Lecture 16: Decision-making I

We now return to the familiar direction discrimination task with variable motion coherence. Note that the design is different from the MT experiments – how, why?

This task has some notable advantages for studying activity linked to decisions:
- It is necessary to attend to the motion stimulus for hundreds of milliseconds in order to judge direction well at low coherence. Thus, unlike other saccade tasks, the decision unfolds slowly over time.
- Reaction-time version of the task allows us to know better when the monkey makes a decision.

Say you have a weak rightward motion stimulus (e.g., 3% coherence). The average motion across time is to the right, but the instantaneous motion energy can fluctuate wildly. For simplicity, we can think of MT as representing the instantaneous motion energy (left).

Bottom right shows the integral of this motion energy trace. Early on, the integral can be negative (suggesting leftward motion), but eventually becomes clearly positive (indicating rightward motion). The longer you integrate over time, the better your estimate of whether the motion is rightward or leftward.

Typical monkey behavioral data obtained during the RT motion discrimination task:
- Percent correct increases with motion coherence (top), whereas reaction times decrease (bottom).
- Monkey takes ~400ms longer to decide direction of motion at low vs. high coherence.
- Why is it useful for the monkey to ‘integrate’ over longer period of time at low coherence?

Average activity of 54 LIP neurons:
- Solid curves: motion toward response field (Tin)
- Dashed curves: motion toward opposite target (Tout)

Things to note:
- Faster ramping up (down) at high coherence
- Solid and dashed curves still separate by choice at 0% coherence
- Before saccade, all solid curves come together.
- Suggests a trigger threshold level of activity?
- MT neurons behave quite differently (inset)
Shadlen’s group suggests that LIP activity represents a *decision variable*, which is essentially a continuous index of how likely one decision (saccade right) is relative to the other possible decision (saccade left).

They further propose a specific model in which LIP integrates the activity of MT neurons that represent the sensory stimulus. Specifically, for left vs. right motion, LIP would integrate the difference in activity between a column of leftward preferring MT neurons and a column of rightward preferring neurons (evidence for R-L).

When activity in LIP reaches a decision bound, they propose that the decision is made and the saccade is programmed. A strong motion signal from MT (red below) reaches the decision bound more quickly. This is called a “drift-diffusion model” or “diffusion to bound” model.

This diffusion-to-bound model predicts that the rate of ramping-up activity in LIP should be related to the monkey’s reaction times, which is exactly what Shadlen’s group found (right, 6.4% coherence case).

Thus, LIP activity can predict both the choice of the monkey and the timing of the choice.

The Shadlen model of decision-making is important because it is a specific, concrete proposal for how sensory signals are transformed into a binary decision. The Yang and Shadlen paper that we will discuss pushes this idea to a more abstract case.

The integration model of LIP does explain a variety of experimental observations. However, whether this model actually explains what LIP does has been a topic of recent controversy in the field (e.g., Latimer et al. *Science*. 2015 349:184-7; Katz et al. *Nature* 2016 535:285-8). Katz et al. (2016) found that reversibly inactivating LIP did not affect performance of the direction discrimination task, for example.

It is not clear presently whether this idea of integrating sensory evidence to a bound will have staying power, but it has advanced the field considerably.

The Shadlen model predicts that the neural representation of the decision to make a saccade in the motion task builds up gradually, and eventually the decision variable reaches a bound to trigger the action.

This model suggests that the decision is partially formed before the bound is reached. This implies that artificially triggering the action early should reveal a trace of the developing decision in the oculomotor circuitry.

To test this, Gold & Shadlen again used the direction discrimination task, but microstimulated the FEF to evoke a saccade shortly before the monkey was ready to make its decision. The evoked saccade was ~orthogonal to the axis defined by the choice targets.

Gold & Shadlen *Nature* 2000

They found that the saccade evoked by FEF stimulation was biased to land in the direction specified by the random dot motion stimulus.

This deviation was greater for higher motion coherences and longer viewing durations, consistent with the effect of a growing decision variable in LIP activity.

This suggests that the neural correlate of the decision develops within the oculomotor circuitry during the course of the trial, as opposed to there being an abstract decision-making center that only signals when the decision is done.
Would you see a neural correlate of the decision in oculomotor circuitry if the monkey did not know what the possible motor outputs would be?

Gold & Shadlen tested this by linking each direction of motion with a colored target. The location of the colored targets were unknown to the monkey until the end of the trial. Thus, the monkey had to decide about the direction of motion but could not plan the saccade to indicate his decision until the end.

In this case, they found no systematic deviation of saccades evoked with FEF stimulation.

This suggests that the neural correlate of the decision process is only seen in the oculomotor circuitry when the monkey knows what possible eye movements it will have to make.

Where is the decision variable represented in the brain during these color trials? Not known. This might suggest a more abstract decision-making center that is not tied to a specific motor system.