Neural Representations of 3D Space

We have no direct way to sample 3D space with our visual or auditory systems, yet we must operate in a 3D environment.

3D representations of space must be computed in the brain – fascinating problems in neural computation.

Today: visual representation of 3D space

Next lecture: auditory representation of 3D space

2 Basic Classes of Visual Depth Cues

Pictorial cues: cues present in a single (static) view of a scene (e.g., occlusion, perspective, size, shading, etc)

Geometric cues: cues arising when a scene is viewed from multiple vantage points (binocular disparity, motion parallax)

An Image Rich in Pictorial Depth Cues

Street Art of Julian Beever
Binocular Disparity
L Eye
R Eye
Retinal Image
Δθ
Motion Parallax
Retinal Image over Time

Random-Dot Stereogram

Color Anaglyph Technique
Other Common Methods:
Shutter glasses
Polarizing filters

The red and blue lenses filter the two projected images, allowing only one image to enter each eye.

An Autostereogram

(C)
5.1.3. Ocular Dominance and Binocular Disparity

- Like those in the LGN, neurons in the input layer of V1 (layer 4C) are generally responsive to only one eye. Monocular neurons are clustered together, forming a pattern of stripes called **ocular dominance columns**.

- Elsewhere in V1, most neurons combine signals from the two eyes, and have a receptive field for each eye. These ‘binocular’ cells are the first neurons in the visual system that are able to make comparisons between the retinal images in the two eyes.

- Binocular neurons form the basis for depth perception. Objects at different distances from the viewer cast images onto different positions in the two retinas. These differences in position are called **binocular disparities**. The disparity of a point in 3D space is related to the depth of the point relative to where the eyes are fixated:

\[
\text{disp} \approx \left( \frac{I \cdot z}{D^2} \right)
\]

where \(\text{disp} = \) disparity, \(I = \) interpupillary distance, \(z = \) depth of object (relative to fixation), \(D = \) viewing distance

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**Depth from Motion Parallax**

- Objects at different depths produce different image motion in response to observer movement (motion parallax).

- Motion parallax can produce a reliable impression of depth in the absence of other cues (Rogers & Graham, 1979)

- However, motion parallax alone is not sufficient to specify the sign of depth (near or far)
Motion Parallax: Near Object

For NEAR objects, image motion is in the OPPOSITE direction as observer motion.

Motion Parallax: Far Object

For FAR objects, image motion is in the SAME direction as observer motion.

Neural Coding of Depth from Motion Parallax?

- In the absence of pictorial cues (e.g., occlusion, size), neurons must receive an extra-retinal signal to compute depth sign from motion parallax.

- Psychophysical studies suggest that depth perception from binocular disparity and motion parallax may share a common neural substrate, but virtually nothing was known about the neural basis of depth from motion parallax.

- Do neurons combine visual motion signals with extra-retinal signals to code depth sign from motion parallax?
Virtual-Reality System

Field coil
Monkey
Projector

90°x90° screen
Six-degree of freedom motion platform

Experimental Design

Stimulus conditions
1) Motion Parallax
2) Retinal Motion

RF

Example MT Neuron Selective for Depth Sign Based on Motion Parallax


Motion Parallax
Retinal Motion

Simulated Depth ( Equivalent disparity, deg)

Near
Far

MP: DSDI = -0.71
RM: DSDI = 0.04

MP: DSDI = 0.65
RM: DSDI = 0.21

MP: DSDI = 0.66
RM: DSDI = -0.04