CS/NEUR125 Brains, Minds, and Machines

Lab 11: A neural model of a perceptual decision

In this lab we will work with a graphical user interface (GUI) program that allows us to view a perceptual stimulus similar to that used in a motion discrimination task studied by Shadlen and Newsome (2001), and explore the behavior of a neural model of the decision process proposed to take place in an area of the cortex called the Lateral Intraparietal area (LIP).

Our main goal is to familiarize ourselves with a simple, concrete neural model of the perceptual decision process in the motion discrimination task. In particular we would like to see how the model can capture basic empirically observed properties of the perceptual judgment:

1. that one makes more errors given less time, and
2. that even with a lot of time one can still make occasional errors.

We are studying this model and the related experimental work because it is a classic example of how people have studied the mechanisms of motion perception "at the single neuron level." But beyond motion perception, this model will give us a first concrete example for thinking about the neural mechanisms of *any* perception or *any* decision. This is relevant to our study of intelligence, to the extent that intelligence means "making good decisions."

The code for this lab is in the **decision_Lab** folder in the download folder on the CS server. Set the **Current Folder** in MATLAB to the **decision_Lab** folder. Run **decisionGUI** to start.

<u>Viewing the stimulus and changing stimulus parameters:</u> On the left side of the GUI press the **show movie** button to display a randomly moving-dots stimulus in a circular window above the button. Note that you can set the duration of the stimulus with the menu below the **show movie** button, to 0.5, 1, or 2 seconds. The other control parameter for the stimulus is the *coherence* of the dot motion, or in other words the *strength* of motion to the left or right. When the dot coherence is set to zero (the default), all the dots are moving in random directions and there is no net movement to the left or right on average. A coherence of 0.5 corresponds to half of the dots moving coherently to the left or the right.

View the stimulus movie for different coherence values and durations.

- Note that when the coherence is set to zero there is no correct motion judgment, but when the coherence parameter is non-zero there is a correct answer about whether the net dot movement is to the left or right, and it is possible to make an erroneous decision about which way they are moving.

- Note that it can be harder to see the correct net movement direction given shorter time, at least for low motion coherence.

In the neural decision model proposed by Shadlen and Newsome, neurons in cortical area MT (middle temporal; see Figure 2 below) are *tuned* to motion direction (respond differently to different visual movement directions) and provide *momentary evidence* about movement in the visual scene. Neurons in area LIP (lateral intraparietal; Figure 2) add up (integrate) the momentary evidence over time until a high enough confidence is reached that the monkey judges (perceives and responds accordingly) that the movement is to the left or the right.

In particular, it appears that LIP neurons accumulate the *difference* between the number of MT action potentials from cells favoring motion to the right and those representing leftward motion. As shown in Figure 1 below, the perceptual decision is proposed to occur when the LIP firing rate—the decision variable—reaches some threshold or "bound." This model is known as a "diffusion" model because the evolution of the decision variable is mathematically equivalent to diffusing molecule's "random walk."

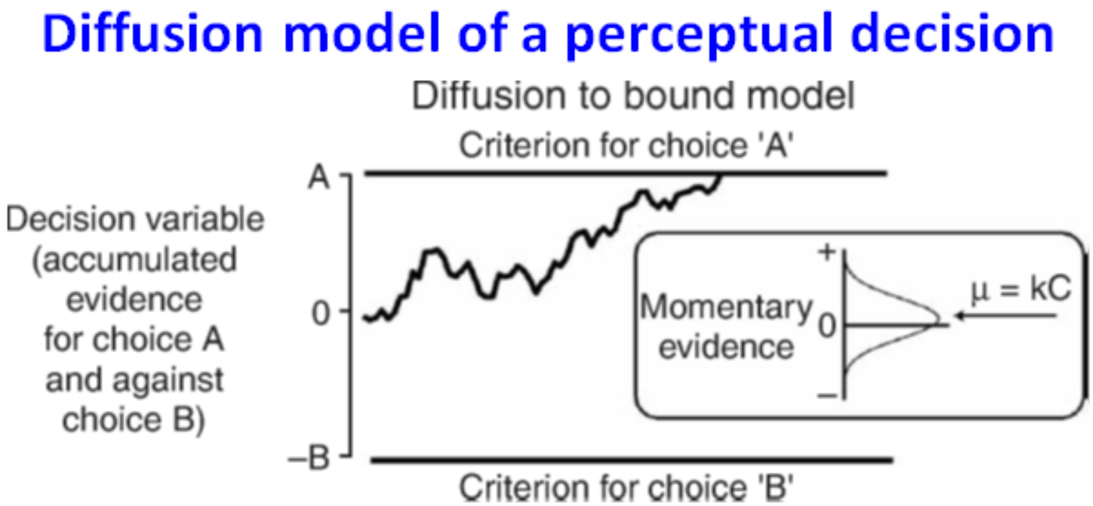

Figure 1: The diffusion model—accumulate differential momentary evidence until a decision criterion is reached.

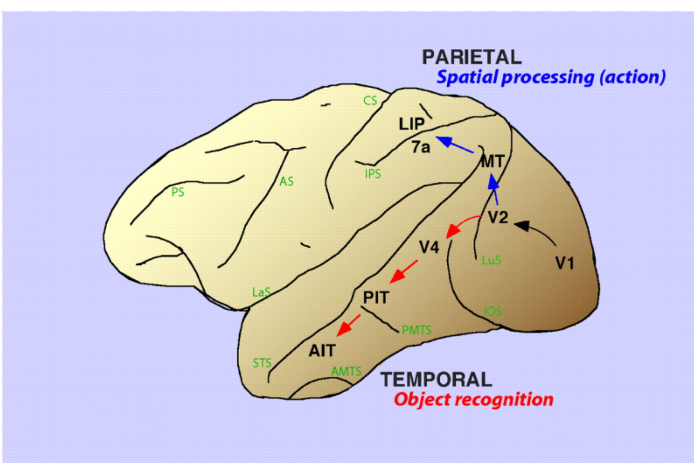

Figure 2: Cortical areas MT and LIP in the monkey brain. The firing of MT neurons represents the momentary evidence for motion in every direction, and LIP neurons accumulate differences in evidence for motion in opposite directions until a decision criterion is reached. From: http://jn.physiology.org/content/jn/97/1/307/F1.large.jpg?width=800&height=600&carousel=1

<u>Simulating motion discrimination trials:</u> Simulate decision for a medium coherence (0.2) trial with 1 second duration. That is, set the coherence and stimulus duration and then press the **run**

simulation button on the GUI. In the plot of the simulation results that appears, the red and blue traces at nearly constant levels near the middle of the plot represent the firing rates of MT neurons with preferred movement directions to the left (red) or right (blue). When there is equal net motion to the left and the right, these firing rates will be equal on average. But when there is more overall movement in one direction, the red and blue firing rates will be different, since one set of cells is getting more of its preferred stimulation than the other cell.

The model simulates the firing of one LIP neuron, whose job it is to accumulate the difference between the left- and right-preferring MT cell firing rates. In the simulation plot, the firing rate of this LIP neuron appears as a **<u>magenta</u> trace if the true net motion is to the <u>right</u>, or a <u>green</u> trace if the true net motion is to the <u>left</u>.** (For the zero coherence case there is no overall motion to the left or right and the LIP rate is always plotted in **cyan**.)

The flat horizontal lines at the top represent the decision criterion for judgments to the right (*magenta, top*) or left (*green, bottom*). If the legend in the figure window gets in the way of the simulation results, you can use your mouse to reposition the legend.

Note how the slight difference of MT rates representing opposite motion directions is being integrated over time in the LIP rate until the decision criterion/threshold/bound is reached, indicating a decision. Positive rates are indicating a rightward decision, while negative LIP rates favor a leftward decision. Of course neural firing rates cannot be negative, so we should interpret zero firing rate as the "baseline" firing rate in the absence of motion stimuli, and negative rates indicate firing at rates below that baseline.

Simulate at least 10 medium difficulty trials (coherence = 0.2) and then at least 10 easy trials (coherence = 0.5). Each time you press the **run simulation** button, a new simulation result will be added to the display. At any time, you can press the **clear** button to clear the display.

- How does **reaction time** (time to decision) change when motion strength is increased?

Use the menu in the lower right to add more MT neurons and simulate several more trials.

- How does adding more sensory neurons affect the decision time?

Now simulate some difficult trials by setting the coherence to 0.1. These trials are "near threshold" in the sense that we are near the point where one can no longer reliably detect the tiny actual net motion to the left or right.

- Can you observe any error trials, where the simulated decision is opposite the actual net motion?

One way to model pressure to respond quickly is to reduce the decision criterion. Move the decision threshold down from its default of 100 to 50.

- How do reaction time and error rate change when you reduce the decision threshold?

In the experimental context the researchers can control the amount of stimulus time available for making the judgment by simply changing the stimulus presentation time. To observe the effect of changing stimulus presentation time, simulate 10 trials for a near-threshold stimulus using only 1 MT neuron and a stimulation time of 2 seconds. Then, to compare the error rates for a “forced choice” at different stimulus presentation times, note how many errors you would get for 0.5-, 1- and 2-second presentations by assuming the animal’s response corresponds to the *sign* of the LIP firing rate at the forced decision time. For example, if the LIP rate is *negative* at 0.5 seconds, the monkey’s choice would have been to the *left*. If for that trial the LIP rate trace is *magenta (representing actual net motion to the right)*, then this would have been an *error* trial.

- How does the error rate change with stimulus presentation time? Do you observe any errors at the longest (2 second) stimulus presentation time?

Simulate some zero coherence trials with the 2 second duration. In this case the LIP rate is plotted in cyan as there is no correct motion direction.

- Does the model ever reach the decision criterion in the zero coherence case? What might this correspond to perceptually? How does increasing the number of MT neurons affect the likelihood of seeing such “illusory motion”?

Summary and Conclusions

- LIP neurons add up the evidence for and against rightward motion, until a positive criterion is reached (perceive/respond “right”) or a negative criterion is reached (perceive/respond “left”).

- Shorter presentation times or enforced fast responding lead to more errors: the model illustrates a **speed-accuracy tradeoff**.

- Other perceptions or decisions may use a similar mechanism: integrate the evidence for “what’s going on” until you’re “sufficiently sure” to remember it that way (i.e. perceive it), or act on it. The problem for applying the model to other contexts is to come up with the appropriate neural representation for each case, i.e. if the “evidence” is more complex than “motion along direction x,” which neurons represent that, and how? But the framework of **accumulating sensory evidence with neural integrators** may still apply.

Reference

Shadlen, M. N. & Newsome, W. T. (2001) Neural Basis of a Perceptual Decision in the Parietal Cortex (Area LIP) of the Rhesus Monkey, *J. Neurophysiol. 86*, 1916-1936.