[PERCEPTUAL] DECISION MAKING
Challenges

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

A

No correlation

50% correlation

100% correlation

B

Monkey

Postlesion
Prelesion

Human

Brain damaged patient
Normal subjects

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

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

Green & Swets 1966

What about time and accumulating evidence?

Shadlen & Kiani, 2013
Command and Saccade production
Decision processes revealed by microstimulation

Gold and Shadlen, 2000
Evoked saccades biased by perception

Gold & Shadlen; Shadlen & Kiani,
How can this decision happen?
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?
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
   \[ \log LR_{12} = \log \frac{P(e_1, e_2, \ldots, e_n | b_1)}{P(e_1, e_2, \ldots, e_n | b_2)} = \sum_{i=1}^{n} \log \frac{P(e_i | b_1)}{P(e_i | b_2)}. \]
   ➔ Evidence can be accumulated (Log is additive)

4. Form a decision rule
   A threshold can be defined to any given accuracy
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 ($w_i$):

$$w_i = \begin{cases} 
\log \frac{P(e_i = \text{heads}|b_1 : \text{trick coin})}{P(e_i = \text{heads}|b_2 : \text{fair coin})} & \text{if heads} \\
\log \frac{P(e_i = \text{tails}|b_1 : \text{trick coin})}{P(e_i = \text{tails}|b_2 : \text{fair coin})} & \text{if tails}
\end{cases}$$

- 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.
Time!
N options ...
Speed-accuracy tradeoff

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.

Hanks, kiani, shadlen
LIP neurons in reaction time task
LIP neurons reach threshold
Choice correlations

- Figure c: Net motion (z) with MT area showing normalized firing rate over time.
- Figure d: Net motion (z) with LIP area showing normalized firing rate over time.
- Figure e: Choice probability distribution with a peak at 0.54.
- Figure f: Choice probability distribution with a peak at 0.70.
a. Stimulate rightward MT neurons

- Momentary evidence in MT
  - Evidence for right (R - L)
  - Mean

- DV in LIP
  - Stim adds cumulatively
  - Bound for right choice
  - Bound for left choice

- Reaction time vs. rightward choices
- Motion strength
  - Strong leftward
  - Strong rightward

b. Stimulate right choice LIP neurons

- Momentary evidence in MT
  - Evidence for right (R - L)
  - Mean

- DV in LIP
  - Stim adds constant
  - Bound for right choice
  - Bound for left choice

- Reaction time vs. rightward choices
- Motion strength
  - Strong leftward
  - Strong rightward

Gold & Shadlen
Post-decision wagering indicates **certainty**

Choosing more sure-option with less evidence and lower Coh  
Ts waived > no Ts
LIP activity predicts choices and the post-decision wager.
Recent issues
LIP as the decision variable?
LIP harms accuracy

Katz, Yates, Pillow, Huk
Another option

Latimer, yates, meister, huk, pillow
More paradigms of decision making

Vibrotactile frequency discrimination (VTF)

Mountcastle, Romo

Requires working memory (unlike the RDM)
Motion detection

[Diagram of motion detection process]

Cook & Maunsell
VTF detection

- **S1**: Detection of VTF thresholds in sensory areas S1.
- **MPC**: Mapping of preferred stimulation conditions for VTF detection.

Diagram details:
- **a**: Schematic diagram showing pathways PD, KD, Prestim, Stim, Delay.
- **b**: Graph illustrating proportion of yes responses against stimulus amplitude.
- **c**: Scatter plot showing firing rate against stimulus amplitude.
- **d**: Graph depicting proportion of trials against firing rate.
- **e**: Heatmap of stimulus amplitude over time.
- **f**: Graph showing firing rate against stimulus amplitude.
Sources to read


