Cogs 160 (SP12):

Neural Coding in Sensory Systems

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Understanding the Brain/Mind

Behavior

Cognitive Neuroscience

Neurobiology

A powerful analogy: the computing brain
How do We Make Decisions?

Example: Ordering food

Deliberation ... optimizes choice

Delay ... eating alone

Speed-Accuracy Trade-off
Fundamental Trade-off

- Slow response $\Rightarrow$ greater accuracy but higher time cost
- What is the optimal tradeoff?
- Are humans/animals optimal?
- How does the brain implement the computations?
Random Dot Coherent Motion Paradigm

Easy
30% coherence

Difficult
5% coherence

vs.
Monkey Decision-Making
Random dot coherent motion paradigm
Aside: Saccadic Eye Movement

Examine this photograph

Record of saccadic movements examining phot
Monkey Decision-Making
Random dot coherent motion paradigm

Repeated decision: Left or right? Stop now or continue?
Decision-Making Under Time-Pressure

Repeated decision: Left or right? Stop now or continue?
Luckily, Mathematicians Solved the Problem

Wald & Wolfowitz (1948): hypothesis 1 (left) vs. hypothesis 2 (right)

**Optimal policy**

- cost function: \( \Pr(\text{error}) + c \cdot (\text{RT}) \)
- accumulate evidence over time: \( \Pr(\text{left}) \) versus \( \Pr(\text{right}) \)
- stop if total evidence exceeds “left” or “right” boundary

(Smith & Ratcliff, 2004)
Behavioral Data (Monkey)

A. Accuracy vs. Coherence
   - More accurate

B. <RT> vs. Coherence
   (Roitman & Shadlen, 2002)

Easier
Model ⇔ Behavior

Model: harder ⇒
- slower
- more errors

Accuracy vs. Coherence

<RT> vs. Coherence
What Are the Neurons Doing?

Motion info $\Rightarrow$ eye movement

MT: Sustained response

100% (easy)

Preferred

Anti-preferred

26% (hard)

(Britten, Shadlen, Newsome, & Movshon, 1993)
What Are the Neurons Doing?

Saccade generation system

MT: Sustained response

100% (easy)

26% (hard)

MT tuning function

(Britten & Newsome, 1998)

(Britten, Shadlen, Newsome, & Movshon, 1993)
What Are the Neurons Doing?

Saccade generation system

LIP: **Ramping** response

(Shadlen & Newsome, 1996)
What Are the Neurons Doing?

Saccade generation system

LIP response reflects sensory information
• ramping slope depends on coherence (difficulty)

LIP response reflects choice
• 0% stimulus $\Rightarrow$ different response depending on choice
• neural activation reaches identical height before saccade

(Roitman & Shalden, 2002)
Model ⇔ Neurobiology

Saccade generation system

Model

Selected or preferred (strong)
Selected or preferred (weak)
Nonselected or nonpreferred (weak)
Nonselected or nonpreferred (strong)

LIP Neural Response

Motion strength
- Orange: 51.2
- Purple: 25.6
- Green: 12.8
- Red: 6.4
- Brown: 3.2
- Blue: 0

Time (ms)

Firing rate (sp/s)
Putting it All Together

Saccade generation system

- Model: motion discrimination = optimal decision-making
- Monkeys behave like optimal decision-makers
- Neural activities in LIP = optimal evidence integration
- Behavior ⇔ theoretical model ⇔ neurobiology
Other Experimental Paradigms

Oddball Detection

- $p = P(\text{correct})$ in easy condition, $q = P(\text{correct})$ in difficult condition
- *accuracy instruction* leads to slower responses (but more accurate)
- model produces qualitatively similar quantile RT curves as data
Other Experimental Paradigms

Oddball Detection

- trials split into fast, intermediate, and slow thirds of categories
- superior colliculus (SC) neural activities shifted in time, like behavior
- model fit to behavioral data also produces responses like neurons
Taxonomy of RT Decision Models

(b) Diffusion model

Evidence 'right'-'left'

RT distribution 'right'
Respond 'right'
Between-trial variability in accumulation rate
Sample paths
RT distribution 'left'

(c) Leaky competing accumulator model

Evidence 'right'
Mutual inhibition between totals
RT distribution 'left'
Respond 'left'
Evidence 'left'
0

0
Taxonomy of RT Decision Models

Sequential-sampling models

Relative stopping rule
(Single evidence total)

Absolute stopping rule
(Two evidence totals)

Random-walk models

Continuous time
Continuous evidence
Diffusion processes

Discrete time
Continuous evidence
Accumulator model

Continuous time
Discrete evidence
Poisson counter model

Continuous time
Continuous evidence
(mutual inhibition)
Leaky competing accumulator model

Random walks

Perfect integration
Wiener diffusion

Leaky integration
(Information decay)
Ornstein–Uhlenbeck diffusion

 accumulator models and counter models

Evidence (R−L)
Time

Evidence (L)
Evidence (R)
Time
Extensions

- Multiple choices (Yu & Dayan, 2005)
- Temporal uncertainty about stimulus onset (Yu, 2007)
- Deadline (Frazier & Yu, 2008)
- Learning about Pr(right) vs. Pr(left) over trials (Yu, Dayan, & Cohen, 2009)
- Minimizing Pr(error)+c*(mean RT) versus maximizing reward rate = Pr(correct)/(RT) (Dayanik & Yu, in press)