Learning opposite neurons in a firing rate-based model

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Introduction

- Opposite neurons are found in brain areas (MSTd and VIP) responsible for integration of visual and vestibular self-motion cues.
- Opposite neurons combine opposite information, for example a rightward vestibular motion cue and a leftward visual motion cue.
- This is in contrast to congruent neurons, also found in the same areas, that combine congruent information and perform multisensory integration.
- While congruent neurons can be learned easily with Hebbian learning, the same cannot be said for opposite neurons. We show that our model can learn these opposite neurons.

Methodology

Model architecture and dynamics

- Our model consists of:
  - two sensory inputs S1 and S2
  - congruent neurons C
  - opposite neurons O
- Neurons lie on a 1D ring indexed by angle \( \theta \).
- Recurrent connections are fixed, but feedforward connections (both excitatory and inhibitory) have the following learning rule
  \[
  \tau \frac{dw_{ij}}{dt} = r_i (r_j - aw_{ij})
  \]
  where \( w_{ij} \) is the weight of a connection from neuron \( j \) to neuron \( i \), and \( r_i \) is the firing rate of neuron \( i \).

Mechanism of opposite tuning

- Orange line: Spontaneous activity of the ring of opposite neurons.
- Red line: S2 input at angle \( \theta \) inhibits opposite neurons at \( \theta \).
- Green line: Recurrent excitation and divisive normalizations result in a bump of activity at \( \theta + 180^\circ \). Thus tuning to S1 and S2 is opposite.

Learned feedforward weights are approximately von-Mises

- Feedforward weights of 10 evenly-spaced opposite neurons. Blue lines are their feedforward weights, which are fitted with von-Mises distribution.
- Left: excitatory connections from S1 to O. Right: inhibitory connections from C to O.
- Von-Mises distribution is a good fit for the shape of feedforward weights.

Results

Opposite neuron tuning is “contrast-invariant”

- Change in tuning of an opposite neuron as reliability of S1/S2 input decreases.
- Color labelling of input reliability: blue - 100%, orange - 80%, green - 60%, red - 40%, purple - 20%, brown - 0%. Left: tuning to S1. Right: tuning to S2.
- For both S1 and S2, decrease in input reliability decreases peak-to-peak amplitude of tuning response, but tuning width is invariant to input reliability, agreeing with experimental observations.

Discussion

Summary

- Using biologically realistic learning rules, our firing rate-based model can successfully learn opposite neurons with von Mises-shaped feedforward weights, and preserves topographical organization of input.
- Our opposite neurons learn the correct opposite tuning. Change in tuning in response to change in input reliability agrees with experimental observations.

Future directions

- Information segregation with opposite neurons: Opposite neurons are hypothesized to be involved in segregating multisensory information in MSTd. Both theoretical analysis and computational modelling are needed to examine this hypothesis.
- Derivation of learning rules: While the Hebbian learning rule used is widely accepted, it is instructive to derive the rule we used from some objection function in order to understand the computational role of opposite neurons.

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