

# **Modeling Mice Sensory Perception of Whisker Stimulus in Simple Learning Task**

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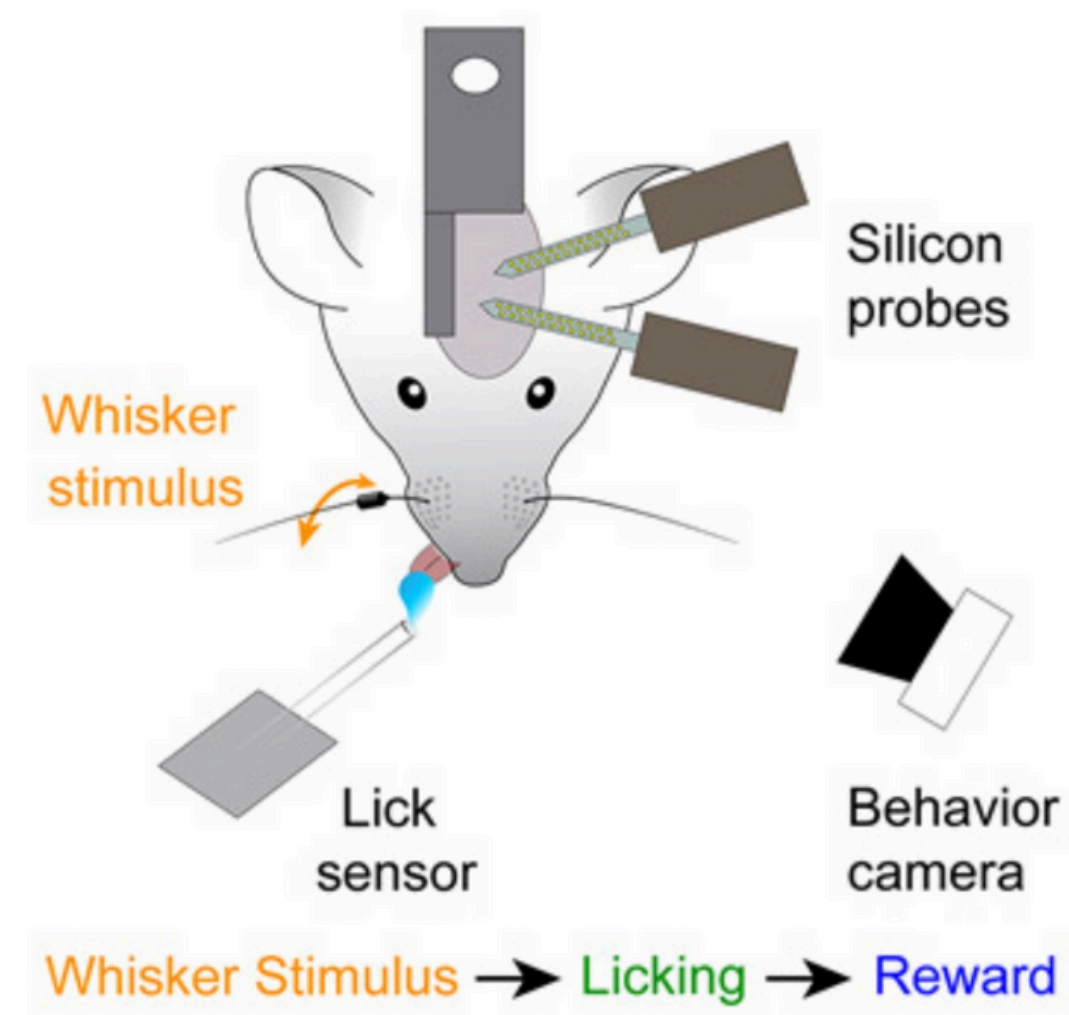
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**Sensory Processing Lab, EPFL**



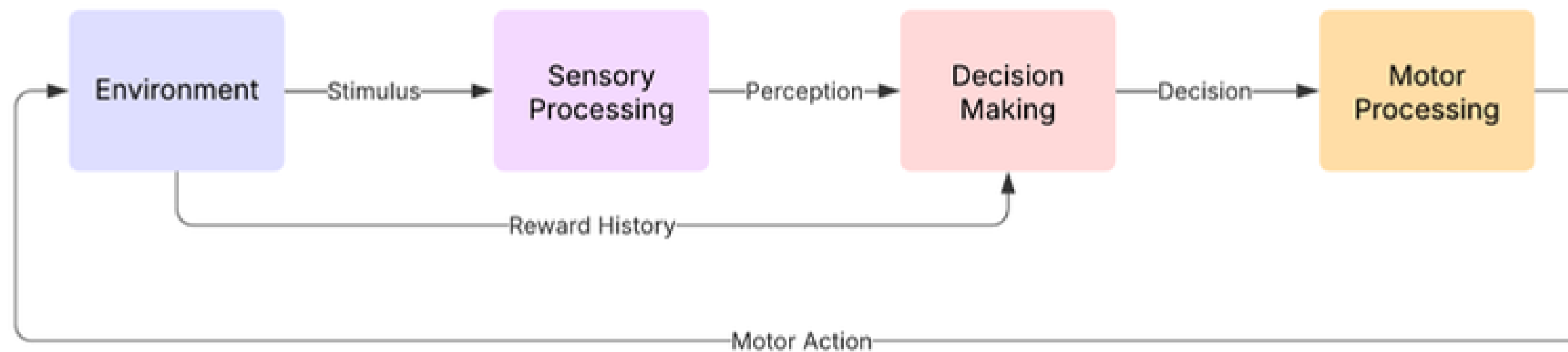


# Grand Picture: Modeling Learning of a Goal-Directed Behavior In Mice



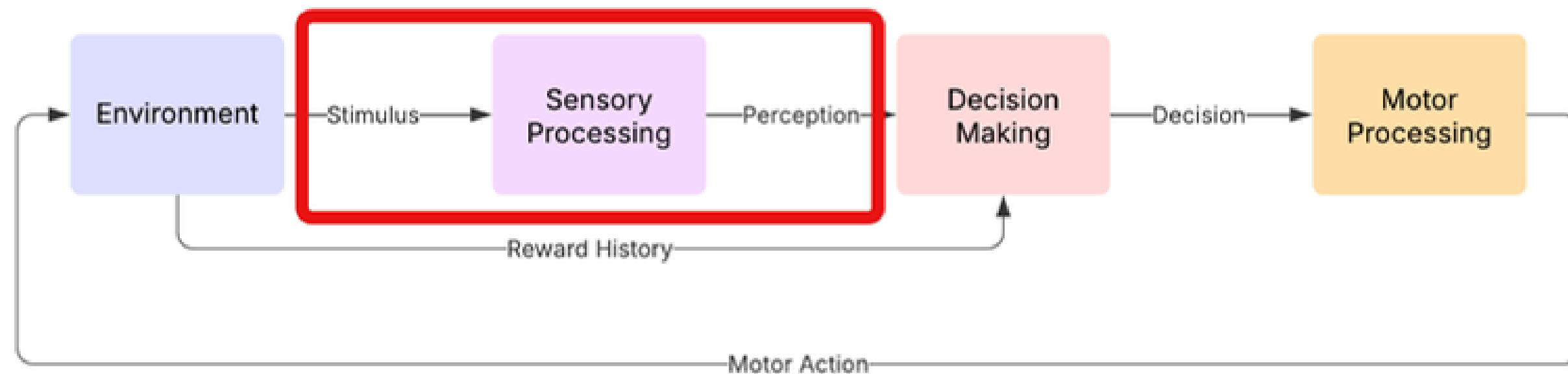
# Grand Picture:

## Modeling Learning of a Goal-Directed Behavior In Mice



# Grand Picture:

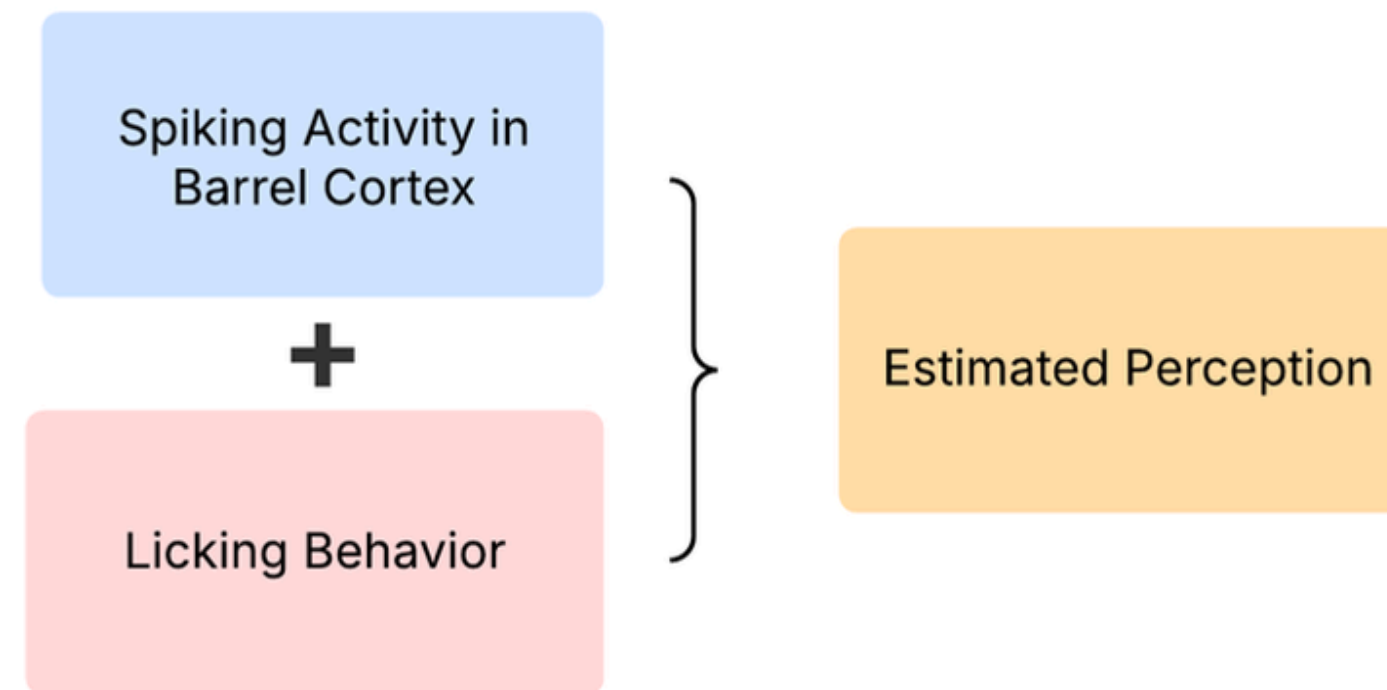
## Modeling Learning of a Goal-Directed Behavior In Mice



# Project Goal

## Goal:

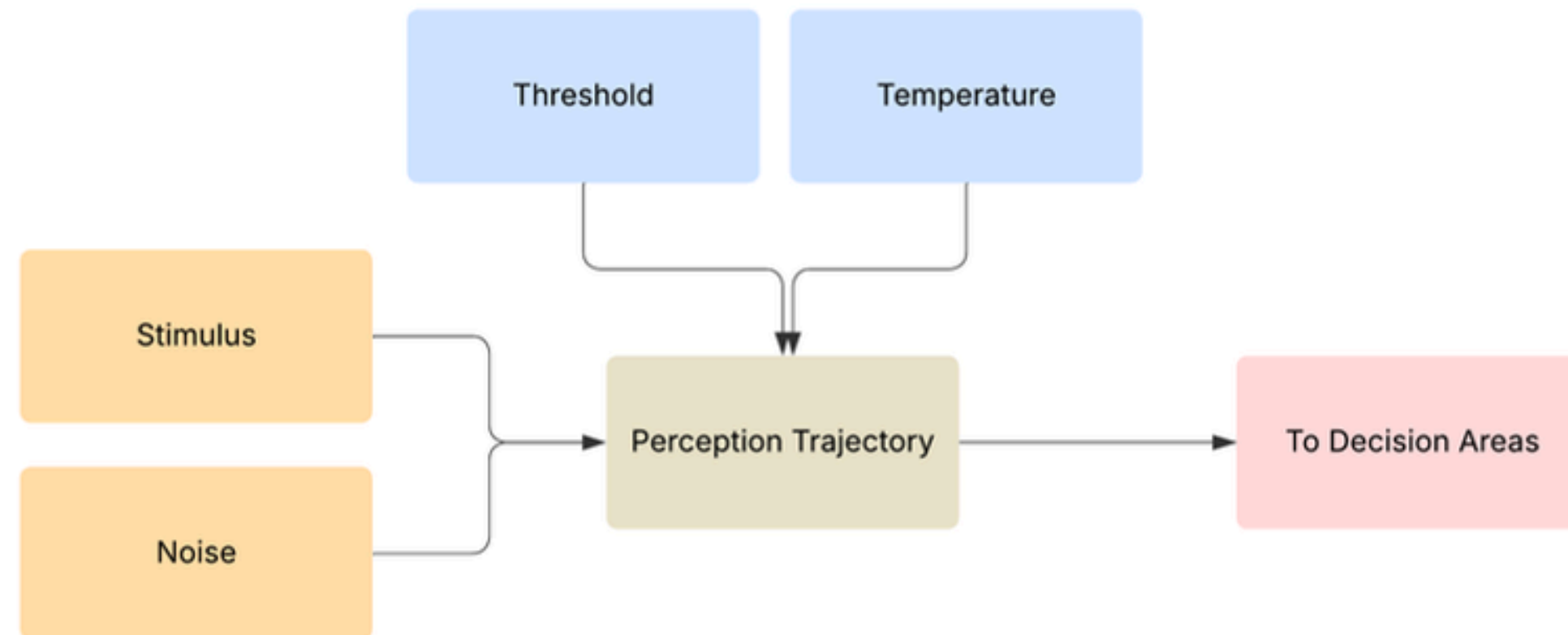
Infer the latent variable **perception** from neural activity and behavior



# 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

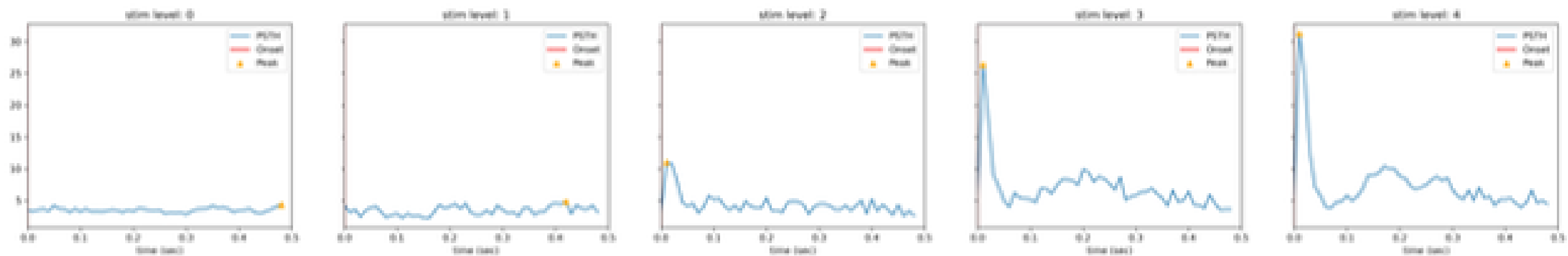
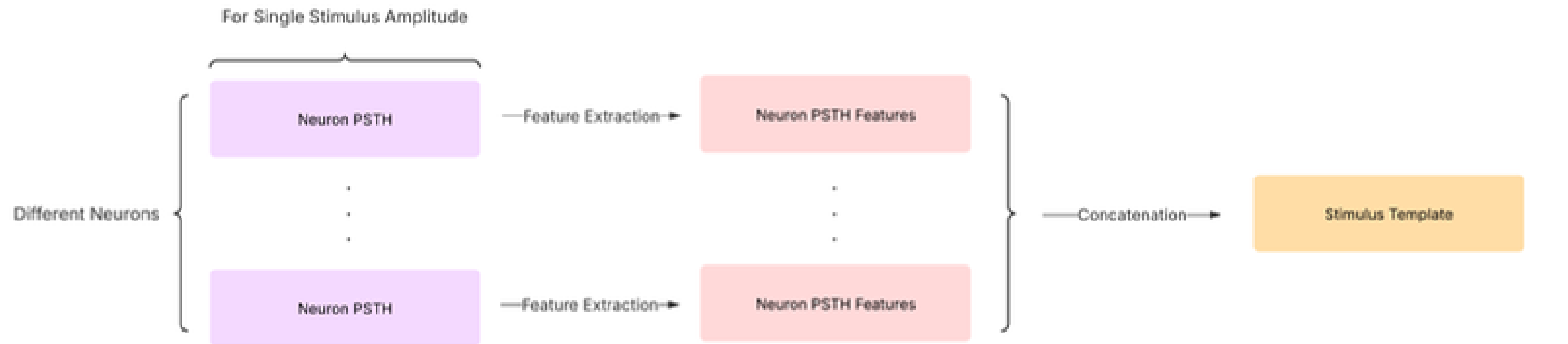
## Goal

- 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

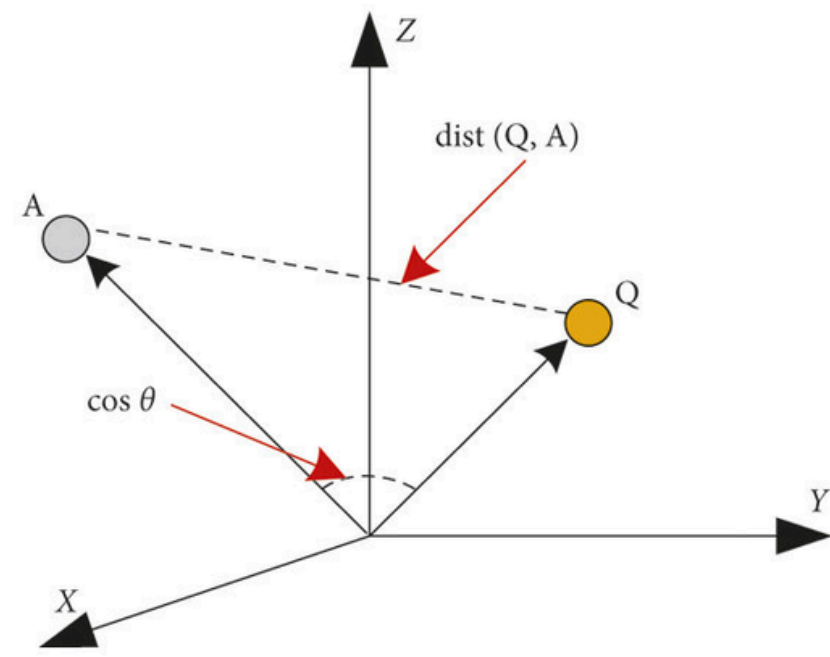
# Template Construction



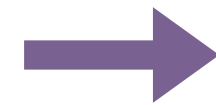
Sample PSTH for Stimulus Levels



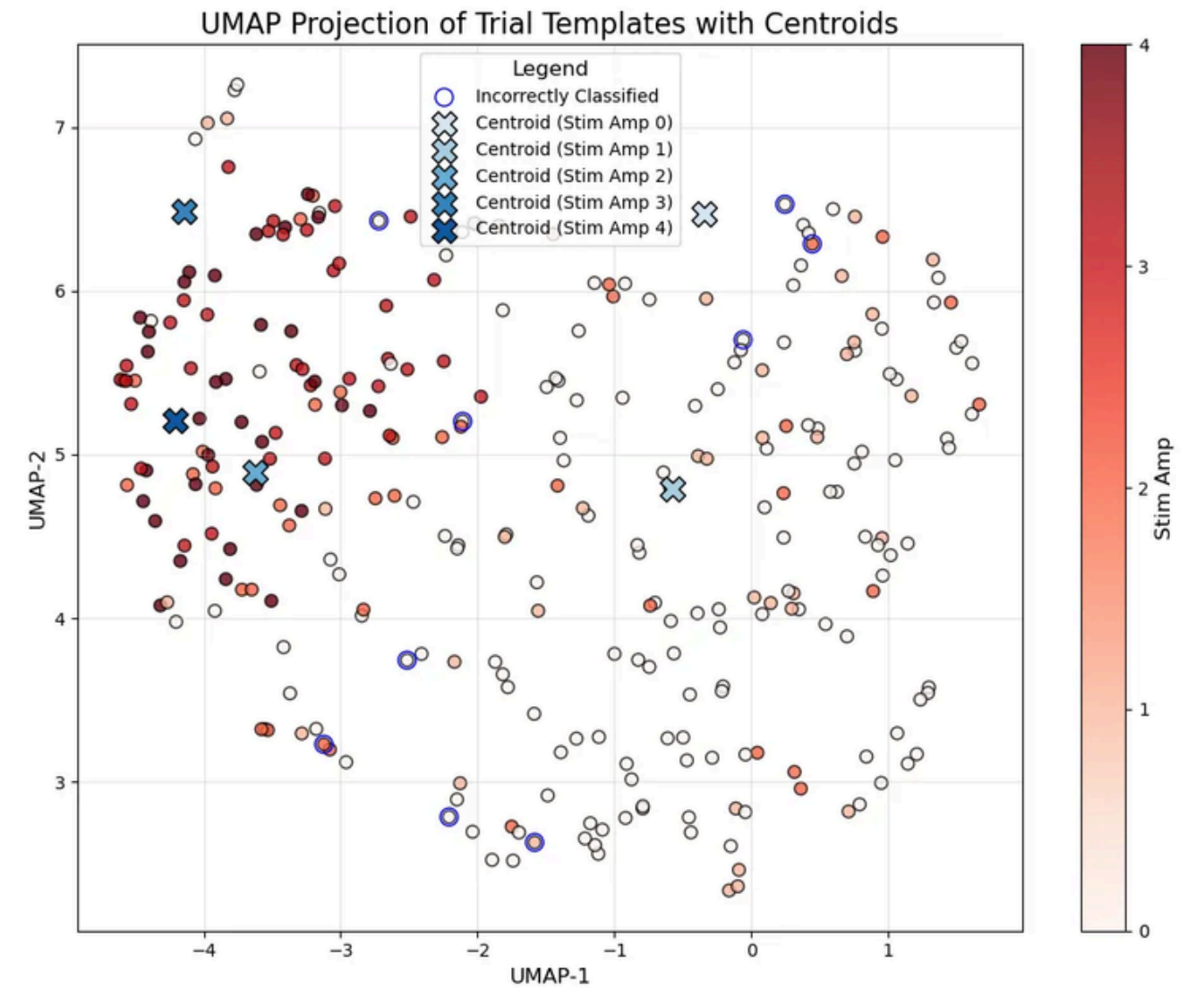
# Similarity Metric



**Cosine / Euclidean Distance**

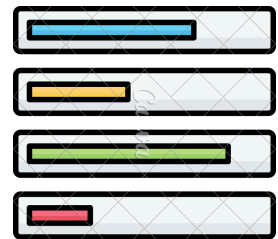


**Assign Trial to Stimulus That  
Corresponds to Nearest Template**



**Trials get clustered based on stimulus levels**

# Decoder Parameters



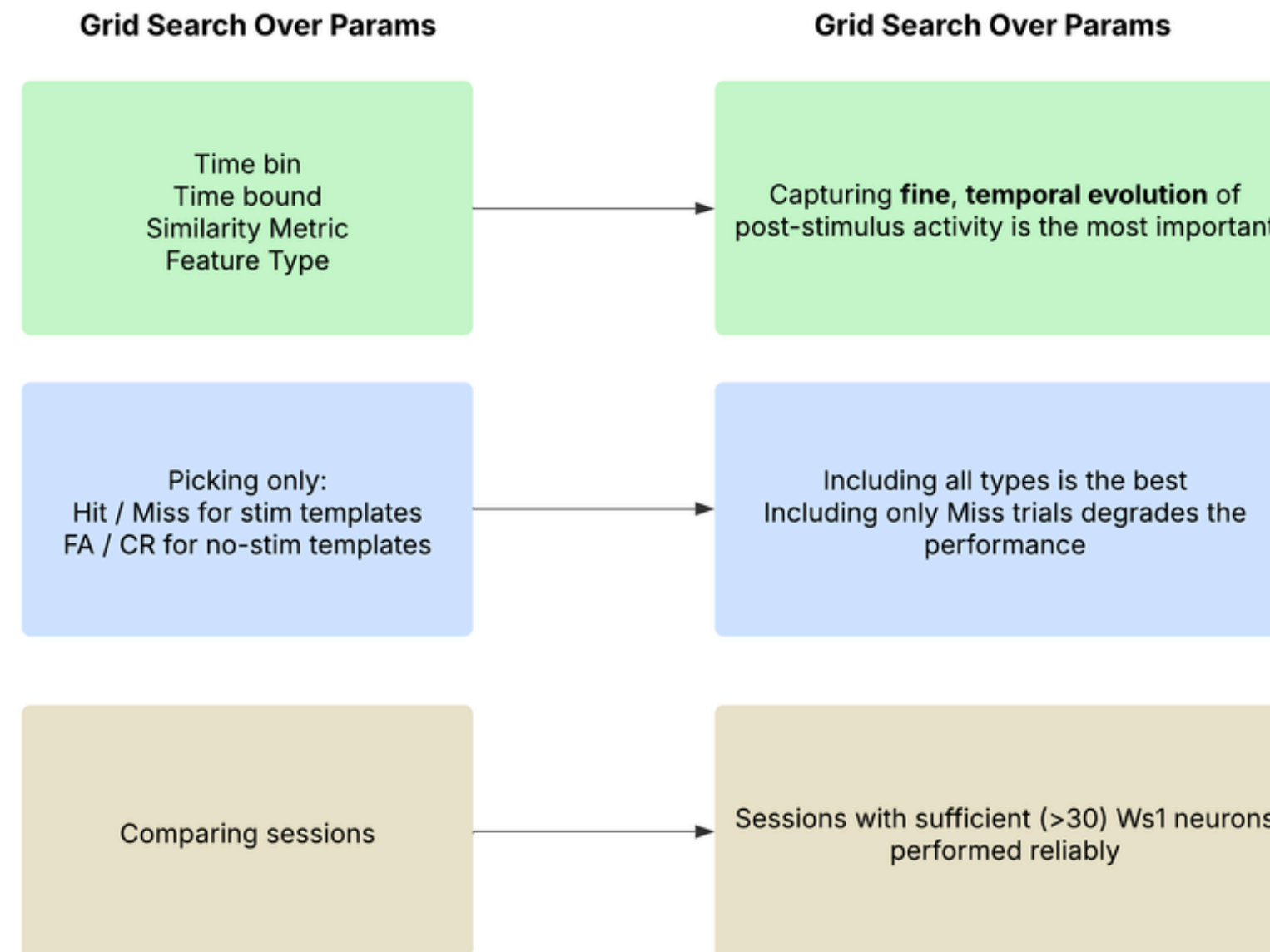
- Features extracted
- Time bound for feature extraction
- Spike binning size
- Similarity metric
- Multi-Level or Binary Templates
- Which trials to use for template construction

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

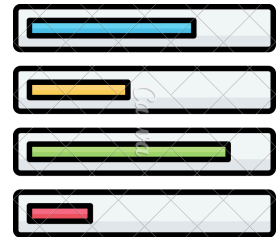
**Evaluation Method:** F1 score in prediction of binarized stimulus in trials

# Decoder Parameters: Insights

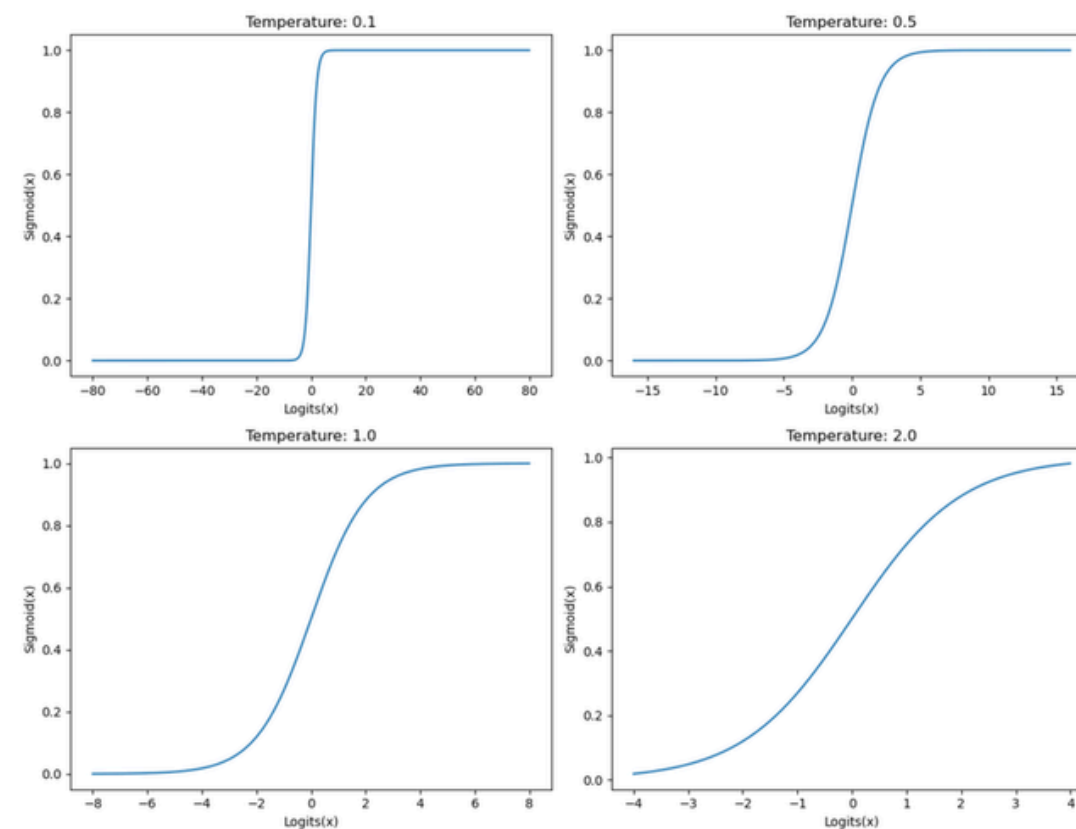
Grid search on decoder parameters in 3 phases:



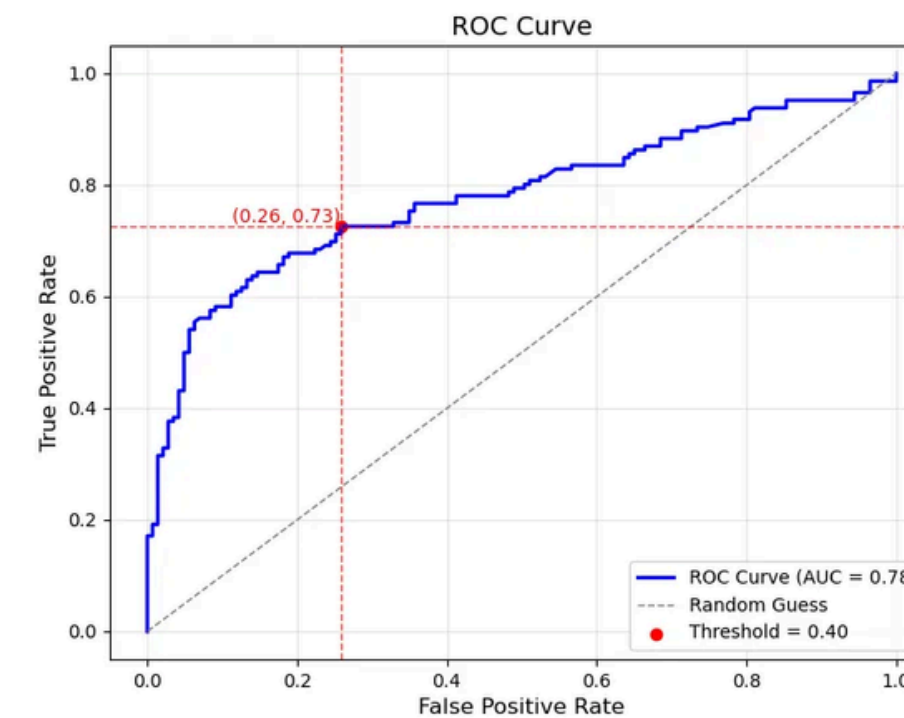
# From Trials To Continuous Decoding



- 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



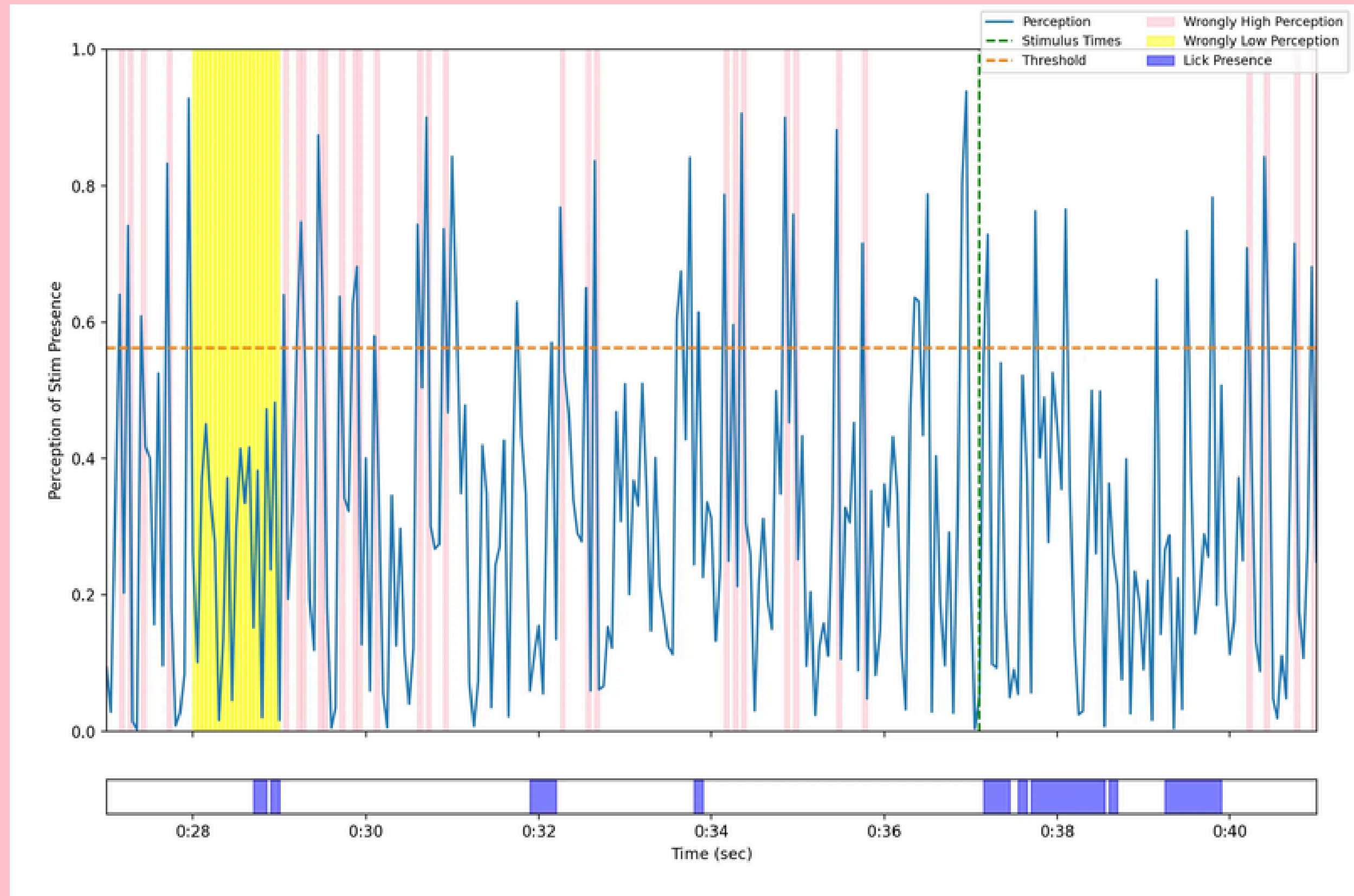
Role of Temperature



Role of Thresholding

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# Perception Trajectory Over Time





# Method of Optimization

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

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

## Decoding Loss:

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

# Method of Optimization

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

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

## Behavior Loss:

- Goal: Better alignment of perception and licks
- Losses:
  - Miss loss:  $\text{loss}_{\text{miss}} = \text{mean}\{d[t]\}$  (over timepoints not in windows preceding lick)
  - False alarm loss:  $\text{loss}_{\text{fa}} = \text{mean}\{1 - \max(d[t])\}$  (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

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

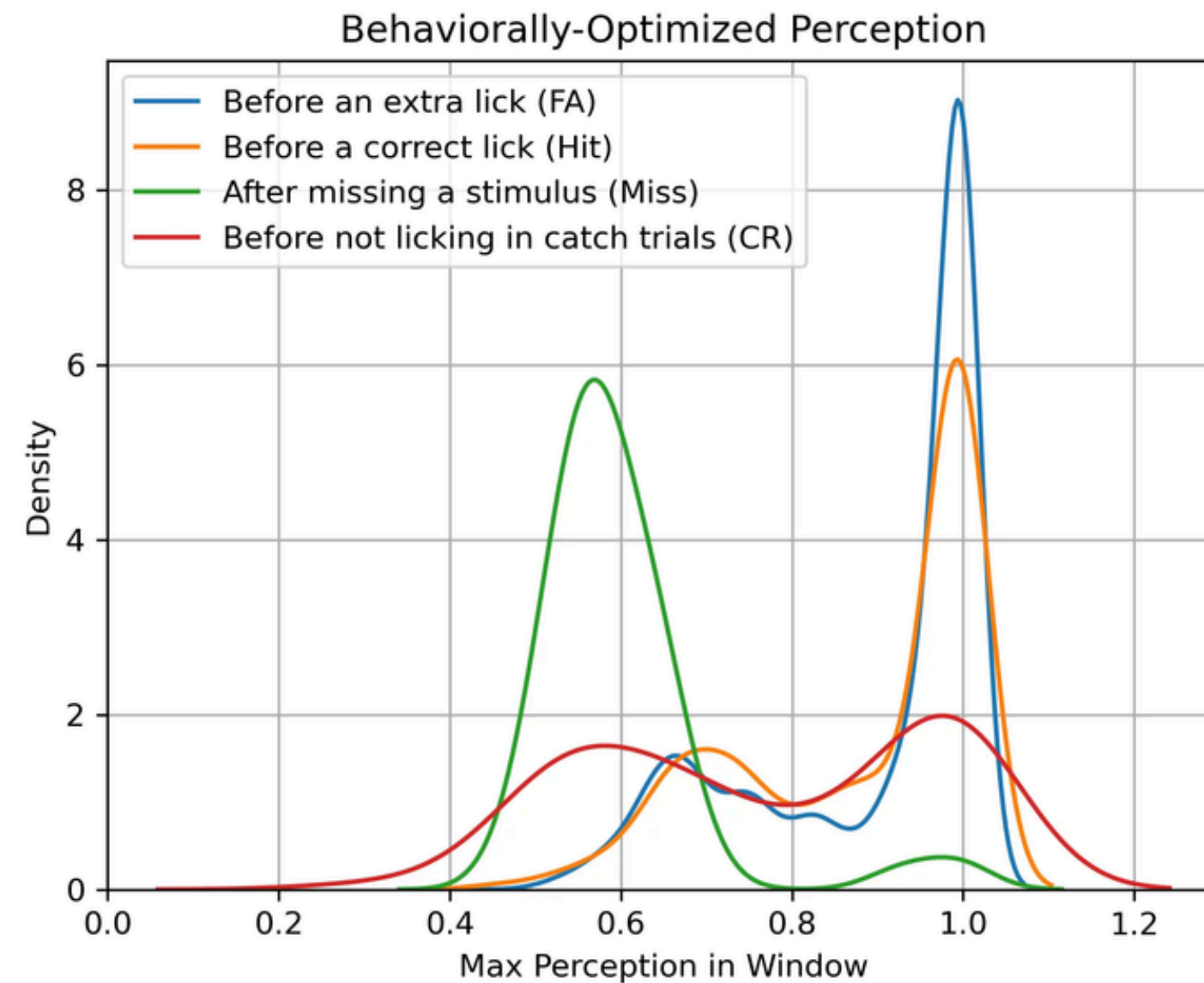
$$\text{Rate of lick prediction false alarm} = \frac{n_{\text{no licks after a threshold crossing}}}{n_{\text{all threshold crossings}}}$$

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

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# Distribution of Perception Surrounding Behavioral Windows

**KDE of Max Perception Surrounding Different Behavioral Windows**



# Extractable Parameters

To use in artificial perception generation:

$\lambda$  : Representing lick cost

$T$  : Exploration / Exploitation Balancing

$\theta$  : Risk Averseness

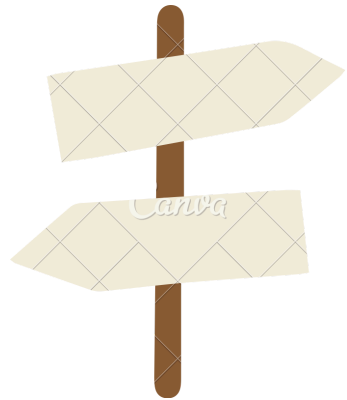




- Decoding presence / non-presence of stimulus in trials
  - Exploring interplay of parameters in template matching decoding scheme
- Extending perception from trials to whole session (doesn't work well honestly)
  - Interpretable and extractable parameters for simulating perception
  - Checking if the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

# Possible Future Directions

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- 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

# Reproducible Analysis

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Whisker-Stimulus-DecodingPublic

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src	finishing touches	5 minutes ago
.gitignore	initial commit	2 weeks ago
LICENSE	Initial commit	3 weeks ago
README.md	Update README.md	2 minutes ago
SP Lab Project.pdf	Add files via upload	2 minutes ago
environment.yml	Update environment.yml	3 minutes ago
trial_template_matching_eval.ipynb	finishing touches	5 minutes ago

README

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## Project Topic

In this project, we aim to infer how the perception of whisker stimuli evolves in mice during an operant conditioning task.

Since perception is a latent variable, we estimate it by combining stimulus decoding from barrel cortex spiking activity with mice licking behavior. We then adjust the decoder parameters to capture behavioral patterns, thereby bringing the decoded representation closer to the underlying perceptual process.

For more information please refer to the abstract presentation included in the repository.

Semester project in Labratory of Sensory Processing, EPFL

Data from [Oryshchuk et al.](#)

About

Decoding Whisker Stimulation Perception from Cortical Recordings in Mice and Comparing It with Behavioral Responses

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# Thank You!

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