The Retina Predicts Information in Inertial Stochastic Dynamics

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Introduction

- Visual stimuli are first received by the retina, but the processing of visual signals begins first at the retina, instead of the visual cortex [1].
- In experiments on the salamander retina, the mutual information between the visual signals and the responses of the retina with various time differences showed that responses of the retina actually have correlations with subsequent visual inputs [2].
- Not only can the retina transmit information, but it can also anticipate future signals based on what it has received.
- Experiments on the bullfrog retina showed that visual stimuli generated by Hidden Markov Model (HMM) and Ornstein-Uhlenbeck (OU) process resulted in different behaviors [3].
- To model these predictive behaviors, we propose a neural network model to simulate the dynamics of the amacrine cells and ganglion cells [4].

Neural Network Model

\[ U(x,t) = g(x,t) \]

\[ g(x,t) = \exp(-\lambda t) \int_{-\infty}^{t} dt' K(x-x', t-t') \]

Firing rates of ganglion cells

\[ r(x) = \text{ReLU}(U(x,t)) \]

Simulations

We calculated the mutual information between the inputs and the responses (firing rates) of the neural network at different time separations.

\[ x_{2}: \text{Input Positions} \]

\[ \text{HMM (Hidden Markov model)} \]

\[ x_{t+\Delta t} = x_{t} + \eta \Delta t + \xi \sqrt{\Delta t} \]

\[ \text{OU (Ornstein-Uhlenbeck) Process} \]

\[ x_{t+\Delta t} = (1 - \theta \Delta t) x_{t} + \xi \sqrt{\Delta t} \]

Experiment

- Sample: Retina of Bullfrog
- Condition:
  - Room temperature
  - Ringer’s solution
- MEA: electrode size 10 \( \mu \)m
- Stimulation:
  - Moving Bar
    - Video refresh rate: 60 Hz
    - 1 pixel \( \sim 2.8 \) \( \mu \)m on retina
    - Bar luminance: \( 1.47 - 3.7 \) mW/m\(^2\) with \( \sim 100\% \) contrast

MEA provides recording of field potentials from a population of neurons.

Conclusions

- Our model agrees with experiments well (Figs. 1 and 3).
- When the correlation time \( \tau \) increases, the prediction effect becomes more and more prominent for HMM.
- In HMM, the predictive ability is strongest at the arms of the damped harmonic oscillator, where the dynamics can be predicted from its inertia (momentum) (Fig. 2).
- The inertial behavior in the retina is achieved by the local inhibition of the amacrine cells, as the response is weaker in the tail part of a continuously moving stimulus.
- There is no predictive behavior in OU process as it is not inertial.

References


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