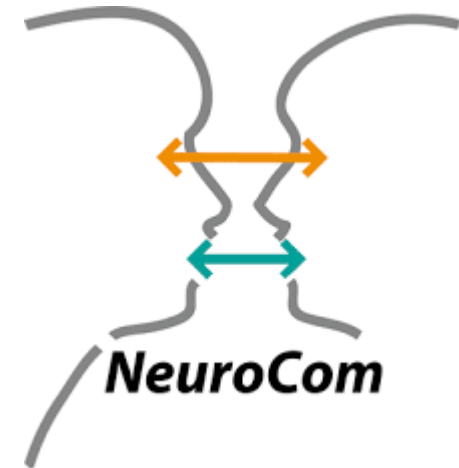# On and Off Responses in Auditory Cortex May Arise from A Two-layer Network with Variable Excitatory and Inhibitory Connections

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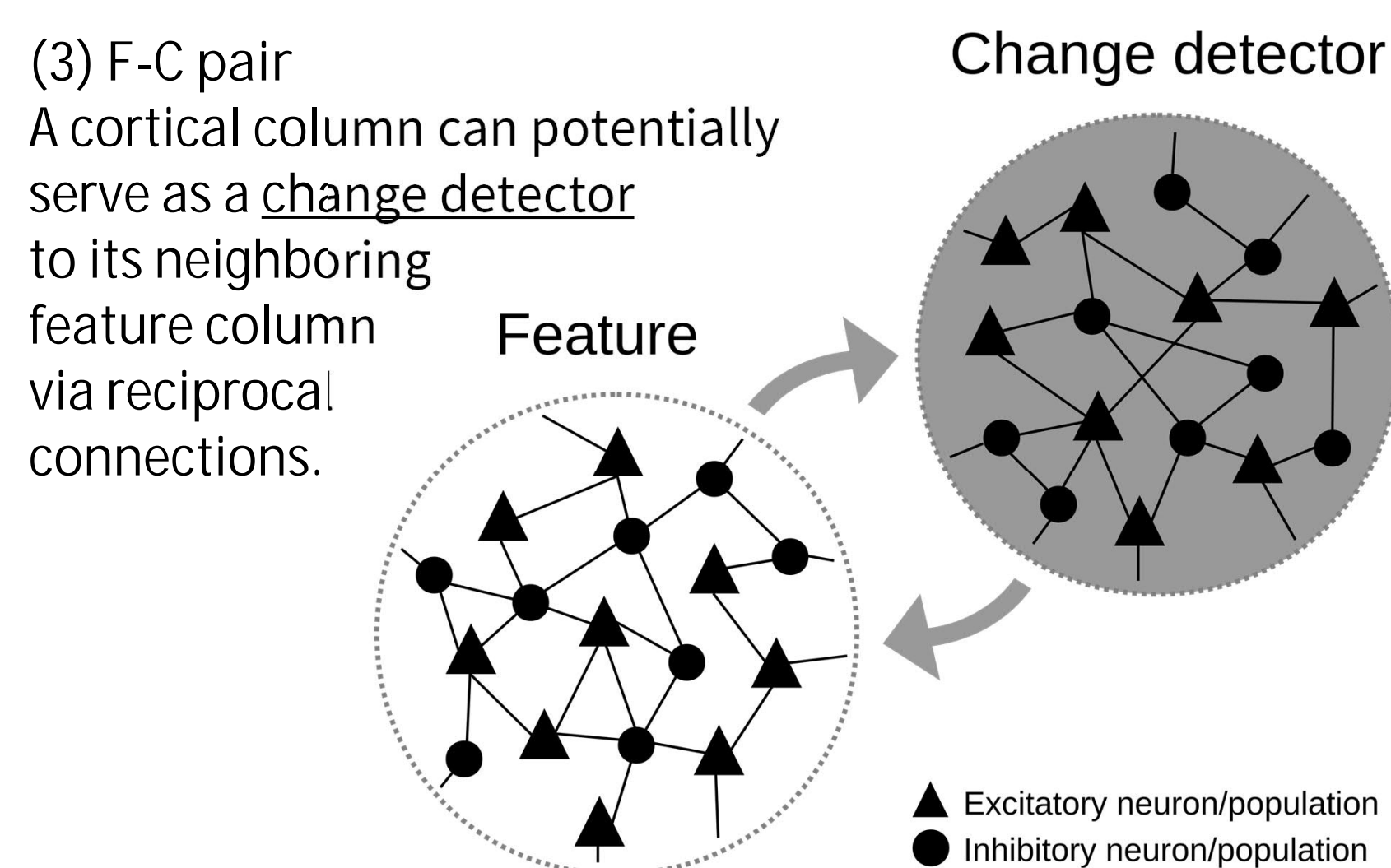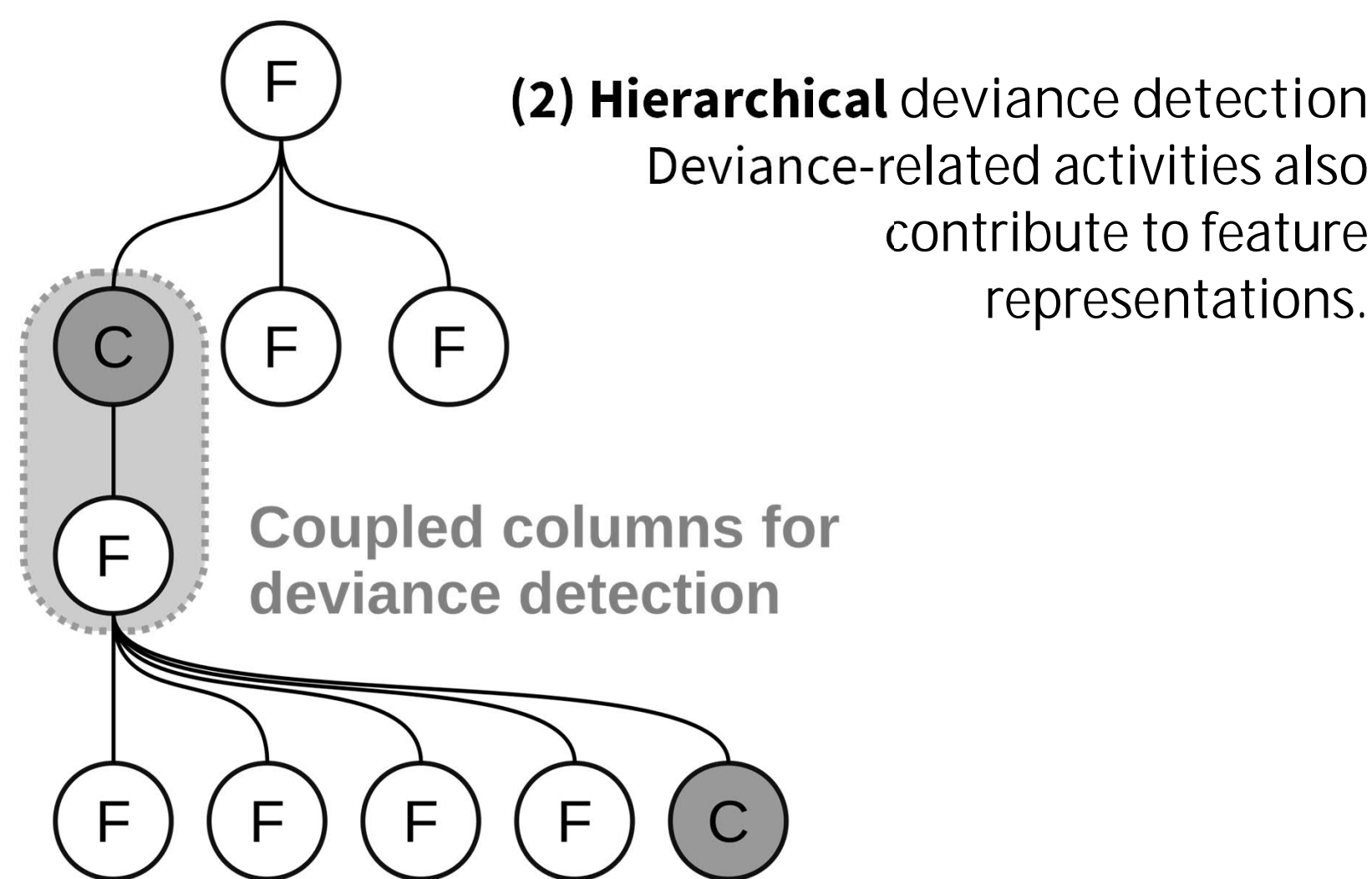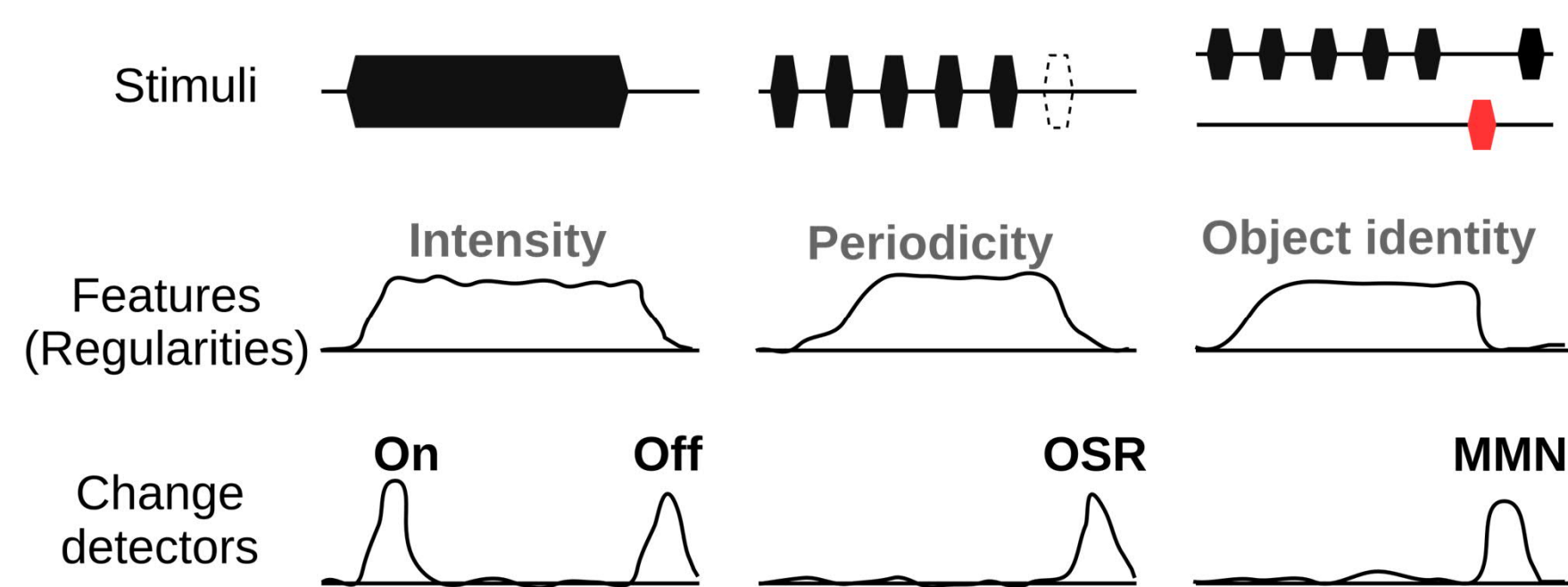
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Introduction

- Deviance detection is a pre-attentive mechanism that causes extra neural activities in response to unexcpected temporal stimulus patterns.

- Deviance-related responses include:
  1. On and Off responses
     – elicited by the onsets and offsets of stimuli
  2. Omitted-stimulus response (OSR)
     – elicited by an unexpected omitted stimulus
  3. Mismatch negativity (MMN)
     – elicited by an infrequent stimulus (or pattern) among regular ones

- Aim: a unifying view of cortical deviance detection.

Hypotheses

(1) Deviance detection = (Feature + Change detection) The stimuli (e.g. prolonged or periodic) lead to steady feature representations (i.e., regularities). The deviance-related responses are the activities of change detectors.

(2) **Hierarchical** deviance detection Deviance-related activities also contribute to feature representations.

Coupled columns for deviance detection

(3) F-C pair A cortical column can potentially serve as a <u>change detector</u> to its neighboring feature column via reciprocal connections.

Change detector

Feature

▲ Excitatory neuron/population
● Inhibitory neuron/population

Methods

Cortical column
- An excitatory (E) and an inhibitory (I) population.
- Fixed intra-column connections.
- Fixed background current to E population.
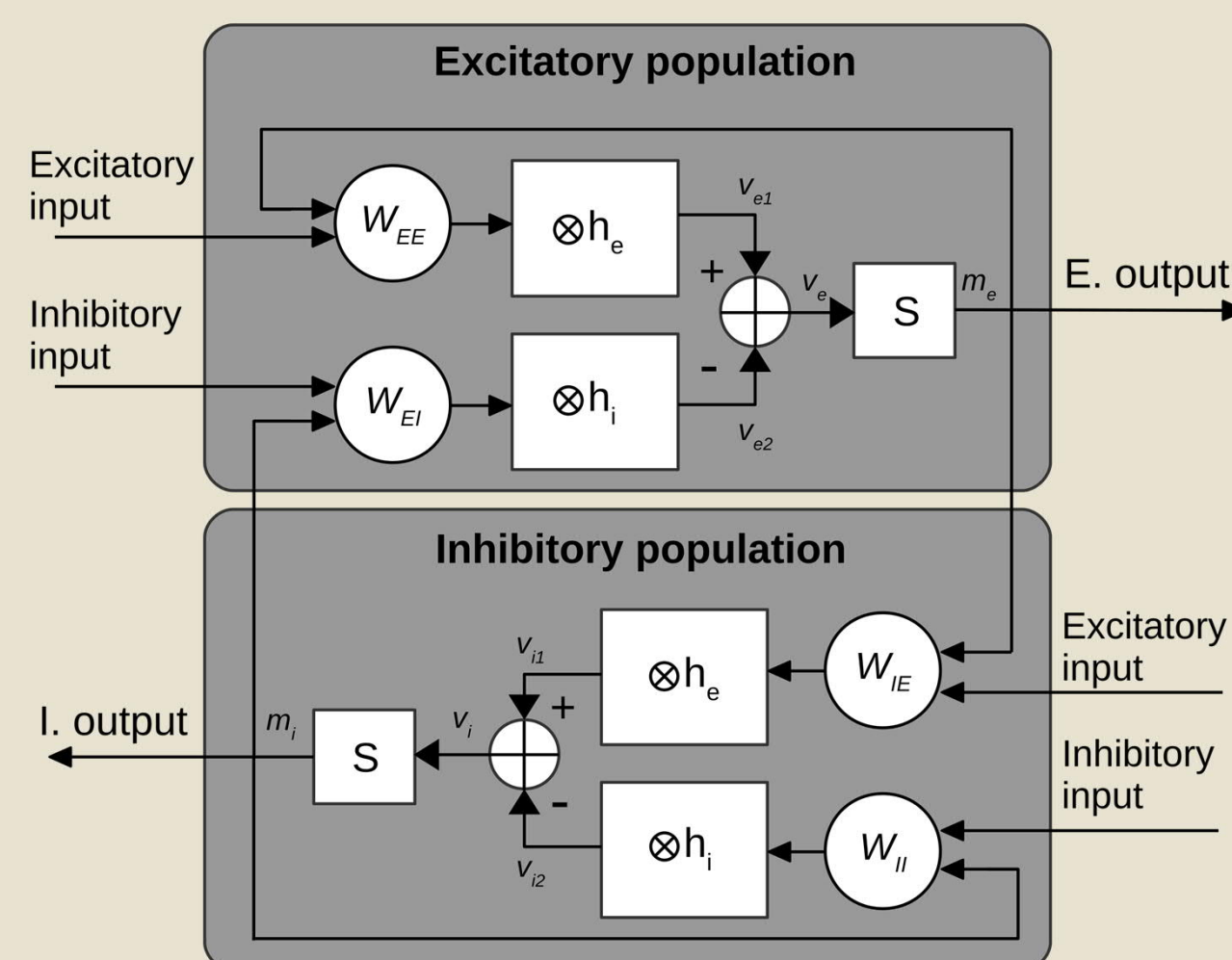
$$h_c(t) = \begin{cases} \dfrac{H_c}{\tau_c} t e^{\frac{-t}{\tau_c}} & t \geq 0 \\ 0 & t < 0 \end{cases}$$
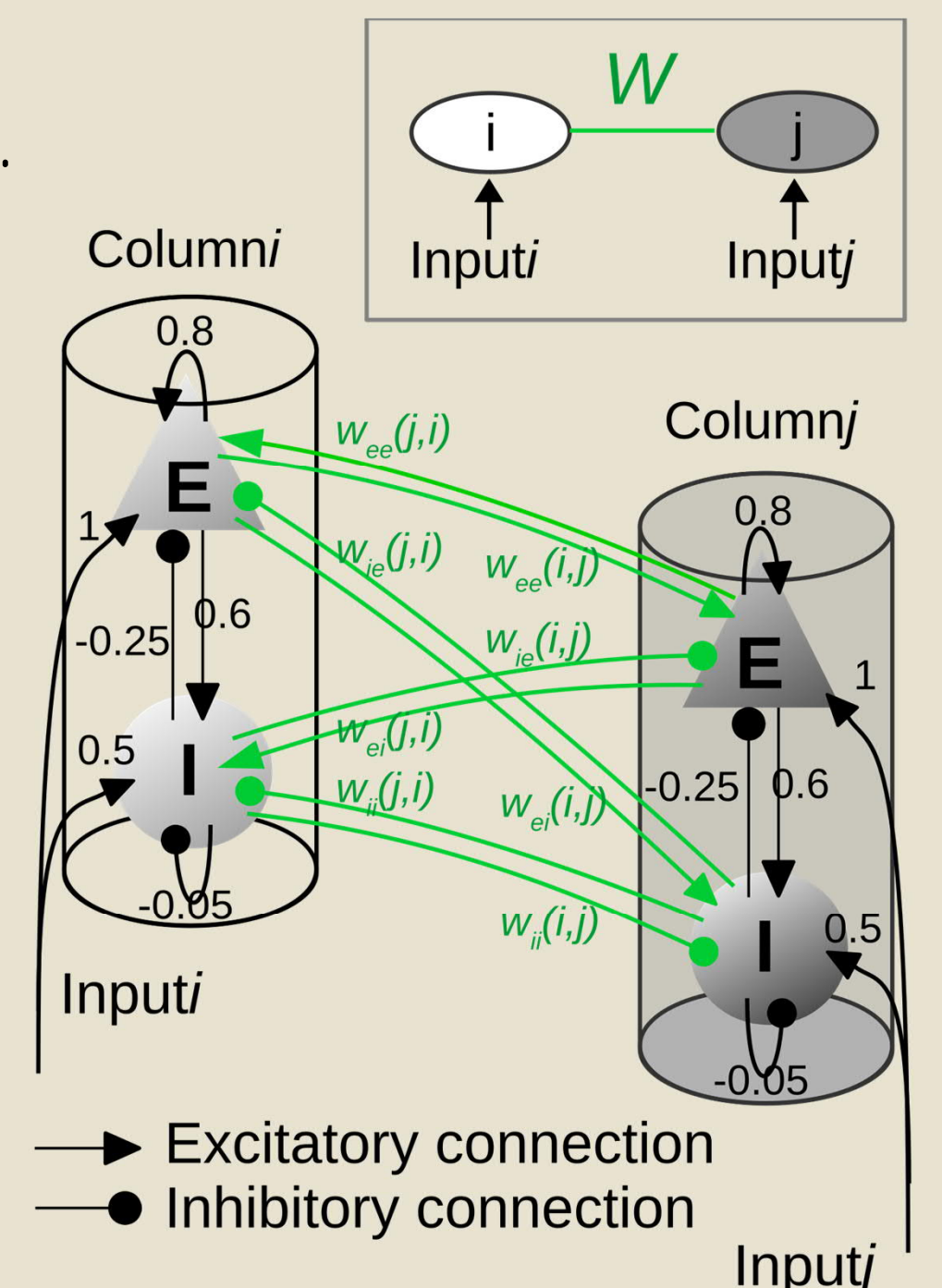
$$S(v(t)) = \frac{2e_0}{1 + e^{r(v_0 - v(t))}}$$

Inter-column connections W
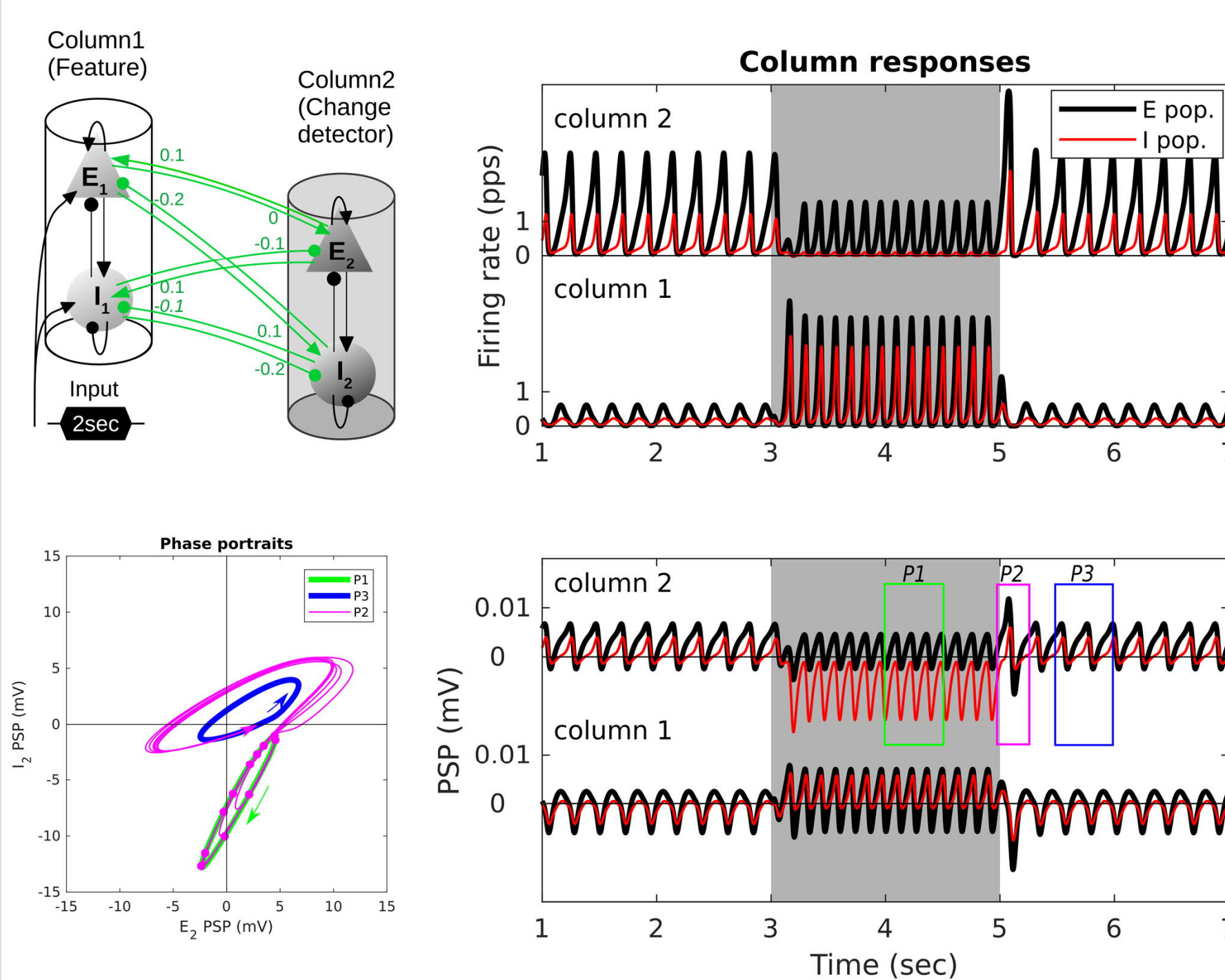- Free parameters (green) in this study.

Inputs
- The inputs are in firing rate.
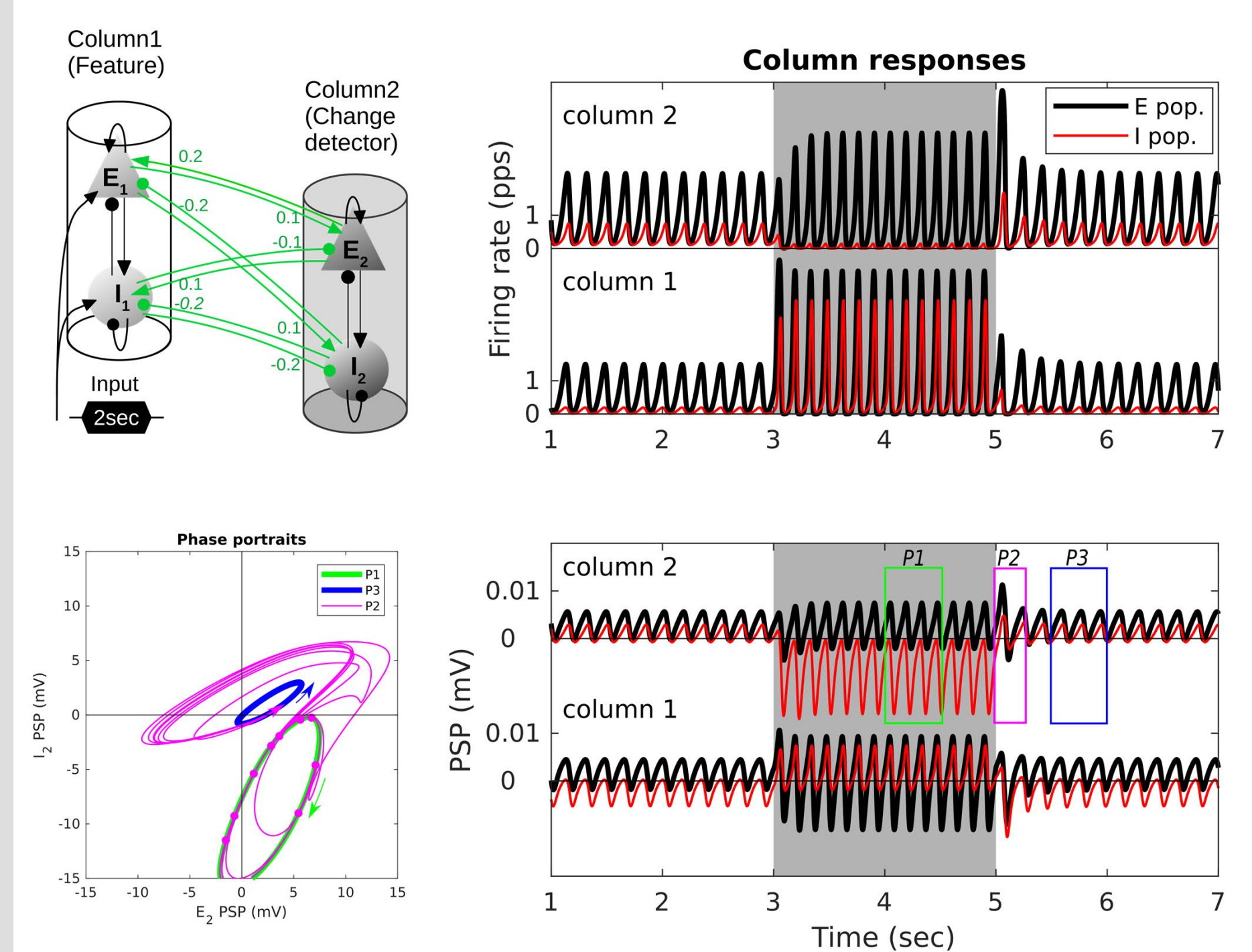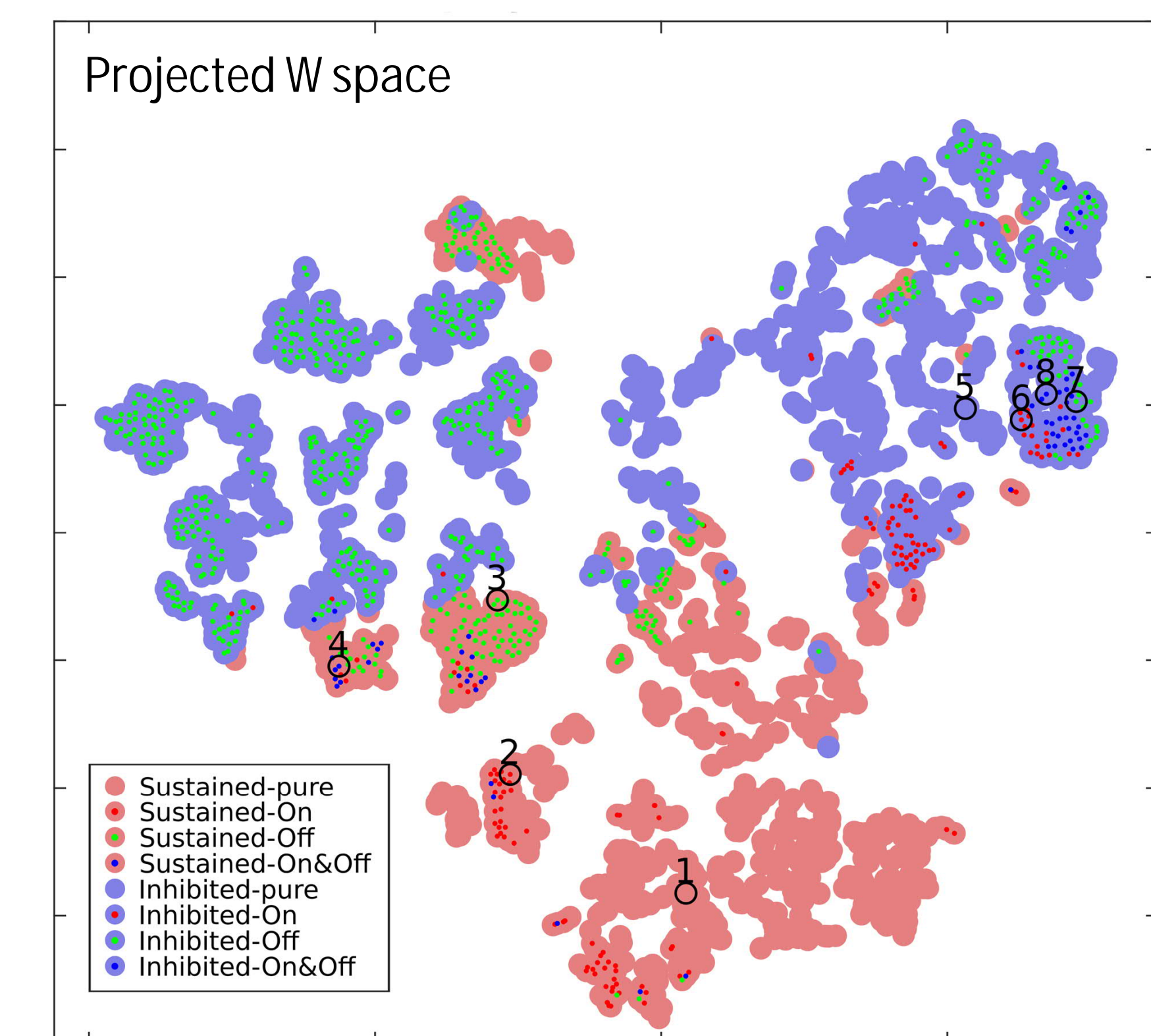- The inputs are fed to the E populations and the I populations (ratio=1: 0.5).

→ Excitatory connection
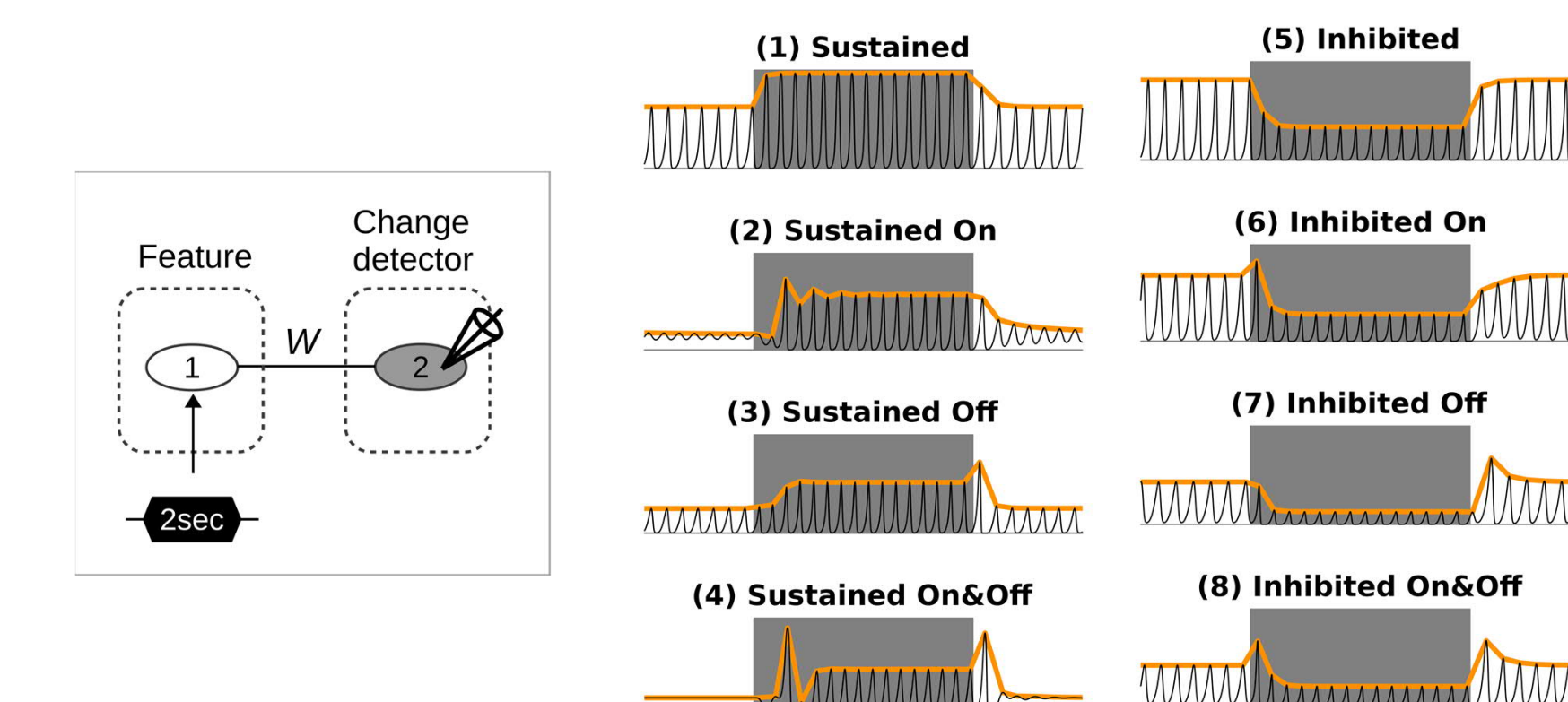● Inhibitory connection

Results

1 Simulation example I: Inhibited-Off response

### 2 Simulation example II: sustained-Off response

3 Diverse On/Off responses (categorized in 8 types)

(1) Sustained
(2) Sustained On
(3) Sustained Off
(4) Sustained On&Off
(5) Inhibited
(6) Inhibited On
(7) Inhibited Off
(8) Inhibited On&Off

Projected W space

- Sustained-pure
- Sustained-On
- Sustained-Off
- Sustained-On&Off
- Inhibited-pure
- Inhibited-On
- Inhibited-Off
- Inhibited-On&Off

By varying W (8 parameters), diverse On/Off responses can be observed in the population E_2. The E_2 responses are catagorized into 8 types, and the corresponding W solutions are projected to the 2D plane for visualization (dimension reduction by Matlab function: t-SNE). Neighboring dots have similar W settings.

4 Onset- and offset-frequency receptive fields (FRFs)

Experimental results by Qin, L., et al. (2007)
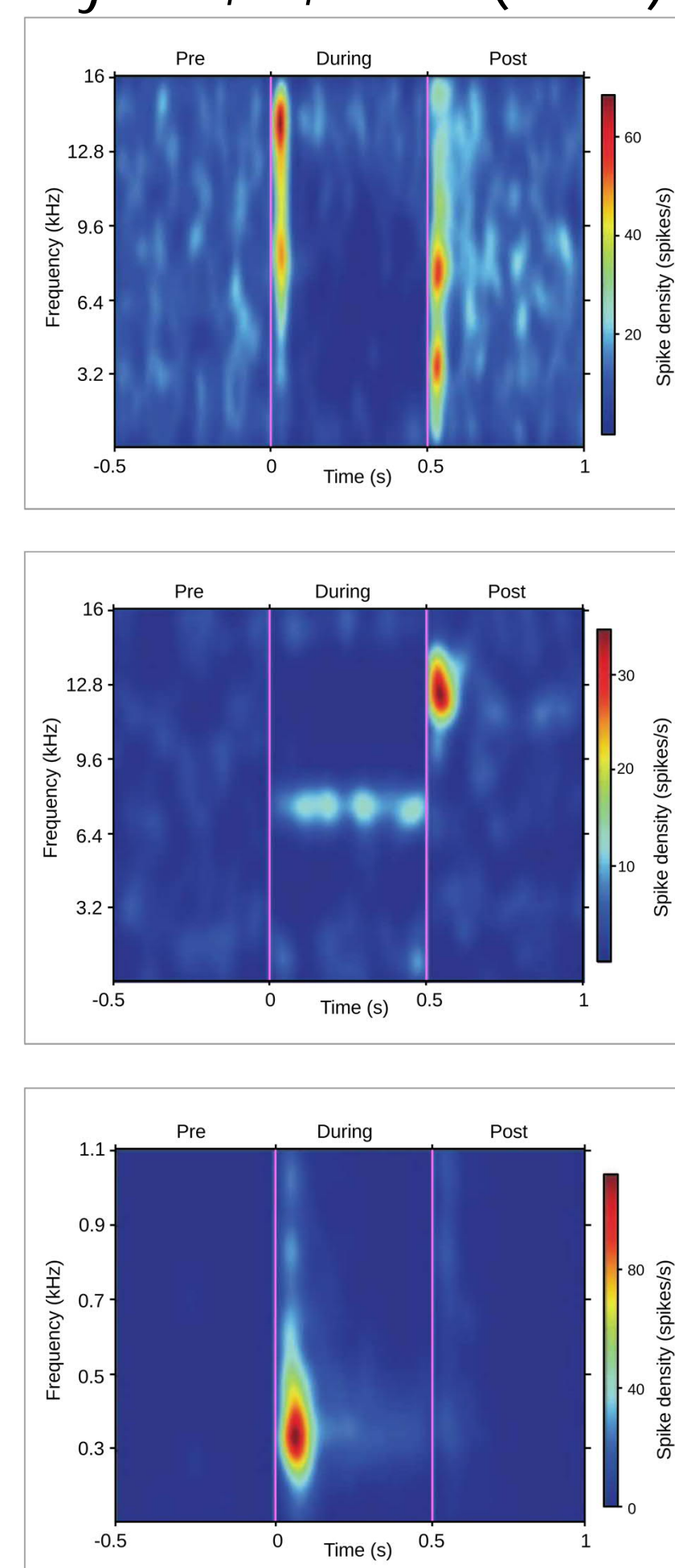
Simulations
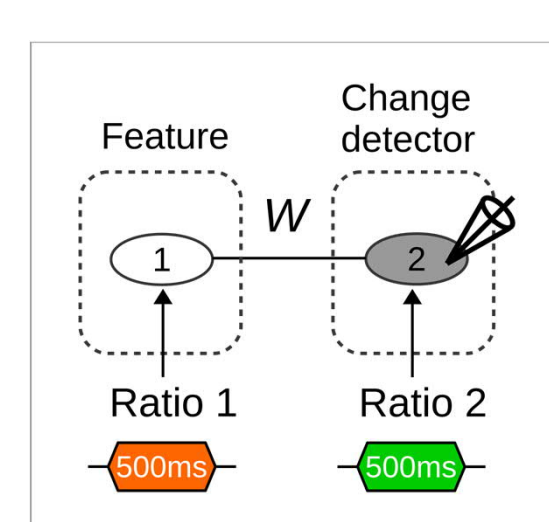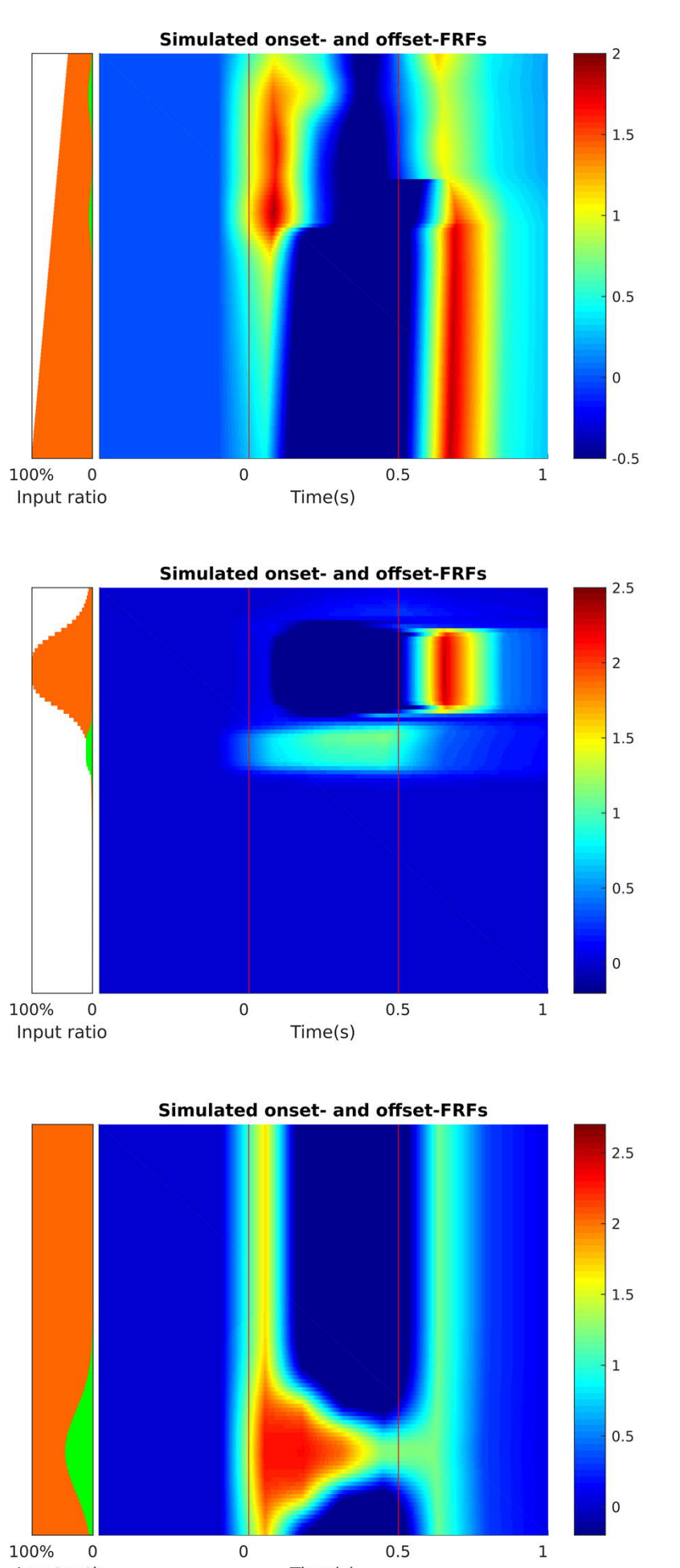
The distinct onset- and offset-FRFs of examplary auditory neurons in [2] can be reproduced by the model. The continuum of tonal stimuli in the y-axis of FRFs is modeled as combinations of two pure tones with different input ratios. The simulated FRFs are generated by choosing proper W and input ratios.

Summary

(Results 1&2)
- The generation of Off responses.
  1. First, strong inhibition on the population I_2.
  2. Then, release of the inhibition on the population I_2. The E_2 activity peaks before I_2 recovers.
- This matches the observation in [1] where the NMDA-r antagonist MK-801 causes disinhibition and reduces the Off responses thereafter. (Note: excitatory synapses on inhibitory neurons are more sensitive to MK-801.)

(Result 3)
- A subtle change in W switches the response type between On, Off, and On&Off.
- The diverse On/Off responses observed at different locations in the auditory cortex [3] may reflect diverse effective connections between the input source and observation spots.

(Result 4)
- Distinct onset- and offset-FRFs observed in A1 neurons in [2] may result from the differential influences of tonal combinations due to the tonotopic arrangement in the auditory cortex.

References

[1] Baba, H., et al. (2016). Auditory cortical field coding long-lasting tonal offsets in mice. Scientific reports, 6, 34421.
[2] Qin, L., et al. (2007) Comparison Between Offset and Onset Responses of Primary Auditory Cortex ON-OFF Neurons in Awake Cats. Journal of Neurophysiology, 97:3421.
[3] Deneux, T., et al. (2016). Temporal asymmetries in auditory coding and perception reflect multi-layered nonlinearities. Nature communications, 7, 12682.