From chemical kinetics to spikes: an adaptive LIF model of olfactory receptor neurons

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Olfactory receptor neurons (ORNs) are cells specialized to detect and encode the presence, nature and concentration of odors in their environment. They convert the olfactory signal in a sequence of biochemical and electrical events, called *transduction*, resulting in a train of action potentials (spikes). This process includes chemical reactions in which odorants bind to receptors and activate them, the activated receptors then trigger opening of ion channels. The evolution of membrane conductance resulting from the odorant-triggered channel opening requires a tailored modeling approach.

Biophysical modeling of ORN neurons has substantially developed in last decades. There are detailed biophysical models describing receptor activation and transduction processes taking place at receptor sites (e.g. [1, 2]). The aim of these models is to describe the receptor potential. Other models are based on a simplified scheme of chemical processes and take into account also the propagation of the receptor potential to the soma (e.g. [3, 4]). Nevertheless, these highly complex models are too complicated for studying ORN spiking activity, especially its dynamics.

We constructed a simple model, aiming to reproduce the typical phasic-tonic response of moth ORNs to constant stimulation. The model is based on a simplified chemical kinetics describing receptor activation and opening of ion channels. The number of open channels is proportional to the stimulus-evoked conductance, which is incorporated in the standard leaky integrate-and-fire model [5]. An essential part of the model is the adaptive threshold [6] that is necessary for achieving a peak in the neuronal firing rate. Basic properties of the model, such as the dynamics of the stimulus-evoked conductance and the steady-state behavior, are studied.

Fitting the model to average responses of ORNs obtained from extracellular recordings in moth shows that the model can mimic the ORN firing rate across several magnitudes of odorant concentration. The model works also surprisingly well in reproducing responses of single neurons to intermittent random stimulation. Moth ORNs are highly heterogeneous [7], therefore the key parameters of the model are adjusted for each particular cell. We analyze which parameter of the model governs the specific part of a neuron's behavior and compare the heterogeneity of responses predicted by the model with experimental observations.

References

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