A Modelling study on the discrimination of visual motion patterns

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Recently, there is much attention on the decision-making processes which link perception and action. A series of experiments have been carried out, where monkeys are presented with patterns of a set of moving dots. A fraction of the dots are moving in an identical direction, and the monkey is asked to make a quick eye movement to indicate that direction. It is possible to predict the eye movement of the monkey based on the recorded activity of individual neurons. The neurons in the lateral intraparietal cortex (LIP) and prefrontal cortex are identified as the 'decision neurons'. In addition, similar findings are reported for the decision-making based upon tactile, smell and sound stimuli.

We propose a novel, modelling approach to investigating how different input signals can be discriminated by single neurons. For the aforementioned visual stimuli, we model the moving direction of each dot with a firing rate of a Poisson Process and study the neuronal responses to such synaptic inputs. It is found that the neuron can definitely tell the different inputs as long as the dot coherence in the input exceeds a critical value, in agreement with the experimental data. In addition, the inhibitory synaptic inputs may help neurons more easily discriminate signals. Theoretical arguments, based on the Integrate-and-Fire model, are presented to elucidate the observed phenomena. A detailed dynamical analyse is also carried out via numerical simulations. The firing rate, the interspike interval histogram (ISIH), the coefficient of variation in ISIs, and the power spectrum are introduced to measure neural responses.

To further explore the neural responses in visual discrimination tasks, we assume that the firing rate of Poisson process is modulated by a cosinusoidal signal and model the moving directions with different frequencies. The efferent firing rate r of the neuron is modulated by the stimulus frequency. There exist two different frequency ranges: 20-60 and 60-150 Hz. For the former r is nearly equal to the afferent frequency, whereas for the latter r is largely reduced. It is shown that the neuron can more effectively discriminate such input patterns than with the static stimuli. This implies that more dynamic stimuli may evoke better performance of neurons, at least on the discrimination task.

A more challenging task is to model the visual system involving the discrimination task. By this we mean that the natural stimuli, such as the patterns of moving dots, are presented to a neuronal network model, rather than simply assuming that the single neuron receives Poisson distributed synaptic inputs. A three-layer BP network model is constructed to pre-process the input patterns. After learning the whole system can indeed tell between different moving patterns. Both the histograms of the firing rate and the coefficient of variation in ISIs of the output neuron exhibit the results similar to the experimental observations.

In summary, our modelling study provides us with a 'template' for further exploring the decision-making mechanisms and other related illuminating issues.