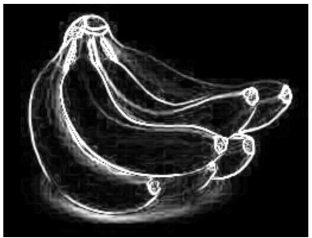
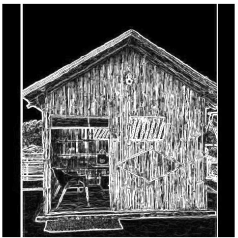
Biological Vision and Applications
Module 02-02: Edge detection

Hiranmay Ghosh

Why edge detection is important



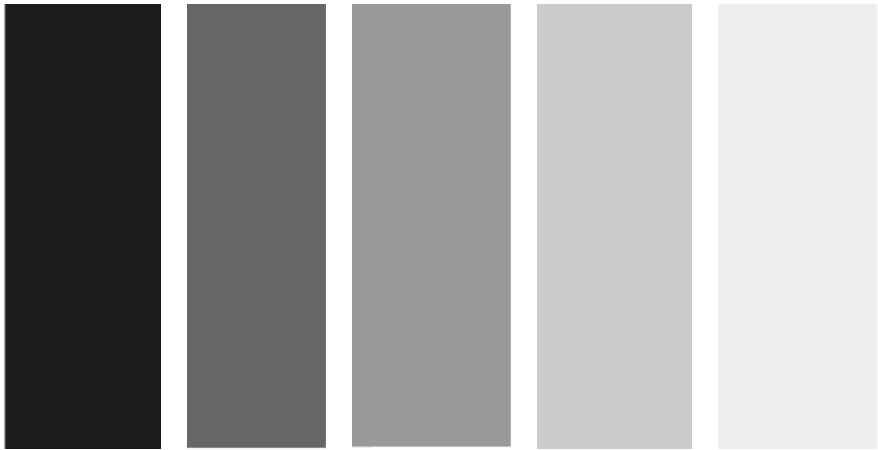



- Most of the objects are identified by their shapes

- How are the shapes detected ?

Machband Effect

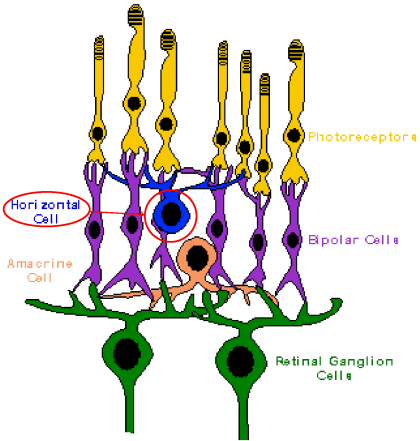
Bars of uniform illumination



Machband Effect

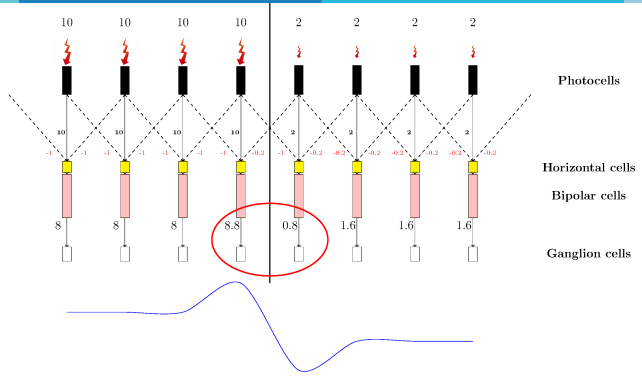
Adds contrast to vision

The Horizontal cells



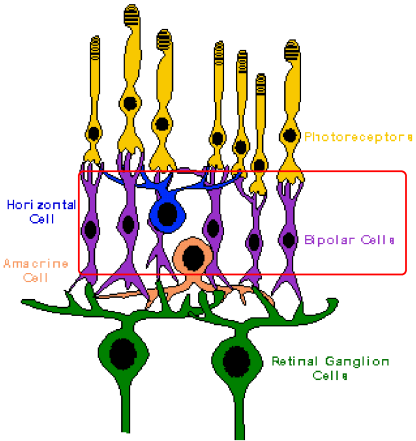
- Connects nearby photo-receptors of the same kind
- Carries a Lateral Inhibition signal
  - proportional to the response level

Computational Model



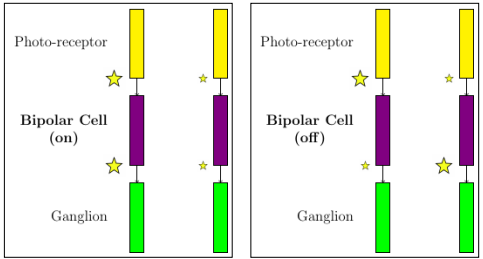
This example assumes $\frac{1}{10}$th of response to be transmitted as inhibition signal

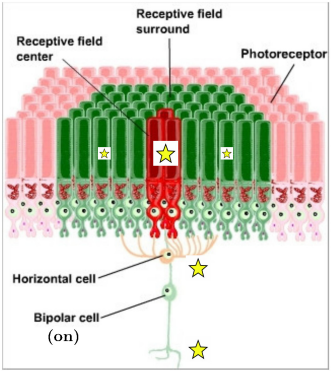
The Bipolar cells



- Photo-receptors are connected to Ganglions through bipolar cells
- 10 million bipolar cells connects to 125 million photo-receptors
  - Connects to few cones (even 1)
  - Connects to many rods
- Data reduction

Center-Surround effect

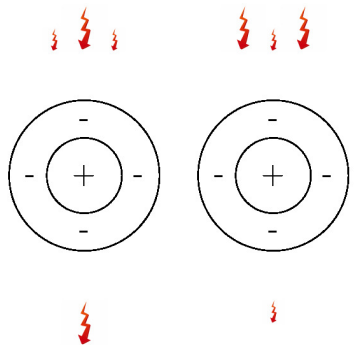




The ganglion output is a weighted linear combination of excitation levels of the photoreceptors in the receptive field.

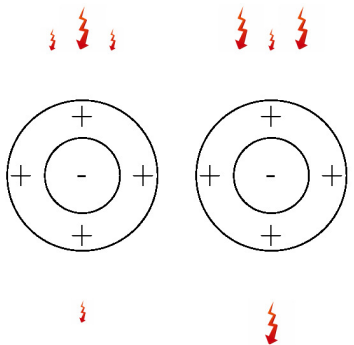
Center-Surround effect

... continued



On-center configuration

"On" bipolar cell at center

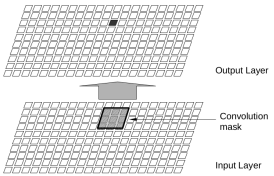


Off-center configuration

"Off" bipolar cell at center

Generic model of signal processing in early vision

Digital Convolution (2D)



Inputs:
Image $I = [[I_{xy}]]$, $x = 1 : W, y = 1 : H$
Mask $M = [[M_{xy}]]$, $x, y = -m : +m \quad (m << W, H)$

Output:
Transformed Image $I' = [[I'_{xy}]]$, $x = 1 : W, y = 1 : H$

$$where\ I'_{x,y} = \sum_{i=-m}^{+m} \sum_{j=-m}^{+m} M_{x+i,y+j}.I_{x-i,y-j}$$

- Compute weighted average of surrounding pixels
- No data reduction at this stage

Fundamental operation in a Convolutional Neural Network (CNN)

Image filters

$$\frac{1}{273}\begin{bmatrix} 1 & 4 & 7 & 4 & 1 \\ 4 & 16 & 26 & 16 & 4 \\ 7 & 26 & 41 & 26 & 7 \\ 4 & 16 & 26 & 16 & 4 \\ 1 & 4 & 7 & 4 & 1 \end{bmatrix}$$

- Integrating filters
  - Gaussian filter (with $\sigma = 1$)
  - Used for noise reduction

Laplacian filters

-1	-1	-1
-1	8	-1
-1	-1	-1

on-center

1	1	1
1	-8	1
1	1	1

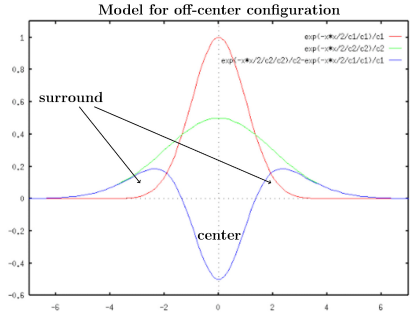
off-center

- Differentiating filters
  - Implements center-surround operation
  - Used for contrast enhancement

In classical image processing, the filters used to be hand-crafted
In CNN, they are machine learnt

Difference of Gaussian

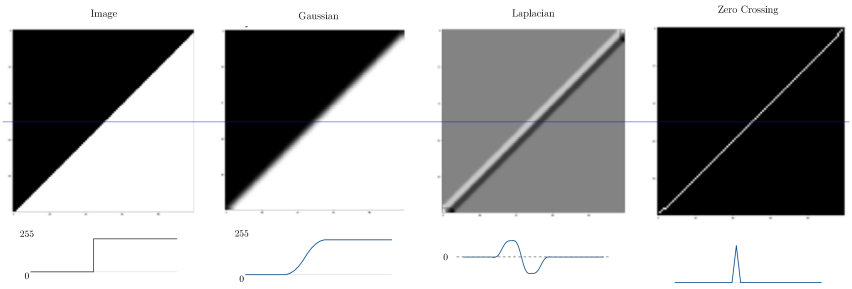
Approximates Laplacian of Gaussian (LoG)



- Gaussian smoothing (noise reduction) precedes differentiation
- DoG is an approximation of LoG

Edge detection

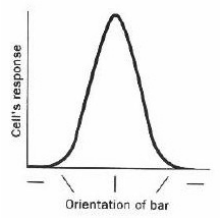
Zero-Crossing of LoG/DoG

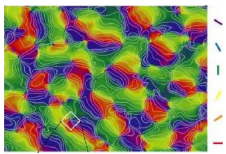


- Orientation ?

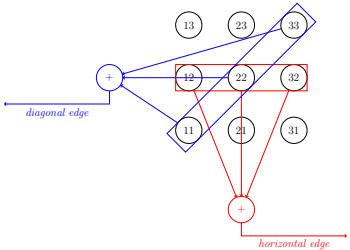
Detection of Edge Orientations

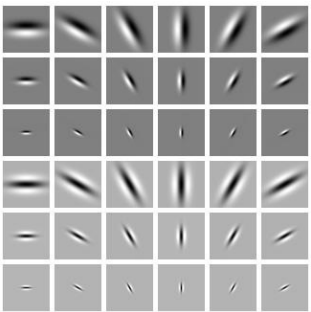
- It has been observed that
  1. Some cells in the visual cortex respond to edge orientations
  2. Different cells respond to different orientations
  3. The cells that responds to same orientation are grouped together





Oriented Filter Banks





- Ganglions connect to orientation detection cells in different combinations
- Results in edges with different orientations to be detected
- Motivates design of Gabor filters

More in EdPuzzle

Convolution filters for edge detection

Sobel filters

+1	+2	+1
0	0	0
-1	-2	-1

-1	0	+1
-2	0	+2
-1	0	+1

- Integration and Differentiation

$$\mathbf{G_x} = [1\ 2\ 1]^T * ([+1\ 0\ -1] * \mathbf{I})$$

$$\mathbf{G_y} = [+1\ 0\ -1]^T * ([1\ 2\ 1] * \mathbf{I})$$

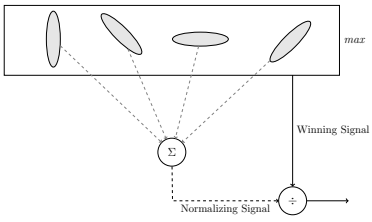
$$|\ \mathbf{G}\ | = \sqrt{\mathbf{G_x}^2 + \mathbf{G_y}^2}$$

$$\theta = tan^{-1}\ \frac{\mathbf{G_y}}{\mathbf{G_x}}$$

Does not happen this way in brain

Winner Take All (WTA) and Normalization

Applicable to all sensory signals



- The output of the filter with strongest output is transmitted
  - The strongest oriented edge is detected
- Output is normalized by the average response
  - The winner needs to stand out to produce strong response

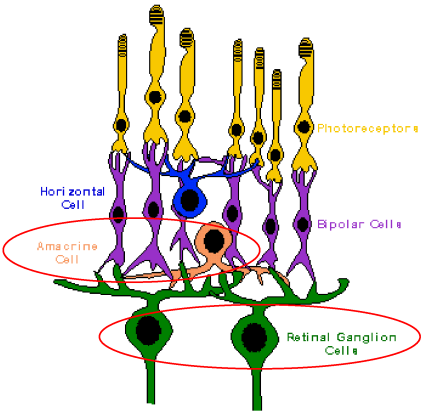
Transformation in the eye

Retinal image

Neural image

- Human vision is sensitive to contrast, and not to brightness
- There is huge data reduction
  - 126 mn photo-receptor $\rightarrow$ 10 mn bipolar cells $\rightarrow$ 1 mn optic nerves (approx)

The amacrine and the ganglion cells



- Ganglions connect to the brain
- Amacrine cells contribute to motion detection

Quiz 02-02

End of Module 02-02