Mehdi A. Azadgoleh (UW ID#: 20335400)

Computational Neuroscience/ Assignment #3: The Visual System

1. **Choose 4 feature detectors in the visual system, including at least one from each of (a) the retina, (b) areas V1-V4, and (c) inferior temporal cortex or parietal lobe. Describe how neural networks implement these feature detectors, discussing receptive fields, connectivity, and inputs/outputs as necessary. How do each of these features contribute to vision as a whole?**

   Form (including contrast & orientation), Color, Movement, and Depth are the four main features detected by the visual system. However, these features are detected through some serial (successive) and parallel (simultaneous) processing in different part of the system as described, to some extend, below.

   - ***Features detected in the retina:*** *Contrast (pre-processing)*

   The center-surrounding pattern of the retinal ganglion cells (RGC) receptive fields make them capable of detecting contrast with high sensitivity.

   - ***Features detected in V1:*** *Initial processing of Orientation**,** Color, and Direction*

   The selectivity to orientation of contours, as a key property to detect Form, first happens in V1, while they are still equally sensitive to contrast like retinal ganglion cells and lateral geniculate nuclei neurons.

   Inside orientations columns and ocular dominance columns, there are some neurons which show preference to color and are organized in distributed clusters.

   In deeper layer of V1 cortex (i.e., IVB layer) there are the neurons which are selective to direction of movement

   - ***Features detected in V2:*** *Orientation (final processing), Color (intermediate processing), Direction (intermediate processing), Depth*

   The *thick* stripes of V2 hold neurons with orientation and binocular disparity (depth) selectivity. The *thin* stripes contains neurons which keep processing the color. The *pale* stripes contains specialized neurons being selective to orientation.

   - ***Features detected in V4 (final destination of ventral pathway):*** *Complex form and Color (final processing)*

   The high-level neurons of this area are tuned to complex form and specialized ones for color final processing.

   - ***Features detected in V5 or MT: Direction (final processing)***

   The neurons of this deep area do the final processing of direction (motion).

   The interesting thing about the neurons all over the visual cortex is that although they have different *functional properties*, they keep the same *spatial organization* (retinotopy).

The receptive field of neurons gets larger (and even cover the entire visual filed e.g., in MT) as we go forward in visual pathways. Even in one area, as we go deeper, we are faced with neurons with larger receptive fields than the superficial neurons in that area. For example, neurons of V1 which are selective to direction of motion and whose receptive fields include the entire visual filed are located in deep layer in V1. In terms of connectivity, neurons with the same specificity (e.g., color detecting neurons in one and different areas) communicate with each other.

We can see some of these feature detecting mechanisms in artificial neural networks (specially hierarchical serial processing not parallel one). For instance, we make models with simulated neurons in series of layers, each processing the information of the previous layer. The same as visual system, the neurons of ANN's deeper layers show more and more complex selectivity.

2. Describe 3 instances in which retinotopic organization facilitates visual processing. For each example, be sure to both (a) mention its anatomical location and (b) discuss how retinotopy contributes to its feature detection.

We have direct map from retinal ganglion cells to lateral geniculate neurons. So, the center-surround characteristic of the ganglion cells is transferred to LGN neurons. In later stage of visual processing, projecting some LGN neurons whose receptive fields are aligned in a particular direction, to a neuron in V1 can justify the orientation selectivity of V1 neurons.

Another instance, where adjacent parts of the visual field are mapped to adjacent part of that area, is primary visual cortex (V1). As a result of this mapping, the center of gaze- where we have much denser photoreceptors concentration- is over-represented in the cortex (Cortical Magnification). This is a useful property because we can have more resources in terms of neurons for processing high resolution images formed in fovea.

The third area with retinotopy in visual cortex is LOC (Lateral Occipital Complex). This is an area for detecting more complex feature (e.g., angle between two lines) than just orientation. Here, also, retinotopy is helpful, because the complex features are detected from continuous objects whose adjacent local areas form those complexities altogether.

3. Discuss similarities and differences between convolutional neural networks and the visual system.

Similarities

a. Local receptive fields: in visual system we use center-surround patter for receptive filed to extract local features. Similarly, in CNN we use filters to extract features locally.

b. Translational Invariance: In visual system translational invariance achieved by “complex” cells. CNNs have also Translational Invariance property by applying “pooling”.

c. Hierarchy of feature detectors: Both systems have deep structure. The deeper the layer, the more sophisticated the extracted features will be.

d. Learning: Visual experience change our perception. Similarly, CNNs use learning algorithm to be trained.

Differences

a. Feedback: CNNs have feedforward architecture. But, connections between cortical areas are reciprocal- each area sends information back to the areas from which it receives input.

b. Lateral Connection or Context Effect: The response of a neuron in visual system is content-dependent. It depends as much on the presence of contours and surfaces outside the cell's receptive Field as on the attributes within it. The context-dependency is realized in visual system by lateral connection. However, CNNs do not posses this property.

c. CNNs do not have adaptation or normalization property of the visual system in different light intensities.

d. Top-down control: Attention and task demands can change the perception in visual system. But these top-down effects have not any role in CNNs.

4. Why is having two eyes important for vision? Could we get by with just one?

Having two eyes are important to perceive depth- which has an important role in perception of object shape and in surface segmentation. Each eye sees slightly different 2D view of the object (binocular disparity). Then the brain use this difference to calculate depth and make 3D image (stereopsis).

Yes, we can have less accurate perception of depth just by one eye. In this case the brain can predict the depth based on some monocular cues such as size, occlusion, movement, brightness and texture.

5. What would be the effect of strengthening lateral connections between horizontal cells in the retina? What about strengthening lateral connections between orientation columns in V1?

The horizontal cells takes the average level of excitations of a group of photoreceptors and send back inhibitory signal to the photoreceptors. For example, if the photoreceptors around a specific receptor are excited, the given photoreceptor also become inhibited. Strengthening lateral connection between horizontal cell make the retina more sensitive to detect edges and contrast in the receptive field. So, we can also see images with lower contrast.

Lateral connections in between orientation columns in V1 link columns of cells with similar specificity such as orientation. Horizontal connections allows neurons to integrate information over a large area of visual field and therefore important in assembling the components of a visual image in a unified percept. Strengthening lateral connections between orientation columns in V1 will change the neural corelate of our visual experience. The objects shape or their motion direction will “pop-out” faster and easier. Because each local processing is reinforced by non-local processing.

6. How do normalization and adaptation affect the perception of color and luminance?

As the background gets brighter, the intensity at which the visual system can detect a flash of light will increase. In ideal situation, there is a linear relationship between the threshold intensity and background intensity (in log scale). Both the cones which are responsible for detecting colors and the rods which are for brightness shows normalization and adaptation in their response.

7. Briefly summarize the differences between dorsal and ventral streams

The ventral pathway tries to identify *what* the stimulus is. So, the main purpose of this pathway is object recognition. The dorsal pathway processes information to find out *where* the stimulus is, which is critical for visually guided movement such as catching a ball or picking up an object.

The ventral or object recognition pathway starts from V1 then extends to the temporal lobe. The dorsal or movement-guidance pathway includes V1, parietal lobe, and frontal lobe.

This is worth mentioning that these pathways are approximately distinct, i.e., they have many interconnections. For example, information extracted from processing the movement of the object dorsal stream, may be used in ventral pathway to as kinematic cues to recognize the object.

8. Compare the behavioral deficits that result from lesions to inferior temporal cortex versus parietal cortex.

The first case is Patient DF (who has object apperceptive agnosia) after lesions in Ventral Visual Pathway (VVP) including inferior temporal cortex. Object agnosia is a deficit which affects some aspects of visual shape perception. (Ref. Nancy Kanwisher talk)

- She cannot identify objects, at all, from line drawings. She can sometimes identify objects if they are in front of her in the world (maybe because of receiving different cues from real objects such as color & shading).
- She can’t copy line drawing well. But She can draw the same object, say apple, from her memory. However, she can do this till if she keeps the pencil on the paper. If you move the paper, she can’t resume her drawing. This observation suggests that, besides memory for words (e.g., apple), there is inventory of shapes in the memory. Most importantly, this shows that her ability to look at shapes and recognize them (the process which happens in VVP) is ruined.
- She cannot see the orientation of the line shown to her, when she is asked to explicitly report it. This shows the deficit in visually guided perception occurring in ventral visual pathway. But, surprisingly, she can perfectly do the task in which she is asked to put an envelope into a post box slot, oriented differently each time.

She can make a motor action that depends on that orientation. This shows the proper function of her dorsal visual pathway, where visually guided action occurs.

Other deficits in Inferior Temporal (IT) cortex are;

- Prosopagnosia: This is an example of “category-specific” agnosia that patients cannot detect faces.
- Associative agnosia: It is also is a higher order perceptual deficit. In this case patients can see the object and draw it but cannot associate sensory information with meaning, function, or utility and assign a word to their drawings.

Patient RV having dorsal stream deficit (object ataxia) shows the following symptoms;

- She has no difficulty in identifying or describing objects
- She is unable to use visual information to reach out, grasp objects, or track objects

In addition, people having lesion in their MT area have no motion vision. For example, they have problem pouring water in the glass. Because their brain takes snapshot of moving objects. Or they have problem crossing the street because they cannot see cars motion to predict their real-time position.

9. Name a few ways in which prefrontal cortex and hippocampus aid visual processing in cognitive tasks.

After high-level processing at Inferior Temporal cortex, the neurons of this region send projection to hippocampus which is involved in long-term memory storage and formation. As mentioned in patient DF we have inventory of shapes in our memory. The second major projection is the one from IT cortex to prefrontal cortex. Prefrontal cortex has an important role in high-level vision processing such as categorical visual perception, visual working memory, and recall of stored memories.

10. Why is it easier to see objects in your peripheral vision at night?

Because at night fovea is blind due to lack of rods. The fovea is covered by cons which are less/more sensitive to light intensity/color and have no role in night vision. That’s why astronomers look next to a dim star in order to let the image form in the periphery of their retina covered mor by rods which are sensitive even to a single photon of light.

11. What is the purpose of saccadic eye movements?

Because our eyes are designed in a way to design changes. If the image on the fovea gets fixed and does not change for a while it fades after some seconds. However, saccadic eye movement changes the center of gaze, and thus changes the image formed on fovea, continuously to prevent the disappearing of the object we are looking at.