USC Image Understanding Lab

Monday, February 8, 2010
Shape Representation in the Brain

(how we make [visual] ideas)

Expanded Animation

Feb. 8, 2010

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Opening question: How do you tell the difference, visually, between a cat and a dog?
- > it's the FEATURES (ears, tail, nose).
What features of images are we really sensitive to?
Lines are enough; line drawings effectively capture most of the variation to which we’re sensitive in an image.
Line Drawings vs. Images

Massive differences at the pixel level - but we see them as the same thing!

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Lines are enough; line drawings effectively capture most of the variation to which we’re sensitive in an image.
We don’t even need all the lines!

Nonrecoverable

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We don’t even need all the lines!

<table>
<thead>
<tr>
<th>Recoverable</th>
<th>Nonrecoverable</th>
</tr>
</thead>
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We don’t even need all the lines!

Recoverable  Nonrecoverable

[Drawings of various objects: glass, watering can, scissors, stool]
Same parts = same perception
How do we define parts? (non-accidental properties)

1. SMOOTH CONTINUATION

<table>
<thead>
<tr>
<th>Straight</th>
<th>Curved</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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</table>

2. COTERMINATION

<table>
<thead>
<tr>
<th>Yes (vertex type)</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;L&quot;</td>
<td></td>
</tr>
<tr>
<td>Fork</td>
<td></td>
</tr>
<tr>
<td>Arrow</td>
<td></td>
</tr>
<tr>
<td>&quot;T&quot;</td>
<td></td>
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3. PARALLELISM

<table>
<thead>
<tr>
<th>Yes (with bias in depth)</th>
<th>No</th>
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These are the features that will occur at corners / along primary axes of objects; these serve to DEFINE parts.
Non-accidental vs. metric differences in shapes

Non-accidental
- Expansion versus no expansion of the cross-section
- Negative curvature of the sides versus straight sides
- Positive curvature of the sides versus straight sides
- Curved main axis versus straight main axis

Metric
- Amount of expansion of the cross-section
- Amount of negative curvature of the sides
- Amount of positive curvature of the sides
- Degree of curvature of the main axis

Non-accidental differences create different “cognitive categories”; metric differences do not. It’s easy to tell shapes apart that have non-accidental differences; it’s harder to tell metric differences apart.
One proposed “shape alphabet”

1. **Cross Section**: Straight vs. Curved

2. **Axis**: Straight vs. Curved

3. **Size of Cross Section**: Constant (parallel sides) vs. Expand vs. Expand & Contract vs Contract & Expand

4. **Termination of Geon when Nonparallel**: Truncated vs. Pointed vs. Rounded

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“Geometric Ions” or “Geons” proposed by Irving Biederman (1987).
How does the brain get to geons??

- Information comes into the brain through a series of relays: one visual area “talks” to another, and that one passes the signal on to still another.
- Each stage tells the next stage what is important*, and filters out what is not important.
- Gradually we extract line-drawing like SHAPE information about the objects in our visual field.
- We are NOT aware of early stages of the process, but we are aware of later stages.
- We use the same brain regions to *imagine* visual images as we do to perceive them.

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* Lots of feedback, crossovers, etc.
I’m going to give you two examples of how you are not aware of early stages (the retina / V1)
The Retina: Quirks

The retina is 2-D – it’s basically a digital image.

Fovea = most pixels per sq mm; Blind spot = the region where the optical nerve leaves the eye (NO LIGHT-SENSITIVE CELLS THERE!)

Find your blind spot: close left eye, hold thumbs up at arm’s length. Stare at left thumb with right eye, move right thumb away to the right (slowly) till the right thumb disappears.

Also: stare at the fixation cross (x) and try to read the word that appears!
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Also: stare at the fixation cross (x) and try to read the word that appears!
Binocular rivalry: if you stare straight at the cross, your perception should alternate between a star and a circle.
Connections from the eye to the brain have been known for 100 years, but most of the neurological research on vision in the brain has been done in the last 50 years.

25–30% of the brain is “visual cortex.”
Human Cortical Visual Modules

The visual hierarchy: order of inputs
The visual hierarchy: order of inputs
The visual hierarchy: order of inputs
Human Cortical Visual Modules

Cerebral Cortex Overview

V1
V2
V4
LO
IPS
V2
V3
V1
V2
IPS
LO
V2
V3
V1

Frontal lobe
Parietal lobe
Occipital lobe
Visual area
Auditory area

Primary motor area
Somatosensory area
Primary sensory areas

Temporal lobe

thalamus

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Cerebral Cortex Overview

Human Cortical Visual Modules

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The visual hierarchy: the complex version (Felleman & Van Essen’s connection diagram of all known connections between visual areas in the macaque monkey, published in 1991).
Human Cortical Visual Modules

V1
Sensitive to:
- Edges in very particular locations in the visual field

Lesion results in:
- Scotoma (blind spot)

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Discovered in the 1970s (ish).
V1 is organized RETINOTOPICALLY – as in, with the same topography as the retina. Retinotopic organization of visual areas means there is essentially a rendering screen in the brain.
V4
Sensitive to:
- Color differences, radial patterns, curves, angles

Lesion results in:
- Color deficits
- Shape perception deficits
- Relative position deficits
One patient with damage to V4* could tell images in A from B, but not A from C.

- **A. Targets**
  - T1
  - T2
  - T3
  - T4

- **B. Part-changed distractors**
  - D1
  - D2
  - D3
  - D4
  - D5
  - D6
  - D7
  - D8

- **C. Relation-changed distractors**
  - D9
  - D10
  - D11
  - D12
  - D13
  - D14
  - D15
  - D16

from Behrman et al, 2006

*Lesion patient caveats: it is very rare to get a cleanly-circumscribed lesion to a single visual area! This lesion may have encompassed parts of nearby areas (V3, LO) as well.
Human Cortical Visual Modules

LO

Sensitive to:
- “Moderately complex features”
- Part-level features of objects
- Relative position of objects
- Pointed vs. curved parts
- Axis structure (global layout) of objects

Lesion results in:
- Complex perception deficits

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LO (the Lateral [side] Occipital [back] cortex), is defined in (f)MRI as an area that shows a greater response to coherent images (i.e., images with continuous contours in them) than to scrambled versions of the same images.
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Human Cortical Visual Modules

B. Location of LOC in Neurologically-Intact Subjects

(Normal)

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Human Cortical Visual Modules

(Patient DF)

A. Lesions in Subject DF

B. Location of LOC in Neurologically-Intact Subjects

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Patient DF, trying to guess what the picture is...

- “It’s made out of metal - is it aluminium? It’s got red plastic on it.”
- “Is it some sort of kitchen utensil?”

from Humphrey, Goodale, Jakobson, & Servos (1994). *Perception*
BUT, she can still do some tasks!

Patient DF

Control

Goodale et al. (1991) *Nature*
BUT, she can still do some tasks!

Patient DF grasp points

Goodale et al. (1991) *Nature*
Human Cortical Visual Modules

**Fusiform Face Area**

Sensitive to:
- Faces, well-learned categories

Lesion results in:
- Face recognition deficits* (prosopagnosia)

**Parahippocampal Place Area**

Sensitive to:
- Houses, spatial layout, contextual associations (?)

Lesion results in:
- (?)

(notice the asterisks / question marks – this is getting to the bleeding edge of what is known)
Human Cortical Visual Modules

Mind reading: were you thinking of houses or faces?

From O’Craven & Kanwisher, 2000

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Mind reading. Imagery & perception elicit the same fMRI signal.
Reading the minds of patients in a vegetative state: Tennis = “Yes”, House = “No”


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5/54 patients tested could answer questions accurately; 4 were diagnosed as vegetative; 2 were still diagnosed as vegetative (i.e., showed NO behaviorally detectable signs even after it was known that they could respond).
Human Cortical Visual Modules

Cutting edge brain reading: Image reconstruction

image shown to subject

reconstruction based on V1,V2,V3

V1,V2,V3 + low-frequency assumption

best-guess match from 1,000 images

From Naselaris & Gallant,

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Cutting edge brain reading: Image reconstruction

From Naselaris & Gallant,
Are we born with all these areas working?

Probably not.

Early evidence
- Hubel & Weisel, Blakemore, studies with cats
- Idea of a “critical period”

Recent Studies
- I. Fine, P. Sinha (Project Prakash)
- Critical periods may be delayed by lack of visual experience (you can still learn as an adult)

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A critical period is a period in which, if something is not learned, it will never be learned. (I did not talk about this in class...)
Are we born with all these areas working?

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Project Prakash, in India
Are we born with all these areas working?

Motion saves the day. If the stimuli move, then subjects’ performance dramatically improves. This suggests that motion is one of the most primitive cues we have as to which features go together in an image.

Infants can group by motion cues 2 months before they can group by static cues (~10 months).
Are we born with all these areas working?

Subjects can still learn after the critical period
Human Cortical Visual Modules

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