Learning what’s relevant in a largely irrelevant world

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Making sense of a complex world...

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TD-Learning in High-Dimensional Environments

• Assigning values to stimuli through trial and error learning

• In the real world, “stimuli” is ill-defined

• Mechanism for learning representations
Attention and Learning

• Selective attention as an information filter

• Directs cognitive resources towards processing of relevant information

How does the brain decide where and what to attend?
Research Questions

How does attention interact with RL processes?

How do we learn what to attend?
Faces, Houses, Tools (FHT) Task

Features

Dimension
Faces, Houses, Tools (FHT) Task
Faces, Houses, Tools (FHT) Task
Faces, Houses, Tools (FHT) Task
Faces, Houses, Tools (FHT) Task

\[
P(\text{Reward}|\text{Target}) = 0.75
\]

\[
P(\text{Reward}|\text{Not Target}) = 0.25
\]

25 Trials/Game
56 Games
Behavioral Performance

Learning Curve

N = 18 in FHT
Modeling Choice Behavior

Bayesian Inference

\[ p(d, f | D) \propto p(D | d, f) p(d, f) \]

probability that feature \( f \) in dimension \( d \) is the target feature

Stimulus Value:

\[ V(S) = p(r | S) \]

\[ = \sum_{d, f \in S} p(d, f | D) \theta_1 + [1 - p(d, f | D)] \theta_0 \]
Modeling Choice Behavior

Function Approximation (FA)

\[ V(S) = w_T + w_F + w_H \]

\[ \delta_t = r_t - V_t(S) \]

\[ w_{t+1} = w_t + \eta \delta_t \]
Modeling Choice Behavior

Function Approximation with Decay

\[ w_{t+1}(c') = (1 - \eta_k)w_t(c') \]
Modeling Choice Behavior

Bayesian Model  FA Model  Decay Model
Model Fitting

• Choice probabilities computed using softmax

• Find best-fitting parameters for each model that minimizes the negative log likelihood for the model

• Compared model using $e^{BIC/\text{no. of trials}}$
Model Comparison

![Bar chart comparing Bayesian, FA, and Decay models with corrected average likelihood. Stars indicate significant differences.](image-url)
Active-Sensing FHT (asFHT) Task

• Attention is an active sampling process (Schroeder et al., 2011)

• Participants select via button presses the dimensions they would like to view
Active-Sensing FHT Task
Active-Sensing FHT Task
Active-Sensing FHT Task
Active-Sensing FHT Task
Behavioral Performance

N = 18 in FHT
N = 19 in asFHT
Model Comparison

<table>
<thead>
<tr>
<th>Avg Lik/Trial</th>
<th>Bayesian</th>
<th>FA</th>
<th>Decay</th>
</tr>
</thead>
<tbody>
<tr>
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<td><img src="chart.png" alt="" /></td>
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</tbody>
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* n.s. (not significant)
The Decay Model as a Selective Attention Model

• Chosen feature is also attended feature

• If a feature (or set of features) is consistently chosen, the feature weight would increase while all other weights are decayed

• Choice becomes dominated by attended feature
Dimension Viewing Behavior
Modeling Viewing Behavior

Seven possible options:

O1: Faces only
O2: Houses only
O3: Tools only
O4: Faces + Houses
O5: Houses + Tools
O6: Faces + Tools
O7: All Dimensions
Modeling Viewing Behavior

Dimension Value Model

\[ w_{T1} + w_{T2} + w_{T3} = U_T \]

\[ v_n(o) = \sum_d U_d - JN \]

- \( v_n \) = option
- \( U_d \) = value of dim \( d \)
- \( N \) = no. of dim viewed
- \( J \) = penalty term (free parameter)
Modeling Viewing Behavior

Game Horizon Model

\[ v_n(o) = N(\theta - Jn) \]

- \( N = \text{no. of dim viewed} \)
- \( n = \text{no. of trials} \)
- \( \theta = \text{informational value of 1 dim} \) (free parameter)
- \( J = \text{penalty term} \) (free parameter)
Modeling Viewing Behavior

![Graph showing average likelihood per trial for Game Horizon and Weighted Info. The y-axis represents the average likelihood per trial, ranging from 0 to 0.5. The x-axis represents the categories: Game Horizon and Weighted Info. There is a significant difference indicated by an asterisk (*) between the two categories.]
Discussion: Learning

• Statistical Optimality vs. Computational Efficiency

• Learning is constrained by attention
Discussion: Attention

• Scope and focus of attention depend on
  – Relative informational value of viewing each dimension
  – Cost of viewing multiple dimensions

• Attention filter is learned
Discussion

Sensory Units

Attention Units

Value Unit

reward

\(\delta\)

\(w\)

Modified from Gershman, Cohen, Niv, 2010
Discussion

Sensory Units

Attention Units

Value Unit

reward

\( \delta \)

\( w \)

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Discussion

Sensory Units

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Discussion

Value Unit

Attention Units

Sensory Units

Modified from Gershman, Cohen, Niv, 2010
Discussion

- Sensory Units
- Attention Units
- Value Unit

Modified from Gershman, Cohen, Niv, 2010
Ongoing work…

• Elaborate on models of attention and learning
  – Better characterize the dynamics of attention modulation
  – Incorporate reaction time data

• Combining eye-tracking and fMRI methods to directly decode attention

• Searching for neural correlates
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