 1991

Visual system circuitry

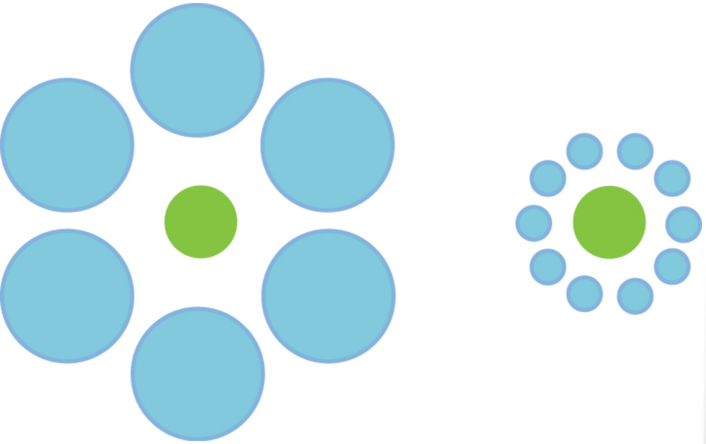
Class 4: Primary visual cortex



Modified from Society for Neuroscience Brain Facts

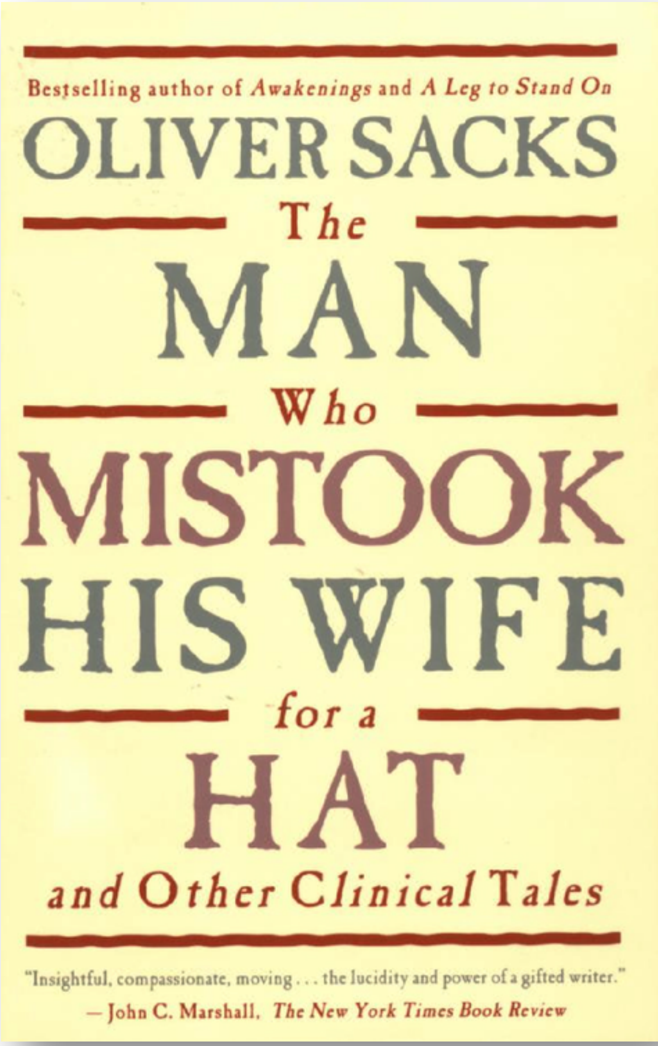
Class 1: Natural image statistics and the retina

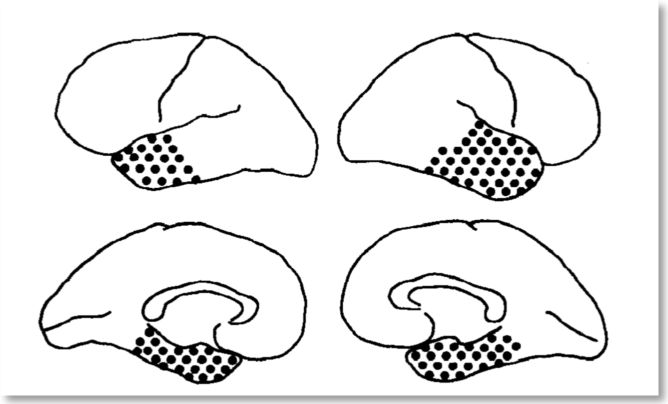
Visual behavior (psychophysics)



Class 3: Psychophysical studies and constraints on visual object recognition

Lesion studies: prosopagnosia



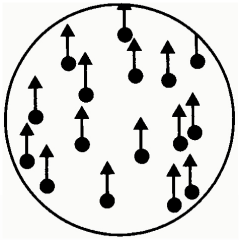


Distribution of lesion sites in cases of face agnosia

Damasio et al. *Face agnosia and the neural substrates of memory.* Annual Review of Neuroscience (1990). **13**:89-109

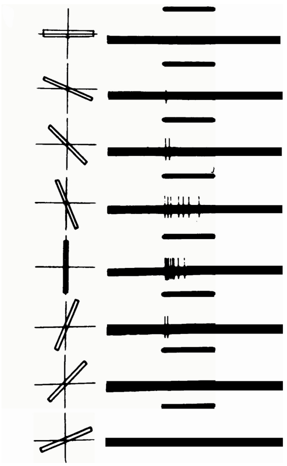
Functional anatomy of the primate visual system

Class 5:
Adventures into *terra incognita*: beyond primary visual cortex

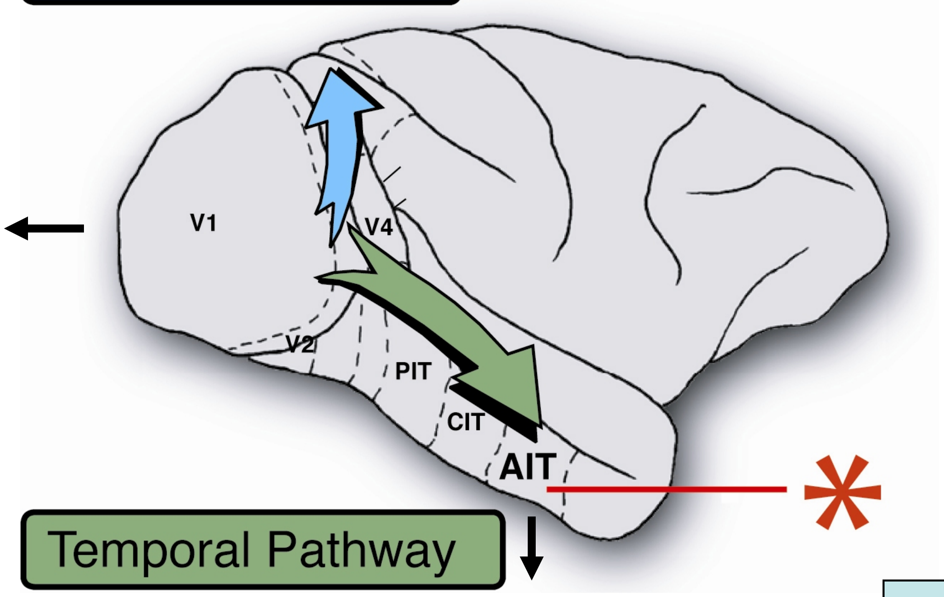


Newsome *et al* (1989)
Nature **341**:52-54

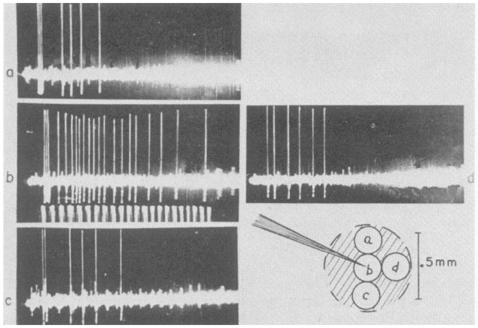
Parietal Pathway



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

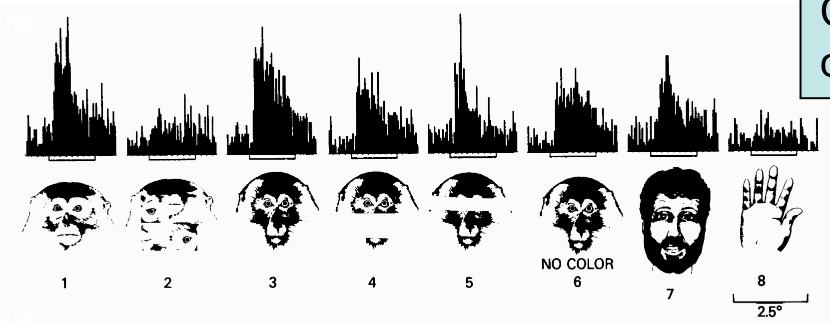


Temporal Pathway



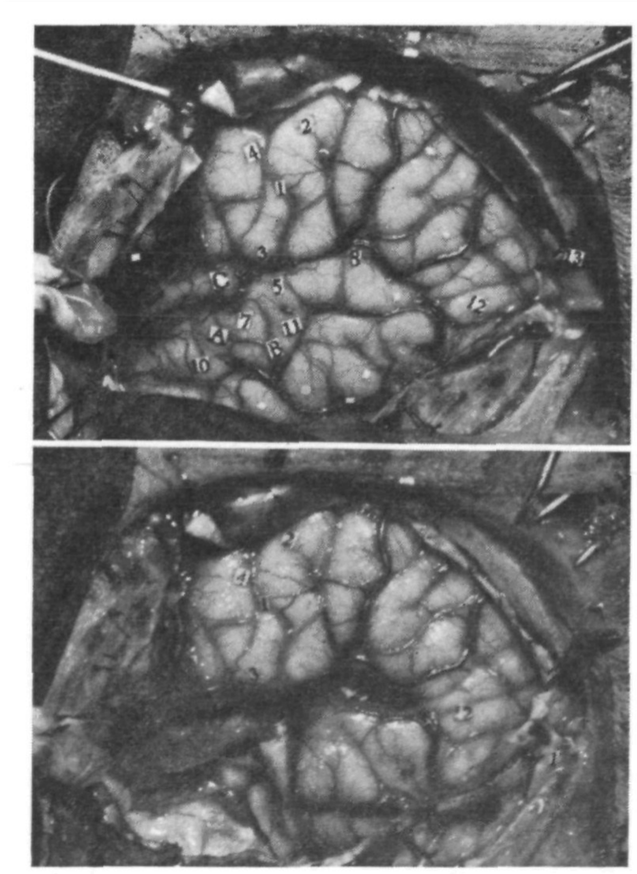
Kuffler, S. (1953)
J. Neurophys. **16**: 37-68

Class 6/7: Inferior temporal cortex



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

Electrical stimulation in the human brain

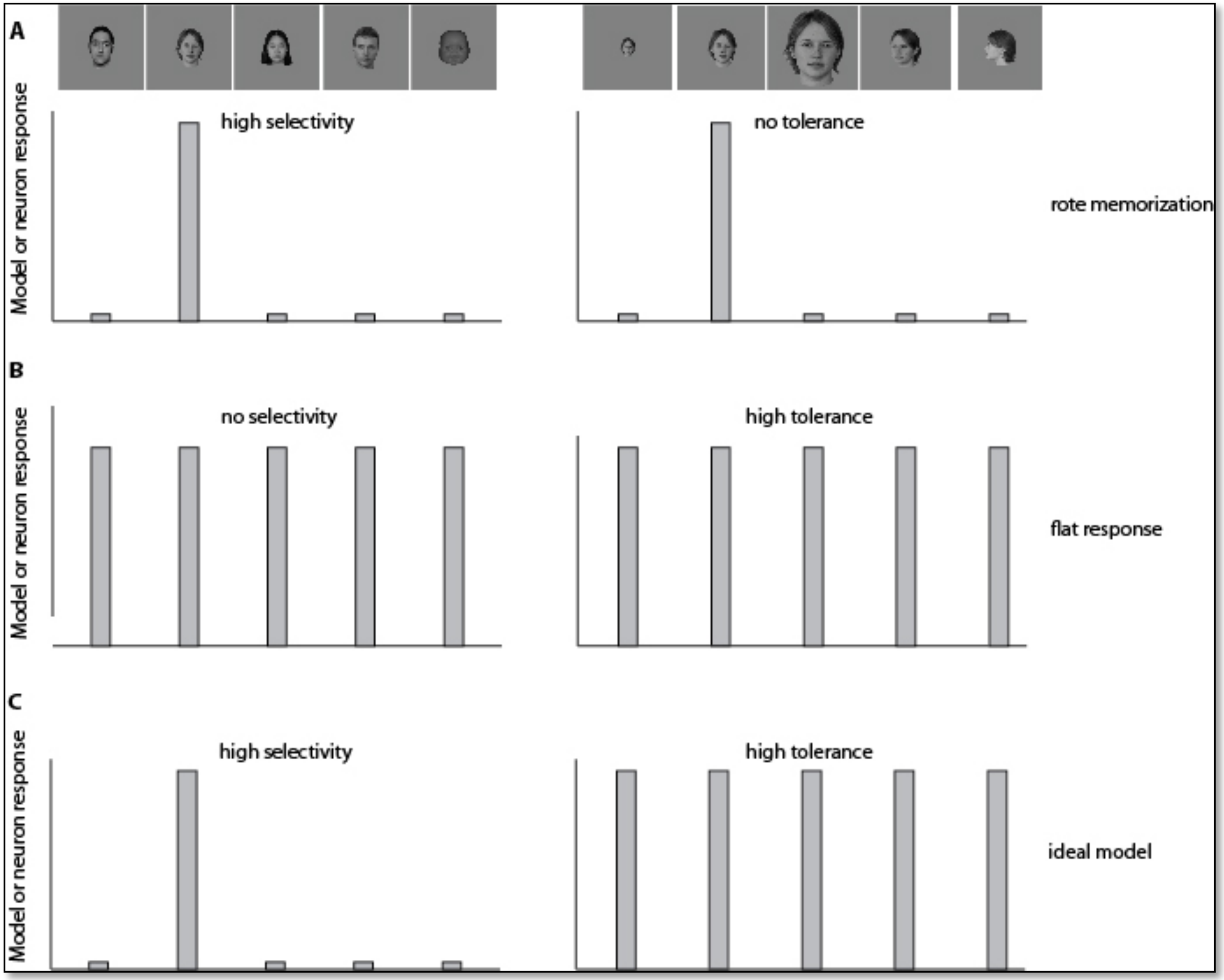


Before the removal was carried out, stimulation at points 5 and 7 produced the following experiential responses.

5. Patient did not reply.
5. Repeated. "Something."
5. Patient did not reply.
5. Repeated. "Something."
5. Repeated again. "People's voices talking." When asked, he said he could not tell what they were saying. They seemed to be far away.
5. Stimulation without warning. He said, "Now I hear them." Then he added, "A little like in a dream."
7. "Like footsteps walking—on the radio."
7. Repeated. "Like company in the room."
7. Repeated. He explained "it was like being in a dance hall, like standing in the doorway—in a gymnasium—like at the Kenwood Highschool." He added, "If I wanted to go there it would be similar to what I heard just now."
7. Repeated. Patient said, "Yes, yes, yes." After withdrawal of the stimulus, he said it was "like a lady was talking to a child. It seemed like it was in a room, but it seemed as though it was by the ocean—at the seashore."
7. Repeated. "I tried to think." When asked whether he saw something or heard something, he said, "I saw and heard. It seemed familiar, as though I had been there."
5. Repeated (20 minutes after last stimulation at 5). "People's voices." When asked, he said, "Relatives, my mother." When asked if it was over, he said, "I do not know." When asked if he also realized he was in the operating room, he said "Yes." He explained it seemed like a dream.
5. Repeated. Patient said, "I am trying." After withdrawal of the electrode he said, "It seemed as if my niece and nephew were visiting at my home. It happened like that many times. They were getting ready to go home, putting their things on—their coats and hats." When asked where, he said, "In the dining room—the front room—they were moving about. There were three of them and my mother was talking to them. She was rushed—in a hurry. I could not see them clearly or hear them clearly."

Penfield & Perot. *The brain's record of auditory and visual experience. A final summary and discussion. Brain* (1963) **86**:595-696

Why is vision difficult?

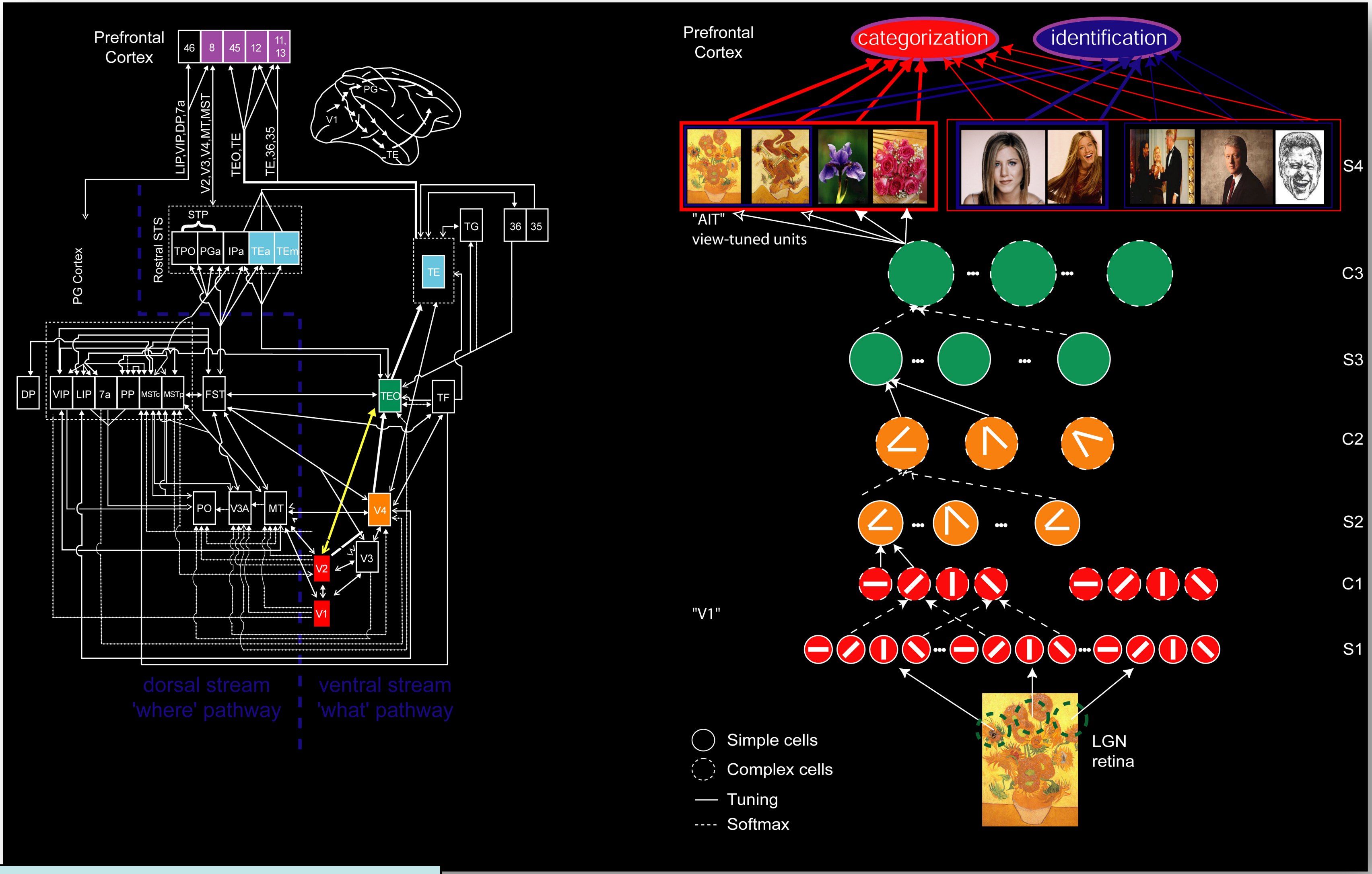


Towards a theory of object recognition

Computational models can

- Integrate existing data
- Explain apparently disparate observations
- Quantify and formalize knowledge
- Suggest experimentally-testable predictions
- Provide a useful engineering tool

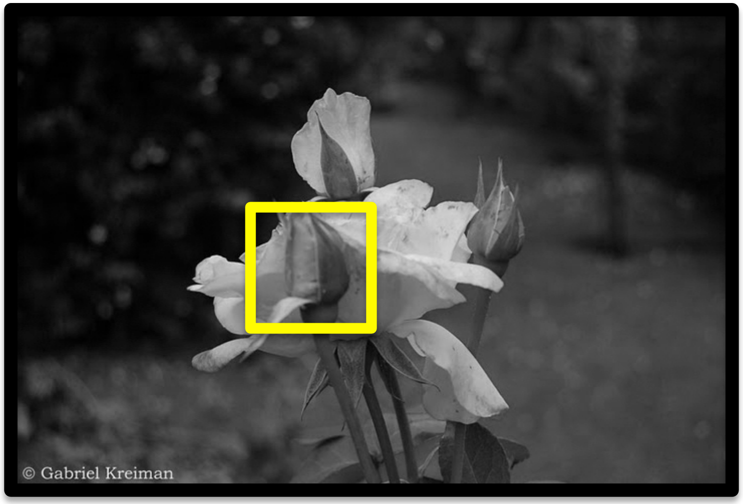
A feed-forward hierarchical model of ventral cortex



Class 11: Computational models

Fukushima. *Biological Cybernetics* 1980;
Serre, Kreiman, Cadieu, Knoblich, Poggio, Progress in Brain Research 2007

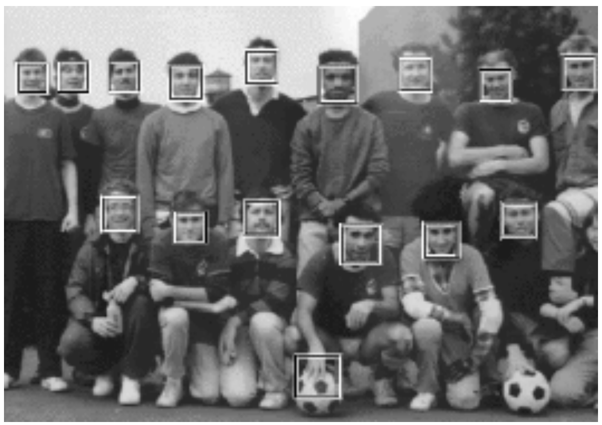
A flower, as seen by a computer



23	16	13	12	13	13	12	12	12	14	16	19	21	22	25	24	20	90	127	101
31	22	13	13	12	12	11	11	13	16	18	18	23	22	21	19	39	83	96	78
34	24	16	14	13	12	21	14	13	17	15	22	15	29	42	82	147	118	63	36
30	20	15	13	14	12	26	34	10	11	79	139	88	91	119	174	172	137	96	78
20	14	12	12	14	14	21	77	35	16	136	148	110	109	127	137	168	157	144	175
13	10	10	12	15	16	14	81	86	52	155	123	91	114	149	120	154	139	138	186
9	9	9	11	14	17	18	54	110	111	143	99	105	104	148	128	103	148	162	172
9	8	9	11	14	18	20	26	97	99	99	91	116	116	141	139	77	88	117	156
9	9	12	12	15	18	15	29	107	99	88	86	121	124	115	123	79	78	98	92
9	10	11	13	15	16	30	97	121	112	98	68	102	125	115	101	100	60	105	109
9	9	11	14	17	13	96	127	145	115	95	60	90	114	118	98	107	72	60	111
9	10	12	13	16	17	117	128	122	114	89	65	94	108	118	116	117	93	59	67
10	10	10	7	9	78	152	127	118	114	77	72	95	109	116	120	128	96	68	50
7	1	10	54	114	166	145	121	125	113	65	70	97	107	110	107	103	93	67	54
33	92	129	151	157	158	146	130	125	104	66	77	100	105	111	108	94	85	62	58
145	144	135	142	151	152	149	137	131	98	69	82	102	111	102	93	89	84	59	54
125	125	140	156	144	150	145	133	128	98	74	87	110	110	106	93	86	80	56	48
147	147	161	143	143	144	138	129	121	94	69	86	107	106	102	91	82	77	50	43
182	181	164	140	143	140	132	128	121	97	71	82	100	109	97	91	93	80	44	40
188	174	143	147	146	144	137	127	119	97	78	83	100	105	104	92	86	81	46	38

Detection, segmentation, recognition

Face detection



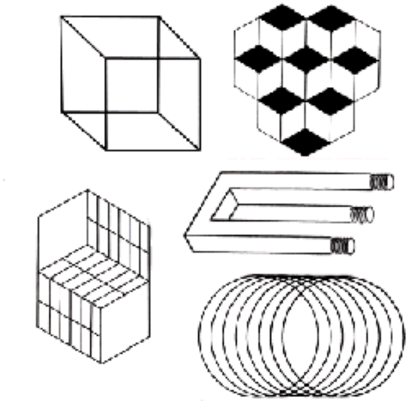
Segmentation

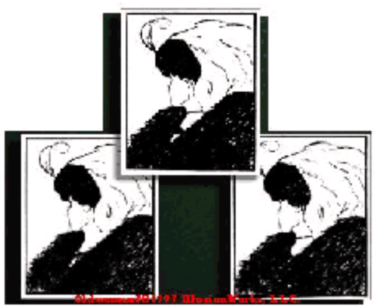
Recognition

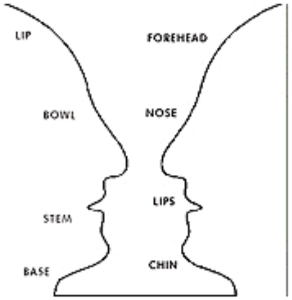
Fig. 7: The 101 object categories and the background clutter category. Each category contains between 45 to 400 images. Two randomly chosen samples are shown for each category. The categories were selected prior to the experimentation, collected by operators not associated with the

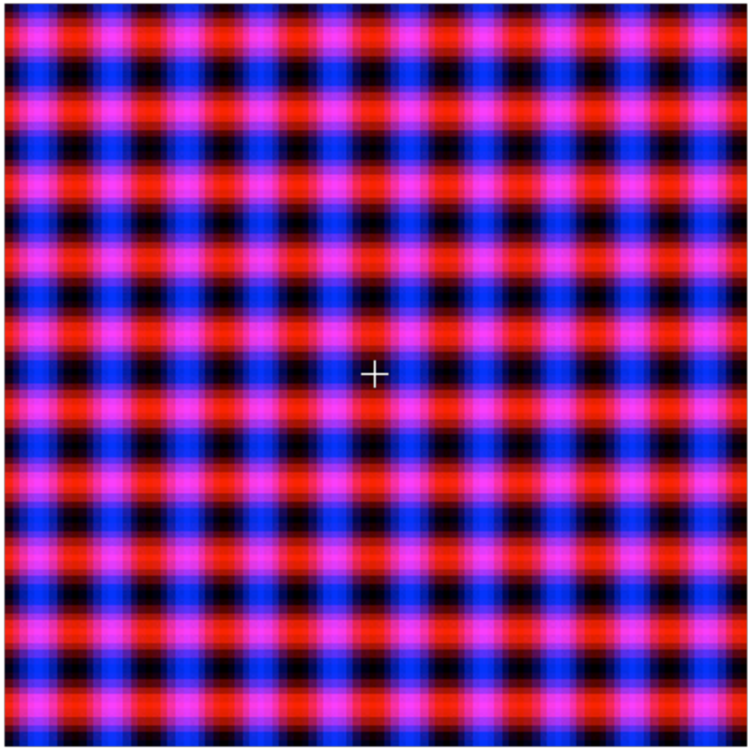
Class 12: Can computers see the way we do?
Computer vision

Bistable percepts and subjective perception









Blake R, Logothetis N (2002) Visual competition. Nature Reviews Neuroscience 3: 13-21.

Class 12: Visual consciousness

Further reading

Reviews

- Logothetis, N.K. and D.L. Sheinberg, Annual Review of Neuroscience, 1996. **19**: p. 577-621.

Further reading

- Tanaka, K., Annual Review of Neuroscience, 1996. **19**: p. 109-139.
- Kreiman, G., Current Opinion in Neurobiology, 2007. 17(4): p. 471-475.
- Miyashita, Y., Annual Review of Neuroscience, 1993. **16**: p. 245-263.
- Kourtzi Z, DiCarlo JJ. Curr Opin Neurobiol. 2006 16:152-8.
- Rolls, E., Current Opinion in Neurobiology, 1991. **1**: p. 274-278.
- Riesenhuber, M. and T. Poggio. Nature Neuroscience, 2000. 3 Suppl: p. 1199-204.
- Kanwisher, N. and M. Moscovitch. Cognitive Neuropsychology, 2000. 17(1-3): p. 1-11.
- Kreiman, G.. Biological object recognition. Scholarpedia. http://www.scholarpedia.org

Further reading

<u>Original articles cited in class</u>

- Churchland, P.S. and T.J. Sejnowski. Science, 1988. **242**(4879): p. 741-745.
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- Thorpe S, Fize D, Marlot C (1996) Speed of processing in the human visual system. Nature 381: 520-522.
- Standing L (1973) Learning 10,000 pictures.
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- Penfield & Perot. *The brain's record of auditory and visual experience. A final summary and discussion. Brain* (1963) **86**:595-696
- Afraz et al. *Microstimulation of inferotemporal cortex influences face categorization.* Nature (2006) **442**: 692-695.
- Fukushima. *Biological Cybernetics* 1980;
  Serre, Kreiman, Cadieu, Knoblich, Poggio, Progress in Brain Research 2007
- Blake R, Logothetis N (2002) Visual competition. Nature Reviews Neuroscience 3: 13-21.