Computational Modelling of Early Olfactory Processing

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Abstract

Chemical sensing is believed to be the oldest sensory ability. The chemical senses, olfaction and gustation, developed to detect and analyze information in the form of air- or waterborne chemicals, to find food and mates, and to avoid danger. The organization of the olfactory system follows the same principles in almost all living animals, insects as well as mammals. Likely, the similarities are due to parallel evolution – the same type of organisation seems to have arisen more than once. Therefore, the olfactory system is often assumed to be close to optimally designed for its tasks. Paradoxically, the workings of the olfactory system are not yet well known, although several milestone discoveries have been made during the last decades. The most well-known is probably the discovery of the olfactory receptor gene family, announced in 1991 by Linda Buck and Richard Axel. For this and subsequent work, they were awarded a Nobel Prize Award in 2004. This achievement has been of immense value for both experimentalists and theorists, and forms the basis of the current understanding of olfaction. The olfactory system has long been a focus for scientific interest within several fields, both experimental and theoretical, and it has often been used as a model system. And ever since the field of computational neuroscience was founded, the functions of the olfactory system have been investigated through computational modelling. In this thesis, I present several approaches to biologically realistic computational models of parts of the olfactory system, with an emphasis on the earlier stages of the vertebrate olfactory system – olfactory receptor neurons (ORNs) and the olfactory bulb (OB). I have investigated the behaviour of the enzyme CaMKII, which is known to be critical for olfactory adaptation (suppression of constant odour stimuli) in the ORN, using a biochemical model. By constructing several OB models of different size, I have shown that the size of the OB network has an impact on its ability to process noisy information. Taking into account the reported variability of geometrical, electrical and receptor-dependent neuronal characteristics, I have been able to model the frequency response of a population of ORNs. I have used this model to find the key properties that govern most of the ORN population’s response, and investigated some of the possible implications of these key properties in subsequent studies of the ORN population and the OB – what we call the fuzzy concentration coding hypothesis.

Key Words

olfaction, olfactory system, olfactory bulb, olfactory receptor neuron, synchronization, CaMKII, mathematical modelling