Invariant selectivity of auditory neurons due to predictive coding

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Results

Learning predictive fields from natural stimuli
• Online Expectation-Maximization algorithm

Network effect on a single neuron
How does a model neuron’s STRF change with network activity?

Modeling of auditory neuronal data
We use decoding filters obtained from neuronal data 1 as an approximation to predictive fields and employ the model to predict neuronal responses

Introduction

What do auditory neurons represent?
• Spectro-temporal receptive field (STRF) is the interpretation of auditory neurons as linear filters. 2
• We propose that auditory neurons are selective rather than filters of their input and we hypothesize that they have a “true selectivity” independent of stimulus context. 3

A predictive coding model for auditory neurons
• We propose a dynamic Bayesian inference model and train it on a large database of natural speech to predict this invariant selectivity, i.e. predictive fields (PFs).
• The model can account for nonlinear contextual effects such as two-tone and forward suppression.
• The model neurons adapt rapidly to new input statistics (such as behaviorally relevant tones).
• The model can be used to explain neuronal and behavioral responses.

Background

Explaining Away: Dealing with overlapping stimuli

Model

• Feature detectors predict the sensory stimuli using the generative model.
• Input from the receptors (predictive fields, PF) are divided 4 by the prediction from other neurons (receptive fields, RF).
• The dynamics is given by a Hidden Markov Model.

A dynamic Bayesian inference model

Discussion

A normative approach to auditory coding
• We derive an optimal inference model where auditory neurons predict their input.
• Each neuron is selective to specific invariant features (PFs).
• We learn these features by training the model on speech data.
• PFs are strongly overlapping and highly structured as opposed to STRFs which are narrow band-pass filters.

Modeling of complex neuronal responses
• Decoding filters obtained from auditory data are qualitatively similar to predictive fields trained on speech data.
• This predicts that auditory responses are shaped as much by other neurons’ responses and selectivity as by the stimulus itself.
• This accounts for the strong inhibitory lobes in STRFs and high temporal precision of neural responses.

References

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Encoding filters (STRF)
Decoding filters (predictive fields)

Encoding: temporal precision of neural stimuli
After
\( f \) frequency
Predictive fields (PFs)
STRF is not a good predictor of model neuron

Decoding: encoding of natural stimuli
Before
\( f \) frequency
Average in time to get predictive fields

Model fit to neural data
• Fit of a model neuron (blue) to a single neuron data (black): \( c = 0.43 \).
• Much better fit (blue vs. red) when there are more neurons in the network.

Simulation of tone
Before
\( f \) frequency
After
40 sec of tone

Neuron x explains away the 2kHz + 1kHz combination and suppresses y.

Reconstruction of speech by model responses

• Predictive fields tuned to speech rapidly adapt to tone stimulation which causes specific changes in their STRFs.

Before
\( f \) frequency
After

36 - neuron case

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