Modeling Mice Sensory Perception of Whisker Stimulus in Simple Learning Task

Sobhan Nili

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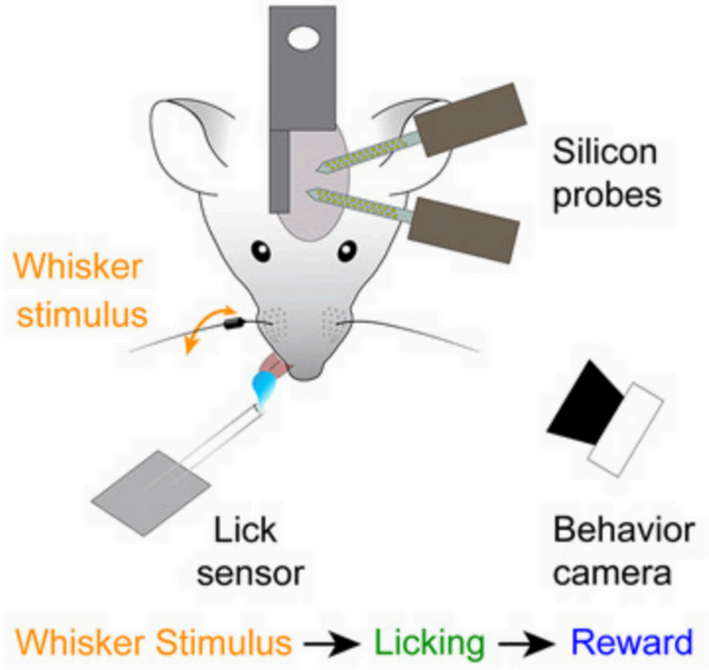
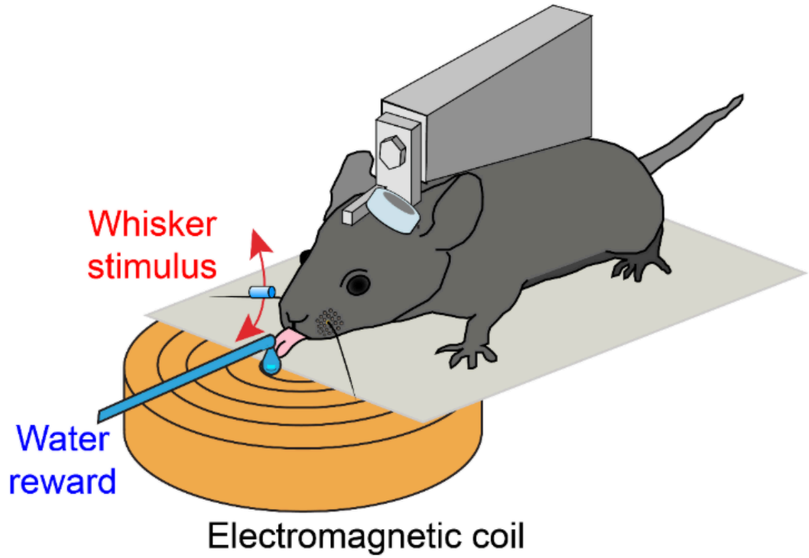
Sensory Processing Lab, EPFL

Grand Picture:
Modeling Learning of a Goal-Directed Behavior In Mice

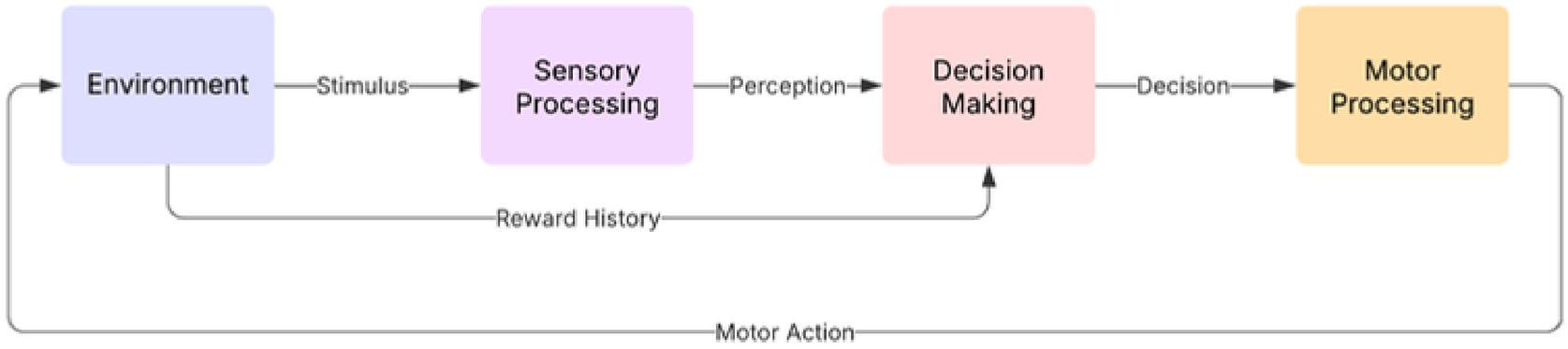




Oryshchuk et al. 2024

Grand Picture:

Modeling Learning of a Goal-Directed Behavior In Mice



Grand Picture:

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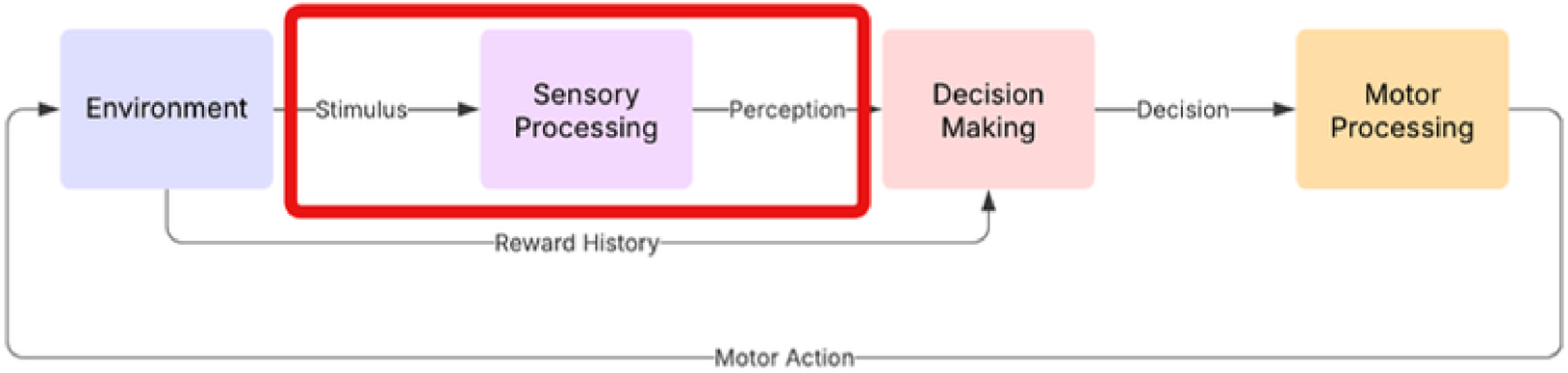
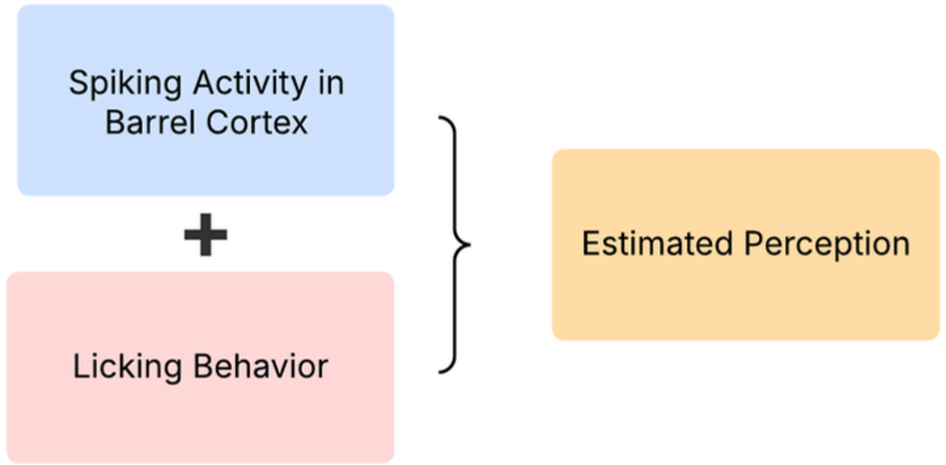


Project Goal

Goal:

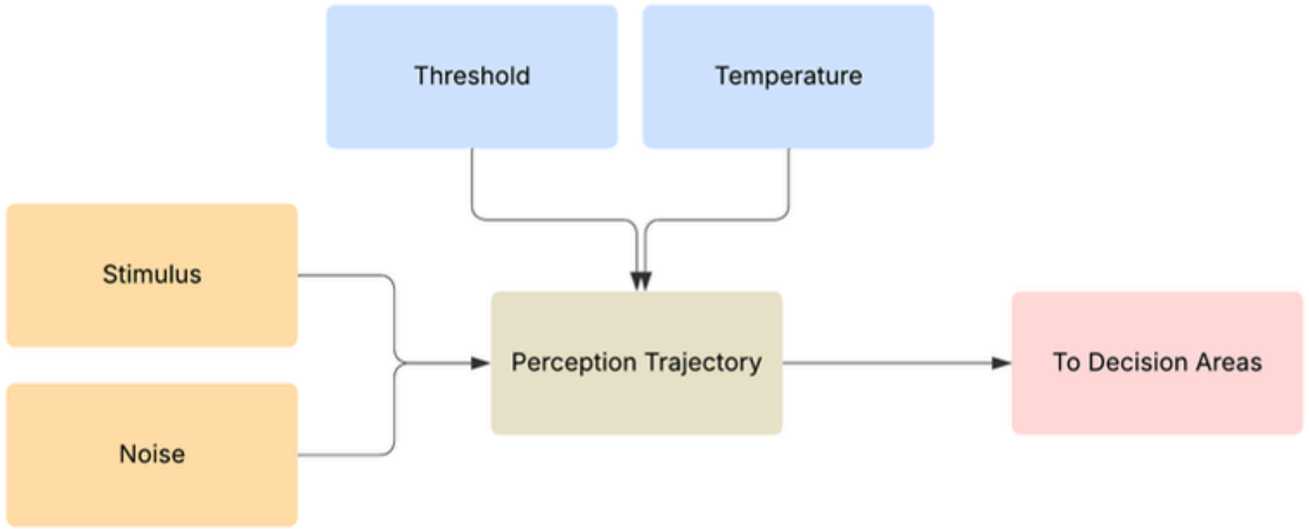
Infer the latent variable **perception** from neural activity and behavior



Project Goal

Motivation

- Exploring the evolution of estimated perception over time and task conditions
- Parameter estimation for block of perception in the learning model



Neural Decoding

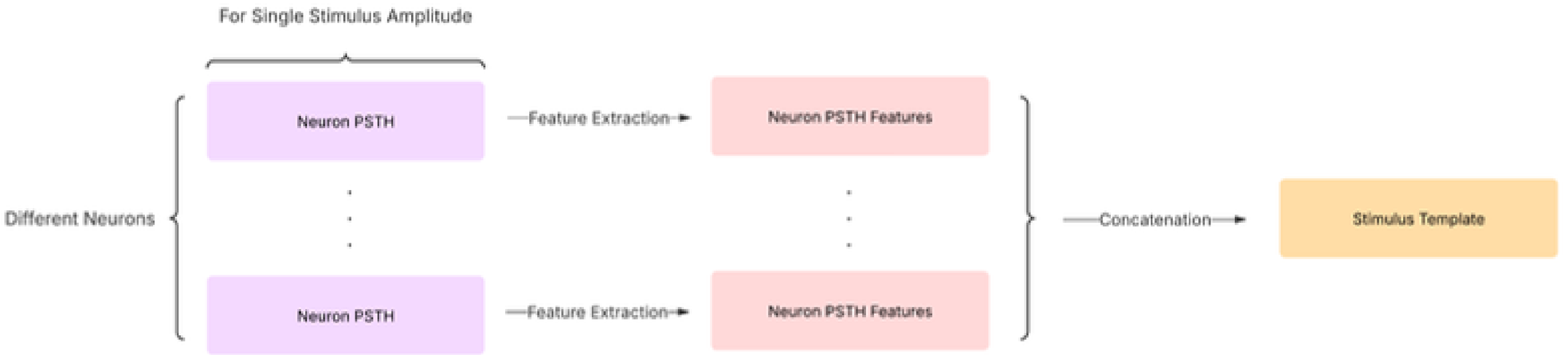
Goal

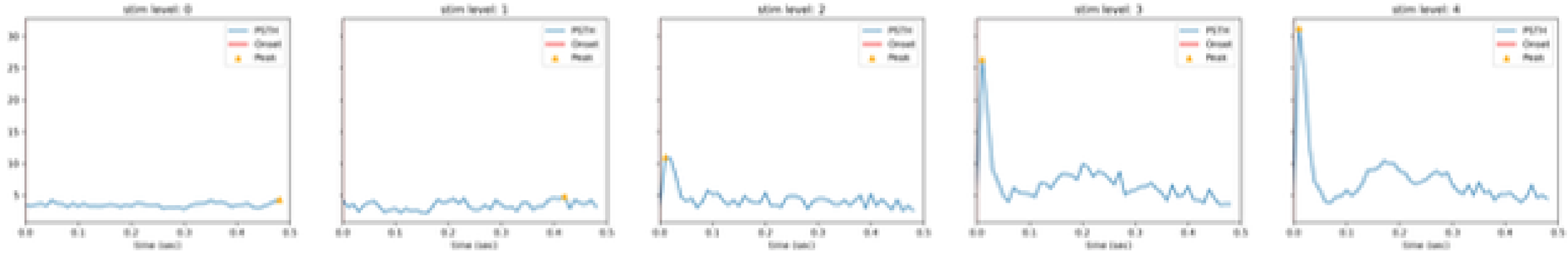
- Decoding the stimulus presence from spiking activity in barrel cortex
- Is not necessarily what the mouse is perceiving
- The decoder should be computationally simple and interpretable

Decoding Method

- Template matching
- Extract useful features from PSTH of neurons and concatenate them in a feature vector
- Compare feature vectors indicating presence/non-presence of stimulus with trial feature vector

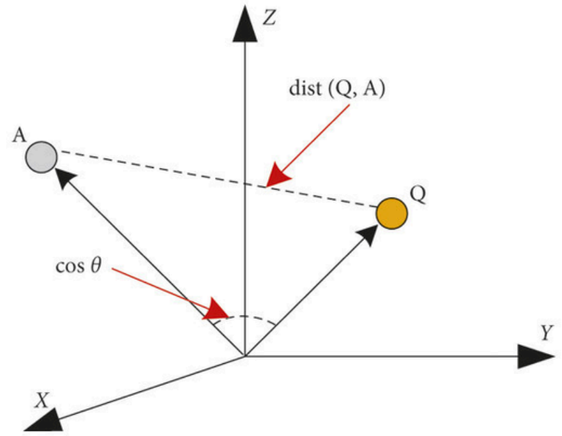
Template Construction





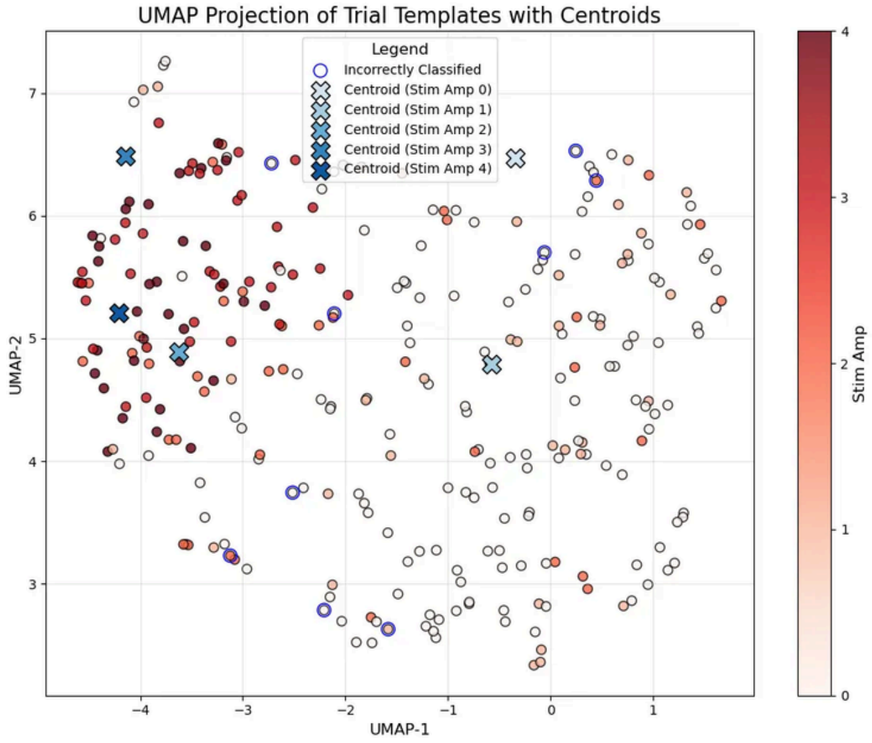
Sample PSTH for Stimulus Levels

Similarity Metric



Cosine / Euclidean Distance

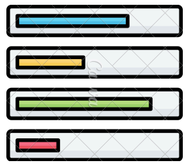
Assign Trial to Stimulus That Corresponds to Nearest Template



Trials get clustered based on stimulus levels

Cai et al. 2019

Decoder Parameters



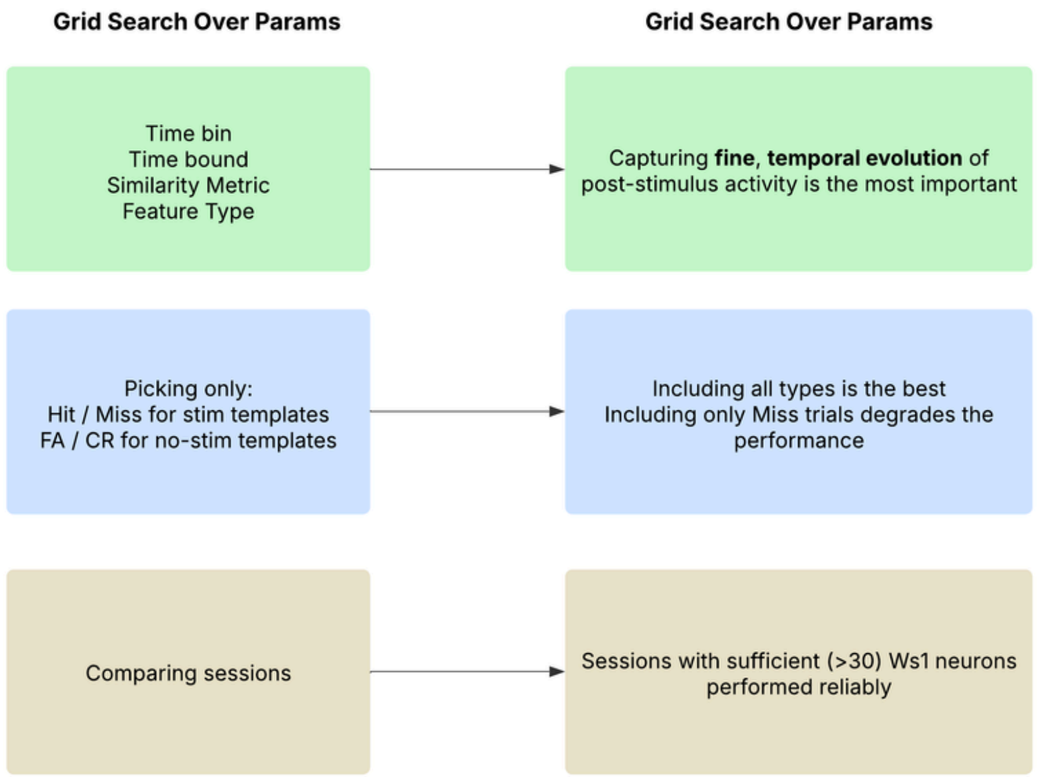
- Features extracted
- Time bound for feature extraction
- Spike binning size
- Similarity metric
- Multi-Level or Binary Templates
- Which trials to use for template construction

Decoder Output: Estimated Perception (between 0 & 1) $\frac{e^{\frac{-d_1}{T}}}{e^{\frac{-d_1}{T}} + e^{\frac{-d_2}{T}}}$

Evaluation Method: F1 score in prediction of binarized stimulus in trials

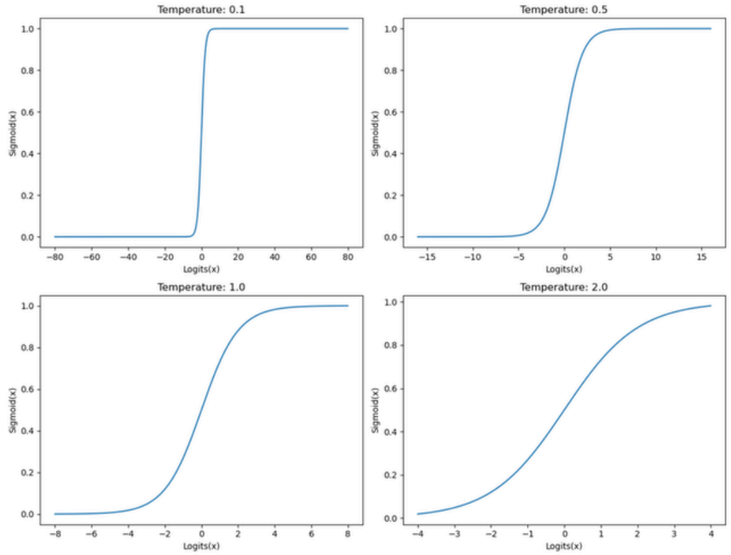
Decoder Parameters: Insights

Grid search on decoder parameters in 3 phases:

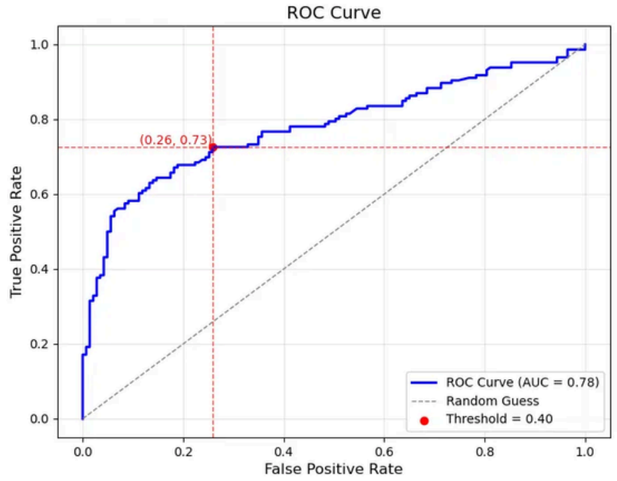


From Trials To Continuous Decoding

- Running the decoder on time windows other than trial surroundings
- Optimize the **temperature** and **threshold** parameters to optimize either:
  - Best decoding accuracy
  - Best behavior correspondence

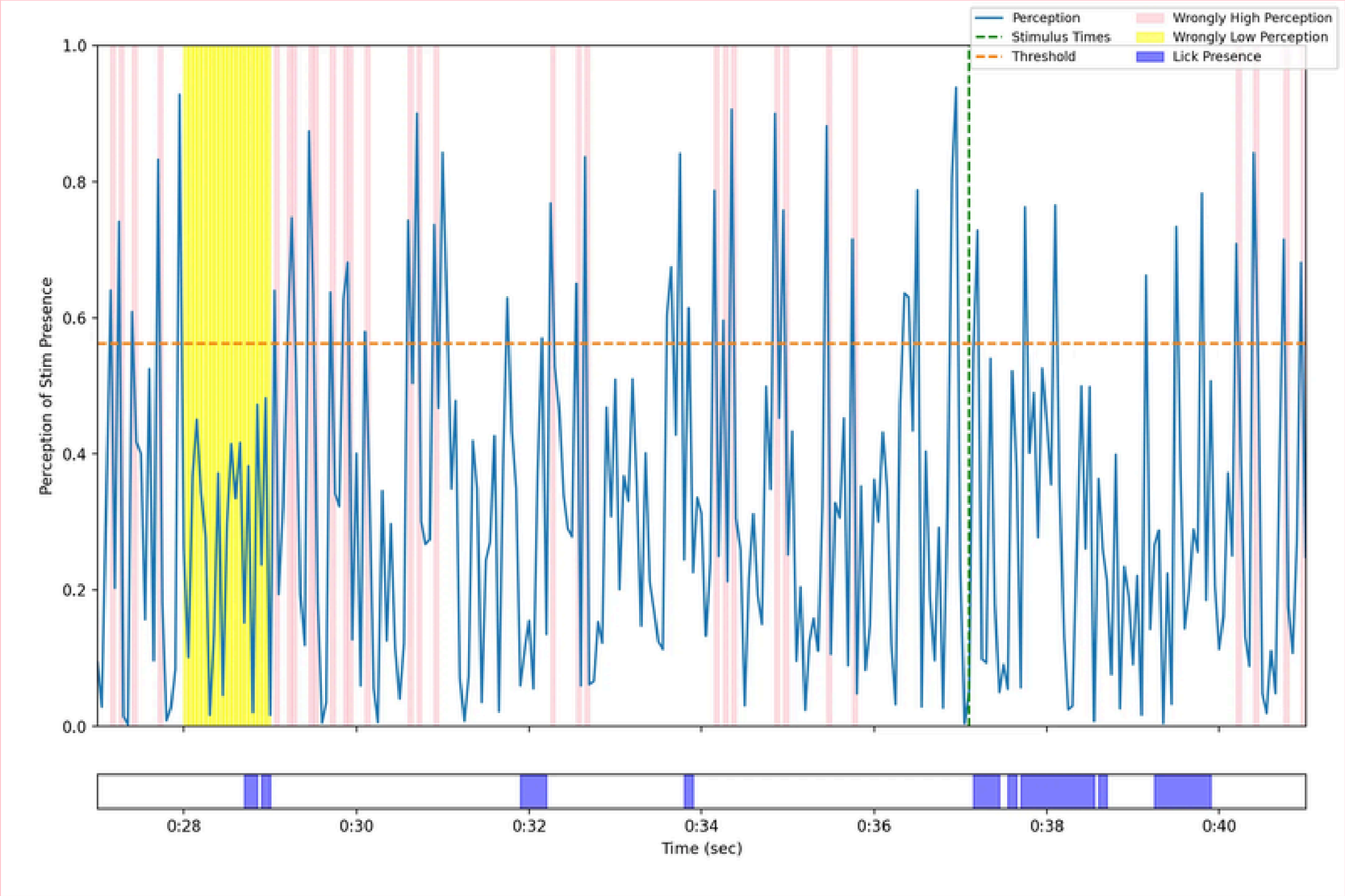


Role of Temperature



Role of Thresholding

Perception Trajectory Over Time



Method of Optimization

First Step: for each timepoint, calculate soft measure of distance with threshold

$$d[t] = \sigma\left(K(s[t] - \theta)\right) \text{ where } s[t] = \frac{e^{\frac{-d_1}{T}}}{\frac{-d_1}{T} + \frac{-d_2}{T}}$$

Decoding Loss:

- Goal: Better alignment of perception and stimulus
- Losses:
  - Miss loss: $\text{loss}_{\text{miss}} = \text{mean}\left\{1 - max(d[t])\right\} \text{ (over windows after stimulus)}$
  - False alarm loss: $\text{loss}_{\text{fa}} = \text{mean}\left\{d[t])\right\} \text{ (over timepoints not in stimulus windows)}$
- Final Loss: $\text{loss}_{\text{total}} = \lambda\, \text{loss}_{\text{miss}} + \text{loss}_{\text{fa}}$

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First Step: for each timepoint, calculate soft measure of distance with threshold

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Behavior Loss:

- Goal: Better alignment of perception and licks
- Losses:
  - Miss loss: $\text{loss}_{\text{miss}} = \text{mean}\left\{d[t])\right\} \text{ (over timepoints not in windows preceding lick)}$
  - False alarm loss: $\text{loss}_{\text{fa}} = \text{mean}\left\{1 - max(d[t])\right\} \text{ (over windows before each lick)}$
- Final Loss: $\text{loss}_{\text{total}} = \lambda\,\text{loss}_{\text{miss}} + \text{loss}_{\text{fa}}$

Evaluation of Continuous Perception & Behavior Matching

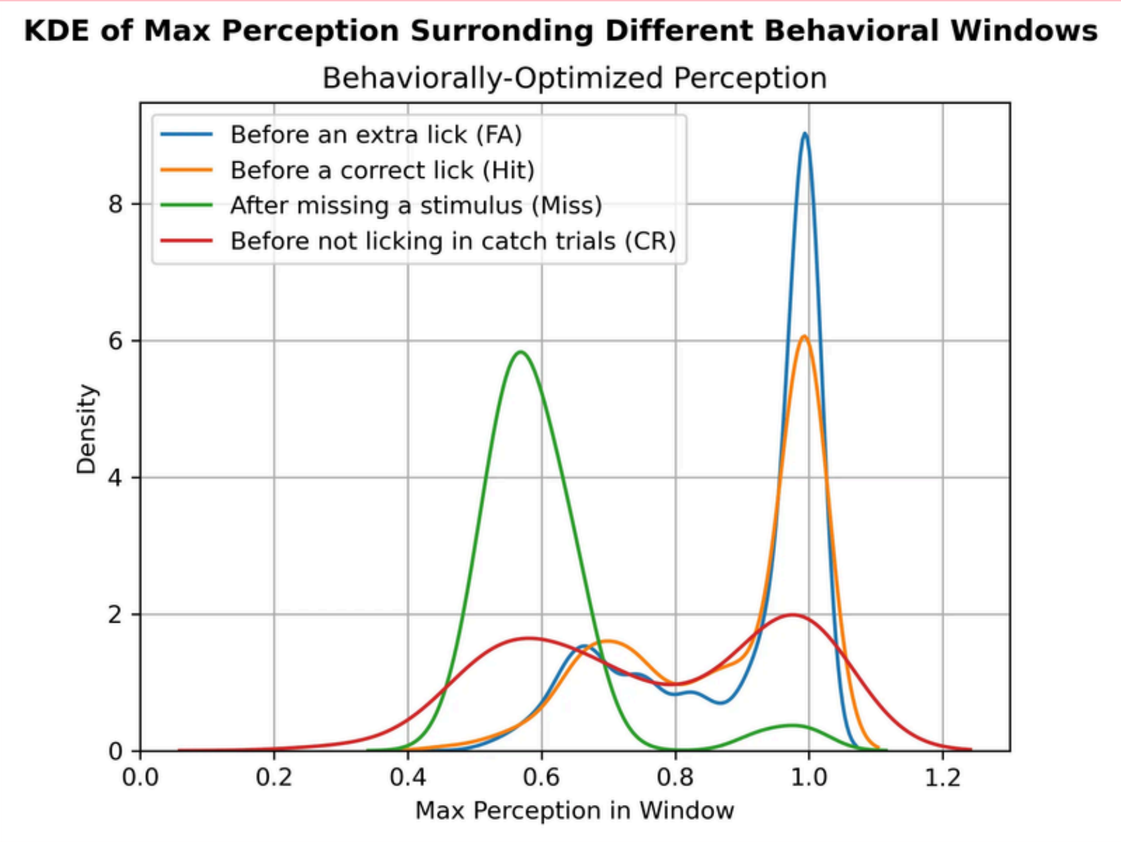
- Gradient decent to optimize temperature and threshold

$$\text{Rate of lick prediction miss} = \frac{n_{\text{ no threshold crossing preceding a lick}}}{n_{\text{ all licks}}}$$

$$\text{Rate of lick prediction false alarm} = \frac{n_{\text{ no licks after a threshold crossing}}}{n_{\text{ all threshold crossings}}}$$

Decoder does better in the first metric compared to the latter → possible inflation of threshold crossings

Distribution of Perception Surrounding Behavioral Windows



Extractable Parameters

To use in artificial perception generation:

λ : Representing lick cost

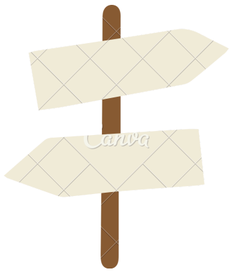
T : Exploration / Exploitation Balancing

θ : Risk Averseness

Recap

- Decoding presence / non-presence of stimulus in trials
  - Exploring interplay of parameters in template matching decoding scheme
- Extending perception from trials to whole session (doesn’t work well honestly)
  - Interpretable and extractable parameters for simulating perception
  - Checking if the optimized decoding scheme justifies the licking behavior
- A GUI for exploration of parameter interplay / visualization of perception trajectories

Possible Future Directions



- Use the parameter ranges as guides for setting sensory block parameters
- Involve the loss balancing (lambda) in optimization and track evolution of its trajectory
- Try to regress out effect of learning / motivation / engagement from perception
- Using autoregressive model for perception estimation

Thank You!

To Dr. Crochet for properly planning the project and guiding me through difficulties...

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