Sparse representations of sensory signals in neuronal networks

Yael Ben Nahum and Noa Elnhorn, Supervised by Hadas Benisty

Introduction

The primary motor cortex (M1) is crucial for motor performance. The central nervous system monitors action outcomes to adapt and improve performance.

Our project explores the relationship between binary signaling of outcome and signaling of outcome value.

We analyze imaging data recorded from pyramidal neurons in layer 2-3 of M1 in mice performing a hand-reach task of a food pellet (Fig. 1). Recent results show that binary outcome (success/failure) is reported by this cells population during this task. Here we explore the effect of exposure to flavored pellets and the existence of value signaling.

We use Sparse Principal Component Analysis (SPCA), classical classifiers, and network centrality to quantify if and how signaling of value (i.e. flavor) emerges with exposure to flavor and its relationship to binary signaling.

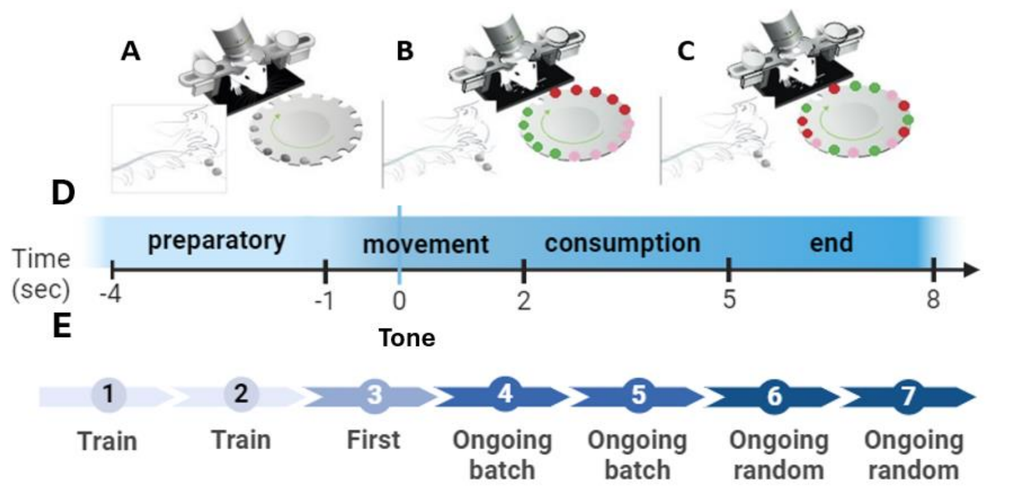

Figure 1. Illustration of the experimental setup and timelines. Mice perform a hand-reach task of grabbing and consuming food pellets positioned on a rotating table. A. "Train" – no flavor. B. Batch sessions. C. Randomized sessions. D. Trial timeline and time segments. E. Training stages.

Objectives

- **How does exposure to different values affect (binary) outcome signaling?**
- **Does the network report value as well?**
- **What is the relationship between binary and value signaling of outcome?**

Methods

- Representation – extract a low-dimensional representation of the population dynamics using Sparse Principal Component Analysis (SPCA):

$$\max\langle\langle v\hat{}T\ \Sigma v\rangle\rangle$$

$$s.t\ \|v\|\_2=1,\ \|v\|\_0\leq STOP$$

- Detect decoding components – train a logistic regression model per component to identify which cells encode binary outcome or value.
- Encoding barcode – label neurons that were detected as encoding outcome
- Compare representation using Hamming distance applied to barcodes
- Network dynamics –degree centrality of the correlation matrices across different stages
- Network dynamics to encoding barcode using Spearman's rank correlation coefficient.

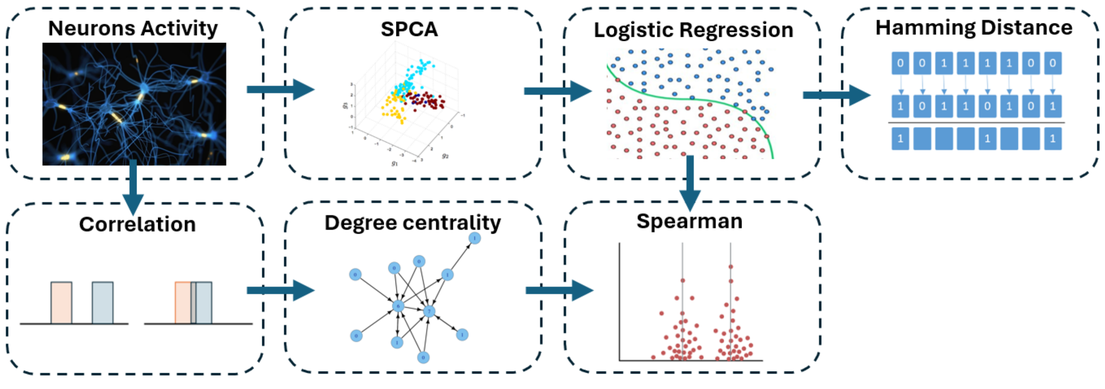

Figure 2. Analysis pipeline.

Results

Binary outcome representation

Binary outcome is encoded in all time segments and stages.

About 15-20% of cells encode outcome in the final segment – higher than previously published results (based on univariate analysis) [1].

Encoding of value

At first the network mostly encode novelty based on a relatively small fraction of cells.

With exposure to flavor more and more cells encode the value – tasty vs. aversive

Encoding of specific flavors – emerges later

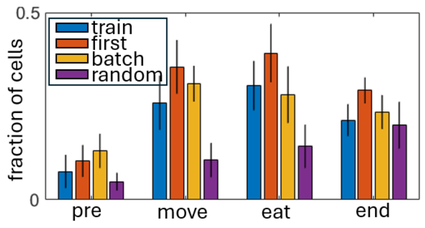

Figure 3. Binary outcome encoding. Fraction of cells encoding successful/failed execution of the task.

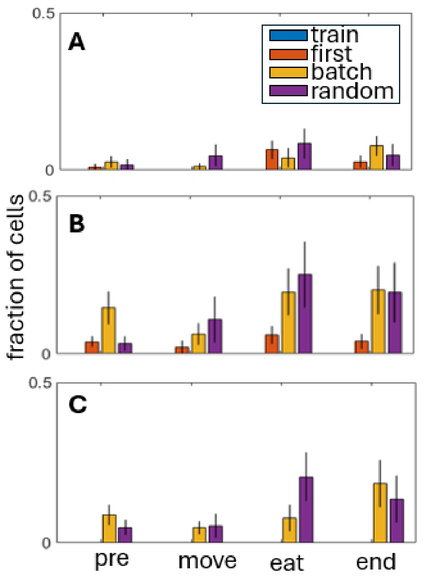

Figure 4. Value encoding. Fraction of cells encoding: A. novelty (grain vs. quinine and sucrose). B. Tasty vs. aversive (grain and sucrose vs. quinine). C. Specific flavors.

Exposure to flavors induces a shift in binary outcome signaling

The Hamming distance between the representation of binary outcome during the preparatory in the first session and all other sessions – increases.

This indicates a monotonic change in outcome signaling, induced by exposure to flavor.

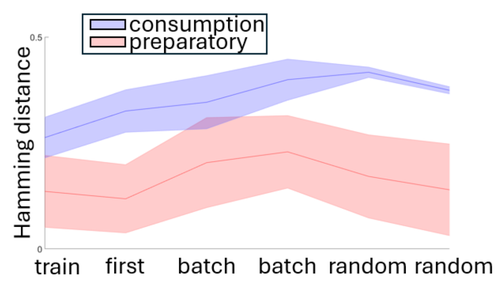

Figure 5. Hamming distance between barcode representation of binary outcome for the preparatory segment (red) and the consumption segment (blue)

Degree Centrality

The distance between the ensemble centrality in the first session and the ensemble centrality in all other sessions increases.

Indicates a monotonic change in the correlational configuration

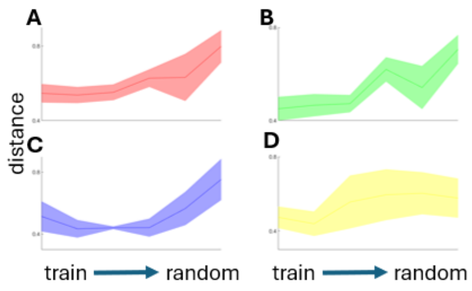

Figure 6. Distance between correlation degree at different stages of training. A. Preparatory segment. B. Movement. C. Consumption. D. End of trial.

Flavor exposure alters the relationship between degree centrality and encoding

Significant and high correlation between the degree and outcome encoding (top) at early stages indicates that network is focused on reporting binary outcome.

With exposure flavor novelty (middle) becomes significant

With exposure flavor value becomes higher than outcome and novelty (bottom).

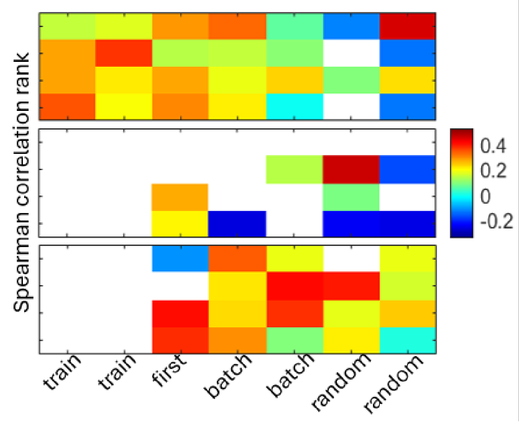

Figure 7. Spearman correlation rank between degree centrality and encoding of: top - binary outcome, middle - novelty (grain vs. quinine and sucrose) and bottom - tasty vs. aversive (grain and sucrose vs. quinine).

Conclusions

- Binary outcome is reported before and during exposure to flavors
- The exposure to flavor changes the way the binary outcome is reported
- Signaling of value develops with exposure to flavor:

  novelty → tasty vs. aversive → a detailed signaling of specific flavors
  - Value is reported also during the preparatory time segment – before the go cue!

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- Guidance and support from Gaia Levin.

References

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