Efficiency in Olfactory Information Processing

Hans Liljenström
Dept of Biometry and Engineering, SLU, Uppsala, Sweden
Agora for Biosystems, Sigtuna, Sweden
hans.liljenstrom@bt.slu.se

The olfactory systems of insects and certain mammals (in particular rodents) are essential for the search of food and mates. Weak signals, and in some cases, single odorous molecules, can be detected, amplified and discriminated in a fluctuating environment. The olfactory systems of these animals also allow for learning and recall of odor memories.

Presumably, the nonlinear dynamics of these neural structures reflect an evolutionary pressure to make the information processing as efficient as possible. Oscillations could amplify weak signals and sustain an input pattern for more accurate information processing, and a chaotic-like behavior could increase the sensitivity in initial, exploratory states. Neuronal noise can modify the signal, and can perhaps even have a constructive and controlling role.

Based on the anatomy of the insect antennal lobe and of the mammalian olfactory cortex, we have developed computational models that mimic the structure, dynamics and function of these systems. For the insect olfactory system, where single or a few neurons and action potentials could be of importance, we model several glomerular networks in the antennal lobe, using spiking Hodgkin-Huxley type of neuron models. For the mammalian system, where it is likely that a large number of neurons and pulses are involved in all odor information processing, we model the three-layered structure of the olfactory cortex, using network nodes with continuous input-output neurons, representing population of cells and a mean firing frequency.

We use these models to investigate how the neural information processing can become efficient under various conditions and with different network properties. We compare the insect pheromone system with the more complex odor detection system of mammalian olfaction. In particular, we investigate how weak signals can be amplified and discriminated, and how different odors can be learnt and recognized in these different olfactory systems.

We study the role of oscillations and fluctuations for an efficient information processing of these systems. We also investigate how different structures can give synchronous oscillations and how noise can either be suppressed, or used to enhance weak signals. The models clearly demonstrate stochastic resonance phenomena in detecting weak signals. Certain glomerular network structures can effectively suppress noise and enhance the signals, while other glomerular network structures can induce synchronous oscillation during noise stimulus.

We also demonstrate how spatio-temporal activity patterns induced by odorous input to the mammalian system can be controlled by neuromodulators. By regulating the network dynamics, shifting between a noisy or chaotic-like dynamics and a more regular oscillatory behavior, learning and memory can become more efficient. Further, for certain optimal noise levels, system performance can be maximized, analogous to stochastic resonance phenomena. and result in an efficient recognition and associative memory.