Odor-driven Calcium Dynamics in the Antennal Lobe of the Honeybee: A Hypothesis about the Olfactory Code

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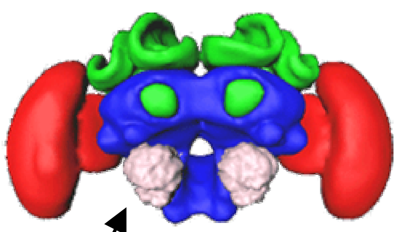
Introduction: The olfactory receptor-neurons located in the antennae transduce chemical signals into neural activity and relay this information into the antennal lobe (Fig.1). There are two types of neurons in the antennal lobe, interneurons and projection neurons, which form substructures called glomeruli (Fig.2). The projection neurons relay chemosensory information mainly to the Kenyon cells in the mushroom bodies (Fig.1). We study how odors are encoded in the neural activity of the antennal lobe and provide a model to explain how the code is deciphered by the mushroom bodies.

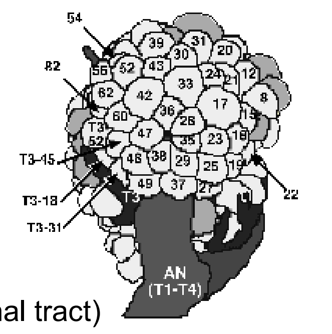
Fig. 1: Frontal view of the Bee Brain

Mushroom Body



Antennal Lobe (shown without the antennal tract)

Fig. 2: Magnified Antennal Lobe and Glomerular Identity



Multidimensional Representation of Network Dynamics: Odors elicit spatial and temporal patterns of active glomeruli in the antennal lobe. The patterns of neural activity can be represented as trajectories in a multidimensional space (Fig.3), where each dimension accounts for the averaged neural activity of the projection neurons in a single glomerulus recorded with calcium-imaging. The trajectories converge to odor-specific regions (attractors) after approx. one second, when the velocity of the trajectories reaches a minimum (Fig.4) and they remain in those regions until stimulation is over.

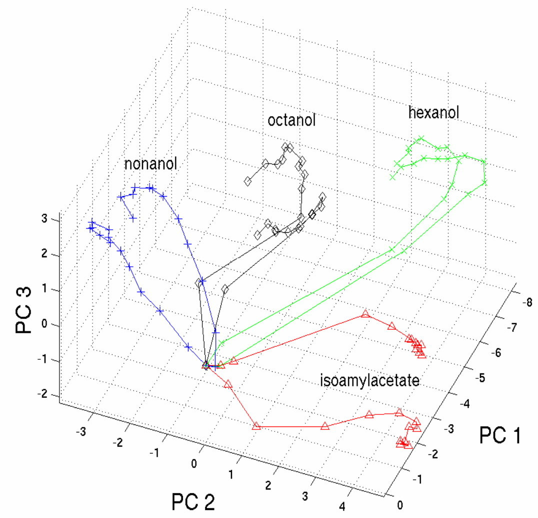


Fig. 3: Odor specific trajectories described by the antennal-lobe dynamics during stimulation. Different odors drive the antennal lobe to different regions (attractors). The original 8 dimensional space has been projected onto the first three principal components to allow the visualization (sampling frequency: 6Hz).

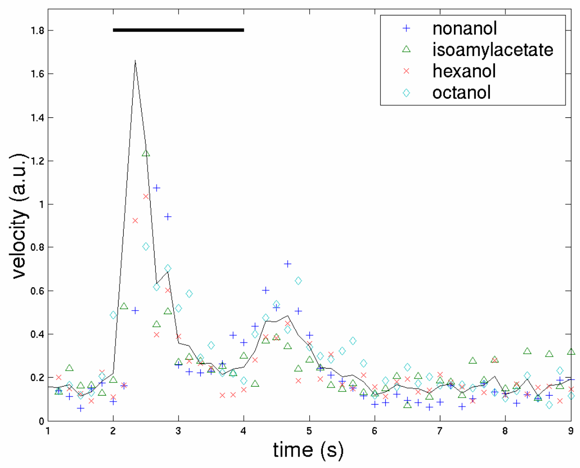


Fig. 4: Instantaneous averaged velocity. For each odor the velocity increases rapidly after stimulus onset, reaches a maximum after approximately half a second and falls to a minimum value after approximately one second, when the antennal lobe settles down in an odor specific region (attractor).

Readout Mechanismus of a Downstream Network: The interaction between antennal lobe and mushroom body can be regarded as a biological implementation (Fig.5) of a support-vector machine (SVM). A SVM is an algorithm to discriminate data points of two different classes (Fig.6). It is a mathematical extension of the perceptron.

if $\sum_{n}^{N} w_{An} \cdot x_n = \vec{w}_A \cdot \vec{x} > b$, then $\vec{x}$ reponds to A, otherwise it does not.

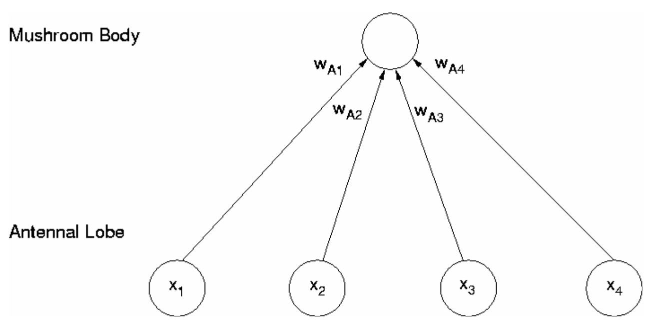
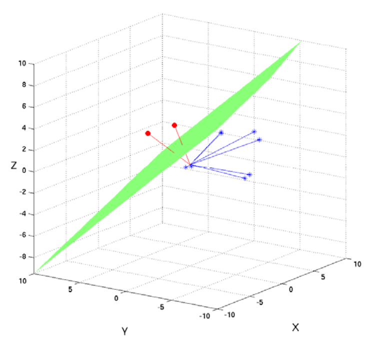


Fig. 5: Biological implementation of the readout mechanism (left) and its geometrical interpretation (right). After two repetitions of several odors, the plane separates the points that correspond to odor A (red) from those that do not encode that odor (blue).



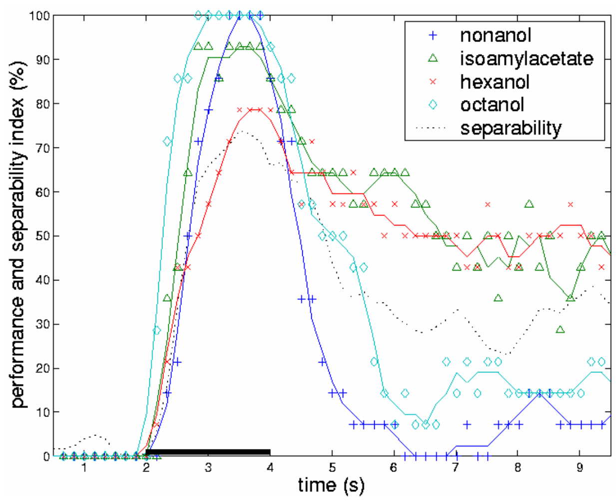


Fig. 6: Separability and Classification Performance. The separability quantifies the reliability of the partition of the antennal-lobe space into odor-specific regions at each time point. It reaches a maximum after approx. one second, when the network dynamics reaches the odor-specific attractors. At this point in time a support-vector machine (SVM) is trained for each odor. Then the ability of the SVMs to classify odors correctly is quantified at each point in time by the classification performance. Note that although the SVM was trained to optimally discriminate the attractors (one second after stimulus onset), it can already recognize the odors much earlier as shown by the pronounced increase of the classification performance.