lecture 8

- retinal coding

- visual area 1 of the cortex

Thurs. Oct 8, 2015
Recall: retinal ganglion cells have receptive fields that are roughly as follows.

\[ \text{DOG}(x, y) \]

\[ \text{DOG}(x, 0) \]
How do such cells respond to a "step edge"?
DOG(x, y) * I(x, y)
Insets in upper left corner show the DOG used.
ASIDE: coding negative values

If \( r(x,y) = I(x,y) \times \text{DOG}(x,y) \) is supposed to represent the responses of retinal ganglion cells, then how are negative values coded?

Recall: classical theory of spikes says that the response of a cell is proportional to the 'firing rate' (spikes/sec)
In fact, cell response (measured by firing rate) is a non-linear function of $I \ast DOG$.

No information is lost if the function is invertible.
(Simplified model)  "half wave rectification"

Cell response = \( \max \left\{ I(x,y) \ast DOG(x,y), 0 \right\} \)
Example: Half wave rectification

On the left, the image is convolved with ON center OFF surround DOG.

On the right, the positive part of $I^*G$ is coded by (half way rectified) ON center OFF surround, and negative part coded by OFF center ON surround.
"Lateral inhibition" (center-surround receptive fields) encode spatial differences, which are useful for:

- edge detection
- data compression


Lateral inhibition is believed to play some role in many perceptual phenomena (see following), but there is no consensus on exactly what role.
"Simultaneous Contrast" effect

The small grey square on the left appears brighter. WHY? Some argue that this is only an artifact of lateral inhibition.
Mach Bands

\[ I(x) \]

perceived decrease

perceived increase
Mach bands are well known problem for interpreting x-ray images, since very subtle changes in dark-bright must be detected.
Craik-O'Brian-Cornsweet Illusion

$\text{perceived}$
In (a), the perceived reflectance (called "lightness") of the two cylinders is nearly the same. In (b) the left half of the object is perceived to be darker than the right.


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The Human Brain

- (primary) visual cortex
- touch (input) & motor (output) cortex
White matter - axons  (info transport)

Gray matter  -  cell bodies  (computation)
Visual pathway (early vision)

- retina to LGN to visual area 1 (V1)

note how different illustrations enhance different details
Left (right) visual field of both eyes is imaged on right (left) half of retina and processed by right (left) brain hemisphere.
The lateral geniculate nucleus (LGN) in the thalamus has six layers, that alternative between the eyes. Note: the eyes are NOT combined here.

Receptive fields profiles are DOGs, like in the retina.

The LGN is not merely a relay station. It also received input from the surface of the brain (cortex) in a big feedback loop.
Hubel and Wiesel's accidental and amazing discovery in 1959 (led to their Nobel Prize in medicine). CHECK OUT VIDEOS.

the moving slide (see 35 sec and on...)
http://www.youtube.com/watch?v=IOHayh06LJ4

3 minutes of exploration:
https://www.youtube.com/watch?v=Cw5PKV9Rj3o
Simple cell

"line detector"

Cell responds when bar is flashed over excitatory region.

Cell responds when bar is removed from inhibitory region.

No response when stimulus has non-preferred orientation.

Stimulus: on off
V1 physiology: orientation selectivity

Average firing rate
("tuning curve")

Hubel & Wiesel, 1968
How might simple cell receptive field profiles arise from LGN input?

How exactly this works is still not yet known, e.g. since there are feedback in the system that are difficult to control.
Even vs Odd: Lines vs Edge "Detectors"
Mathematical model: 1D Cosine Gabor

\[ G(x, \sigma) \]

\[ \cos(k_0 x) \]

\[ G(\cdot), \cos(\cdot) \]
1D Sine Gabor

\[
G(x, \sigma)
\]

\[
\sin(k_0 x)
\]

\[
G(x) \cdot \sin(x)
\]
2D Gabor: standard model of simple cell

\[
\text{cosineGabor}(x,y, k1, k2) = G(x,y) \cos( k1 x + k2 y)
\]

\[
\text{sineGabor}(x,y, k1, k2) = G(x,y) \sin( k1 x + k2 y)
\]
Example: response to shifted line

Run simpleCell.m in
http://www.cim.mcgill.ca/~langer/546/MATLAB/simpleCell.zip
2D cosine Gabors

2D sine Gabors
Filtering with 2D cosine Gabor filters

Inset in upper left corner shows the cosine Gabor used to filter the image.

filtered images
Filtering with 2D sine Gabors

Inset in upper left corner shows the sine Gabor used to filter the image.
Filtering with (smaller) 2D cosine Gabors

The cosine Gabor is half the size (and twice the frequency) of the previous one.
Filtering with (smaller) 2D sine Gabors

The sine Gabor is half the size (and twice the frequency) of the previous one.
Response of one orientation selective cell to a line stimulus of many different orientations

At each pixel, we have the responses of four different orientation selective cells at that pixel, and for a single image.
Q: How to code negative values of response?
A: **Half wave rectification** (like with DOGs earlier).

\[ I(x,y) \times \text{cosineGabor}(x,y) \]

Carried by ON center

Carried by OFF center
EXERCISE: What is the Fourier transform of a 1D Gabor?

Intuitively, a Gabor consists of frequencies near the frequency of the sinusoid that defines the Gabor. A Gabor is thus a bandpass filter.

\[ G(x) \sin(k_0 x) \]

\[ F \quad G(x) \sin(k_0 x) \]

\[ \text{spatial domain} \]

\[ \text{frequency domain} \]
EXERCISE (not optional):
What is the 2D Fourier transform of a 2D Gabor?
Announcements

You should be subscribed to Announcements on mycourses.

I will grade midterm 1 exam this weekend.

I will try to post Assignment 2 late next week.

Survey: I will try to send it out next week (required).