[PERCEPTUAL] DECISION MAKING

Rony Paz
Challenges for studying decision making

A commitment to a categorical action based on information associated with [valuable] outcomes

- Number of options (h1, h2 ....)
- Evidence (e) [Sensory information]
- Noise
- How to combine evidence (e)
- When to commit ( p(h1|e) .... )
- Priors on the state of the world ( p(h1), p(h2) ...)
- Value of action
- Confidence / certainty
Newsome’s random dot task – in search for the neural basis of subjective experience (of motion)
1. Random dot task can be made difficult
2. Random dot task can be made difficult
3. Random dot task can be made difficult
4. Random dot task can be made difficult
Performance

Roitman and Shadlen
Sensory evidence
Area MT: motion sensitive neurons
Is it MT (v5) that supplies the evidence?

Performance depends on signals carried by direction-selective cortical neurons.

1. Is performance impaired following chemical lesions of MT?
2. Are cortical neurons sufficiently sensitive to the motion signal in to account for psychophysical performance?
3. Can we influence perceptual judgments with electrical micro-stimulation?

Newsome et al., 1990
Impaired following chemical lesions

Newsome >1980s...
Shadlen > 1990s
MT neurons’ sensitivity and psychophysical performance

Newsome, Britten and Movshon, 1989
MT microstimulation induces bias

(Salzman and Newsome 1990, 1994.)
How can this decision happen?

Shadlen et al., 1996
Signal detection theory (SDT)

- Observation of noisy evidence => categorical choice

\[
\frac{p(e|h_1)}{p(e|h_2)} > \beta
\]

What about time and accumulating evidence?

Green & Swets 1966

Shadlen & Kiani, 2013
Command and Saccade production
Executing the decision?

Shadlen et al., 1996
Decision processes revealed by microstimulation in FEF

Gold and Shadlen, 2000
Evoked saccades biased by perception

Gold & Shadlen; Shadlen & Kiani
Accumulating evidence?
Sequential analysis (SA): accumulate evidence over time to decide

General framework:

1. Generate alternative hypotheses
2. Define the evidence for each hypothesis
3. Update this evidence with new information
4. Form a decision rule for sufficient evidence
5. Perform judgment

The Enigma: Are two messages encoded by the same machine?

Alan Turing
1. **Generate alternative hypotheses** (machine 1 or 2? Left or right movement?)

2. **Define the evidence for each hypothesis**
   Compute Log likelihood ratio

3. **Update evidence with new information**
   
   ➔ Evidence can be accumulated (Log is additive)

4. **Form a decision rule**
   A threshold can be defined to any given accuracy

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**Log LR framework**

\[
\begin{align*}
e_0 & \rightarrow f_0(e_0) \Rightarrow Stop_{or} \\
\quad \downarrow \\
e_1 & \rightarrow f_1(e_0, e_1) \Rightarrow Stop_{or} \\
\quad \downarrow \\
e_2 & \rightarrow f_1(e_0, e_1, e_2) \Rightarrow Stop_{or} \\
\quad \vdots \\
e_n & \rightarrow f_1(e_0, e_1, \ldots, e_n) \Rightarrow \ldots
\end{align*}
\]
SPRT (sequential prob. Ratio test)

- Two coins are identical except that one is fair and the other is a trick coin, weighted so that heads appears on 60% of tosses, on average. We can base our decision on a series of any amount of tosses.
- In SPRT each observation (toss) \( e_i \) is converted to a weight of evidence, the logLR in favor of the trick coin hypothesis. There are only two possible values of evidence, heads or tails, which give rise to weights \( (w_i) \):

\[
\begin{align*}
    w_i &= \left\{ \begin{array}{ll}
        \log \frac{P(e_i = \text{heads}|b_1 : \text{trick coin})}{P(e_i = \text{heads}|b_2 : \text{fair coin})} & \text{if heads} \\
        \log \frac{P(e_i = \text{tails}|b_1 : \text{trick coin})}{P(e_i = \text{tails}|b_2 : \text{fair coin})} & \text{if tails}
    \end{array} \right.
\end{align*}
\]

- The decision variable (DV) is the running sum (accumulation) of the weights.

- We apply the following rules:

\[
y_n = \sum_{i=1}^{n} w_i
\]

- Where \( \alpha \) is the probability that a fair coin will be misidentified [i.e., a type I error: \( P(H_1 | h_2) \)] and \( \beta \) is the probability that a trick coin will be misidentified [a type II error: \( P(H_2 | h_1) \)].

For example, if \( \alpha = \beta = 0.05 \), then the process stops when \( |y_n| \geq \log(19) \). The criteria can be viewed as bounds on a random walk. To achieve a lower rate of errors, the bounds must be moved further from zero, thus requiring more samples of evidence, on average, to stop the process.
Drift-diffusion models

A Drift-diffusion

Accumulated evidence for \( h_1 \) over \( h_2 \)

Choose \( h_1 \)

Choose \( h_2 \)

mean drift rate = mean of \( e \)

mean of \( e \) depends on strength of evidence
N options ...

Race model

B Competing accumulators

Accumulated evidence for $h_i$

Choose $h_i$

Accumulated evidence for $h_2$

Choose $h_2$
To encourage speed, reward the monkey immediately after each correct response, since monkeys are naturally inclined to make fast responses (at the expense of accuracy). To encourage accuracy, reward was delayed so that fast responses involved additional wait until delivery of reward.
Accumulating evidence?
LIP neurons in reaction time task

Shadlen M + many influential students
LIP neurons reach threshold
Choice-Neural correlations
Post-decision wagering indicates **certainty**

Choosing more sure-option with less evidence and lower Coherence  

<table>
<thead>
<tr>
<th>Motion strength (%coh)</th>
<th>51.2%</th>
<th>25.6%</th>
<th>12.8%</th>
<th>6.4%</th>
<th>3.2%</th>
<th>0.0%</th>
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</thead>
<tbody>
<tr>
<td>Probability correct</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Probability sure target</td>
<td></td>
<td></td>
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</tbody>
</table>

Kiani, Shadlen 2009;
LIP activity predicts choices and the post-decision wager.

Kiani, Shadlen 2009;
Recent emerging debates
LIP as the decision variable?
LIP as evidence accumulator?

Latimer, yates, meister, huk, pillow
More paradigms of [perceptual] decision making
Motion detection

(a) Coherent motion at one patch (750 ms)
(b) Proportion "yes" responses vs. Motion coherence
(c) MT: Firing rate vs. Time (ms)
(d) VIP: Firing rate vs. Time (ms)

Cook & Maunsell
Vibrotactile frequency discrimination (VTF)

Mountcastle, Ronulfo Romo

Requires working memory (unlike the RDM)
VTF detection

(a) Diagram of PD KD with Prestim, Stim, and Delay stages.

(b) Graph showing the proportion of yes responses against stimulus amplitude (µm).

(c) Graph showing the proportion of trials against firing rate (sp s⁻¹).

(d) Graph showing stimulus amplitude (µm) against firing rate (sp s⁻¹).

(e) Graph showing stimulus amplitude (µm) against firing rate (sp s⁻¹).

(f) Graph showing stimulus amplitude (µm) against firing rate (sp s⁻¹).

Only correct
Main sources to read

- **Neuronal correlates of a perceptual decision.**
  Newsome WT, Britten KH, Movshon JA. ; Nature. 1989 Sep 7;341(6237):52-4.

- **The neural basis of decision making.**

- **Decision making as a window on cognition.**

- **Dissociated functional significance of decision-related activity in the primate dorsal stream.**

- **Single-trial spike trains in parietal cortex reveal discrete steps during decision-making.**
  Latimer KW, Yates JL, Meister ML, Huk AC, Pillow JW. ; Science. 2015 Jul 10;349(6244):184-7