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Unsupervised Learning of a Dictionary of Neural Impulse Responses from Spiking Data

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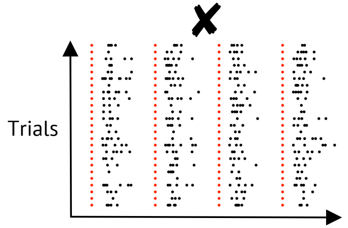
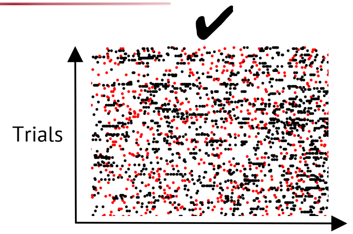
Introduction





Setup of the majority of studies:

- A **stimulus** ● **repeatedly** applied over series of trials.
- Events are **time-locked** and **non-overlapped**.
- Spike trains ● are **averaged** over trials or **smoothed** out.

Our method is capable of studying neural activity with the setup:

- A **stimulus** ● comprises **discrete** and **random** events.
- Events are **overlapped**.
- Neither **averaging** over trials nor **smoothing** of spikes ● are needed.

Experimental Setup

Stimulus (odor)

- Deliver 50 ms pulses of the same peak concentration.
- Pulses have a Poisson-distributed rate between 0.5- 4 pulse/s.
- Trial duration is 5 s.

Recording Device

- A custom-built 32-channel tetrode drive.
- Sampling rate of 30 kHz using Open Ephys recording system.

Spikes

- Neural activity in the anterior piriform cortex.
- Single-unit spiking isolated using Kilosort.
- Isolated 5-40 single units in each session.
- Recorded 388 neurons in total of 17 sessions.

Methods

Probabilistic Model

$$\log \mu^{j,c} = h_c * x^{j,c} + a^{j,c}$$

trial: j; neuron: c

- $\mu^{j,c}$: firing rate
- h_c: neural impulse response (dictionary)
- $x^{j,c}$: presence of odor and strength of response.
- $a^{j,c}$: baseline activity

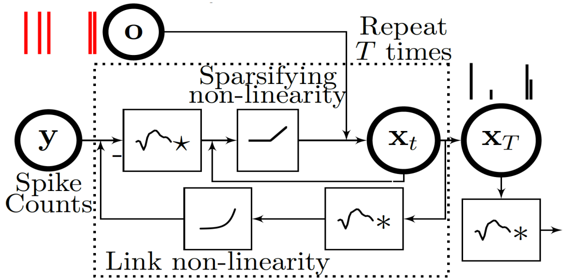
observations $\quad y^{j,c}|x^{j,c}, h_c \sim \text{Poisson}(\mu^{j,c})$

Optimization Problem

$$\min_{h_c, \{x^{j,c}\}_{j=1}^{J}} \sum_{j=1}^{J} -\log P(y^{j,c}|h_c, x^{j,c}) + \lambda \|x^{j,c}\|_1 \ \text{s.t.}\ \|h_c\|_2 = 1,\ x^{j,c} \geq 0$$

Learning Method

- An unrolled neural network based on the optimization model.
- Encoder (sparse coding): Given $y^{j,c}$, estimate $x^{j,c}$.
- Decoder: construct the rate $\mu^{j,c}$ using the impulse response h_c.
- Training: re-estimate h_c through backpropagation by maximizing the log likelihood.



Learning autoencoder architecture.

Results

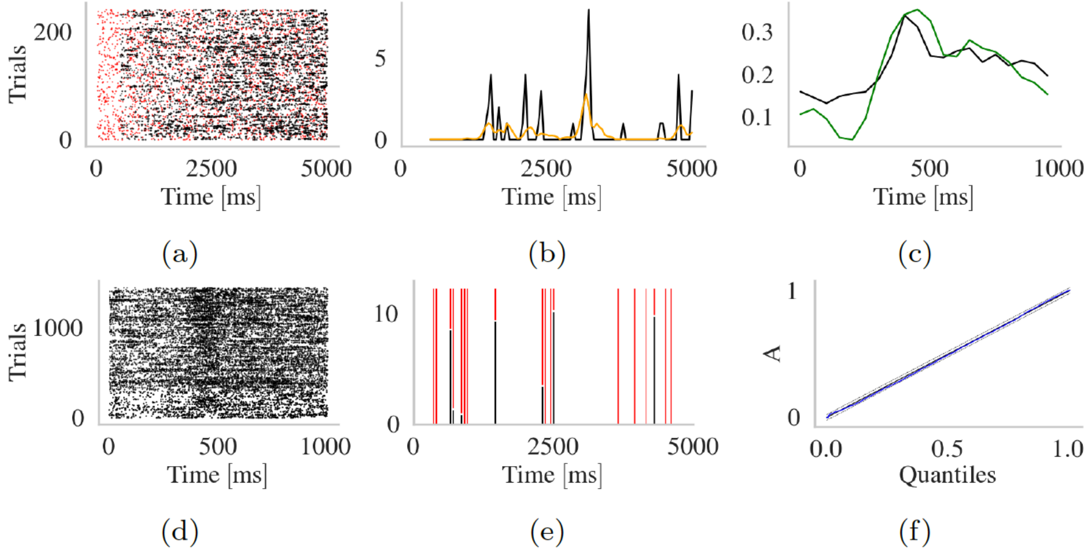
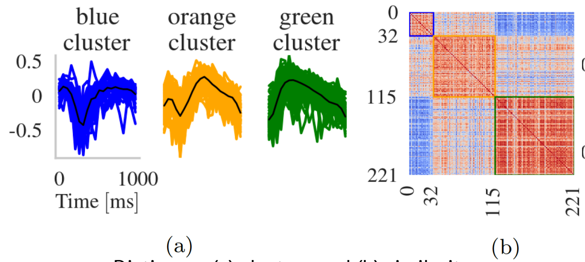
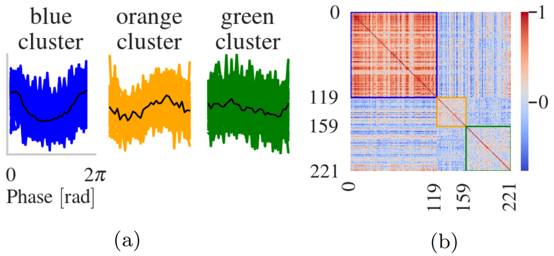


Figure 3. (a) Odors (red) and spikes (black). (b) Spike counts (black) and estimated rate (orange). (c) PSTH of aligned raster (black) and the dictionary (green). (d) Aligned raster given odor onsets. (e) Odor events (red) and the code (black). (f) goodness-of-fit.



Dictionary (a) clusters and (b) similarity.



Breathing phase histogram (a) clusters and (b) similarity.

Abstract