Your Brain Under Risk
Decisions with Imperfect Knowledge

- Uncertainty $\rightarrow$ imperfect knowledge
- Imperfect knowledge $\rightarrow$ risk
- Risk $\rightarrow$ probability of possible outcomes

Neuroeconomic approach: insular cortex and n. accumbens
### Recall:

<table>
<thead>
<tr>
<th>Region</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Ventral Striatum</td>
<td>Anticipated value</td>
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<td>OFC and VMPFC</td>
<td>Derives an integrated value signal</td>
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<td>Insula</td>
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**What about risk??**

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**How does the activity in these regions change under risk??**
Expected utility is all about risk

\[ \text{Expected Utility} = \sum p \cdot u \]

\( p \) is the probability of the outcome, and \( u \) is the utility of the outcome.

What about risk?

How does the activity in these regions change under risk?
Neural Basis of a Perceptual Decision in the Parietal Cortex (Area LIP) of the Rhesus Monkey

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Shadlen, Michael N. and William T. Newsome. Neural basis of a perceptual decision in the parietal cortex (area LIP) of the rhesus monkey. *J Neurophysiol* 86: 1916–1936, 2001. We recorded the activity of single neurons in the posterior parietal cortex (area LIP) of two rhesus monkeys while they discriminated the direction of motion in random-dot visual stimuli. The visual task was similar to a motion discrimination task that has been used in previous investigations of motion-sensitive regions of the extrastriate cortex. The monkeys were trained to decide whether the direction of motion was toward one of two choice targets that appeared on either side of the random-dot stimulus. At the end of the trial, the monkeys reported their direction judgment by making an eye movement to the appropriate target. We studied neurons in LIP that exhibited spatially selective persistent activity during delayed saccadic eye movement tasks. These neurons are thought to carry high-level signals appropriate for identifying salient visual targets and for guiding saccadic eye movements.
LIP neurons make categorical decisions

LIP: lateral intraparietal area of the inferior parietal lobe

Information about visual motion is represented in the extrastriate visual cortex.

These neural signals inform a decision process, constrained by the demands of the task to 1 of 2 possible judgments.

The judgment, once made, persists during the delay period that follows motion offset, ultimately informing the behavioral response.

A neural correlate of the decision formation is not known, but several brain structures contain neurons that would be expected to sustain a representation of the animal's commitment to one of the possible behavioral alternatives. The central hypothesis of the present study, symbolized by the dashed arrow, is that such neurons might also lend insight into the computation of the decision itself.
Population response from 104 LIP neurons during the direction discrimination task.

Neural correlates of decision variables in parietal cortex

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Decision theory proposes that humans and animals decide what to do in a given situation by assessing the relative value of each possible response. This assessment can be computed, in part, from the probability that each action will result in a gain and the magnitude of the gain expected. Here we show that the gain (or reward) a monkey can expect to realize from an eye-movement response modulates the activity of neurons in the lateral intraparietal area, an area of primate cortex that is thought to transform visual signals into eye-movement commands. We also show that the activity of these neurons is sensitive to the probability that a particular response will result in a gain. When animals can choose freely between two alternative responses, the choices subjects make and neuronal activation in this area are both correlated with the relative amount of gain that the animal can expect from each response. Our data indicate that a decision-theoretic model may provide a powerful new framework for studying the neural processes that intervene between sensation and action.
In this paradigm, monkeys had to switch gazes left or right depending on the color of the visual cue.

1. When the cue changed color the animals had to switch their gaze, to the left or right.

2. If the decision was correct, they were rewarded by being given some juice.

High/Low Gain Condition

ANTICIPATES A LARGE GAIN

LIP ACTIVITY IS STRONGER

Neuronal activity is modulated by both expected gains and the probability of the outcome!

Expected utility is all about risk: $(\text{probability of outcome}) \times (\text{utility of the outcome})$
Risk
Can dramatically affect decisions.
What is risk?

As risk increases → worse outcome? Animals vs. economists definition of risk.
Risk is highest when $P = 0.5$.

Certain of outcome.
Recall from previous lecture

Reward and prediction of reward in N. Accumbens

The actual reward & prediction of a reward.

TRANSIENT ACTIVATION OF MIDBRAIN DOPAMINE NEURONS BY REWARD RISK

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Abstract—Dopamine neurons of the ventral midbrain are activated transiently following stimuli that predict future reward. This response has been shown to signal the expected value of future reward, and there is strong evidence that it drives positive reinforcement of stimuli and actions associated with reward in accord with reinforcement learning models. Behavior is also influenced by reward uncertainty, or risk, but it is not known whether the transient response of dopamine neurons is sensitive to reward risk. To investigate this, monkeys were trained to associate distinct visual stimuli with certain or uncertain volumes of juice of nearly the same expected value. In a choice task, monkeys preferred the stimulus predicting an uncertain (risky) reward outcome. In a Pavlovian task, in which the neuronal responses to each stimulus could be measured in isolation, it was found that dopamine neurons were more strongly activated by the stimulus associated with reward risk. Given extensive evidence that dopamine drives reinforcement, these results strongly suggest that dopamine neurons can reinforce risk-seeking behavior (gambling), at least under certain conditions. Risk-seeking behavior has the virtue of promoting exploration and learning, and these results support the hypothesis that dopamine neurons represent the value of exploration. © 2011 IBRO. Published by Elsevier Ltd. All rights reserved.
(A) Two images were presented simultaneously.
(B) Fixation of gaze on stimulus C for 0.5 s resulted in certain delivery of 125 mL of juice after a further delay of 1.0 s, whereas fixation on stimulus U resulted in 240 mL of juice on a pseudorandomly selected 50% of trials, and no juice on the remaining trials.

DA neurons fire more with uncertain rewards.

**Fig. 4.** Responses to stimuli U and C within a single dopamine neuron. Top, perstimulus time histograms, demonstrating a stronger mean response to stimulus U than to stimulus C. Bin size=50 ms. Bottom two panels, rasters of 60 trials each of stimulus U (middle) and stimulus C (bottom), arranged in each panel in chronological order from top to bottom.

**Fig. 7.** Average neuronal responses to reward outcomes. Juice onset (or offset of stimulus U on trials in which juice was omitted) occurred at time “zero.” Consistent with previous studies, when the delivery of juice is uncertain following stimulus U, its delivery causes a strong activation (red), whereas its omission causes a suppression of firing rate below the baseline level (blue). When the delivery of juice is nearly certain following stimulus C, its delivery causes only a small activation (black). The black horizontal line between 80 and 300 ms indicates the period in which firing rates were measured for comparison, as described in the results.
“Just as an artificial sweetener “tricks” the brain into the unconscious belief that it will soon receive the exploitation value of valuable calories, a gamble in a casino may be unconsciously driven by the illusory promise of the exploration value of reward information.”

Difference between Risk and Uncertainty:

“Economists and decision theorists interested in human behavior typically divide uncertainty into two distinct concepts;

risk, where the probabilities of potential outcomes are known and

ambiguity, where the probabilities are not precisely known.”
