Modeling a biologically realistic microcircuit of the *Drosophila* mushroom body calyx

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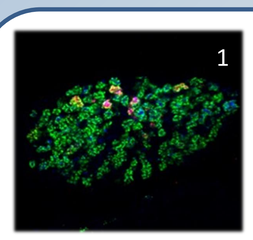
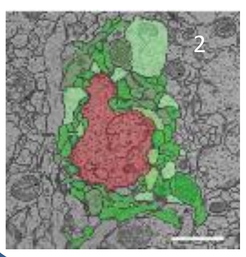




Introduction

The mushroom body (MB) of the *Drosophila melanogaster* is a central brain neuropil that integrates primarily olfactory sensations. Kenyon cells (KC) are the principal neurons of the MB and constitute the third layer of the olfactory pathway. The MB input region, the calyx, is organized in microglomeruli (MG, cf. figure 1). Each MG constitutes a recurrent microcircuit of high synaptic density (cf. figure 2) [1,2,3,4,5]. It involves recurrent connections between one central large bouton of a single projection neuron (PN, providing excitatory olfactory input from the antennal lobe), the primarily postsynaptic Kenyon Cells (KCs, the excitatory intrinsic neurons of the MB) and the inhibitory anterior-paired lateral neuron (APL). Based on the detailed structural data from a fly connectome [6] (cf. figure 3) the aim is to implement a biologically realistic MG- model with a focus on local computation in a single MG through the inhibitory APL neuron, which we hypothesize to be non-spiking.

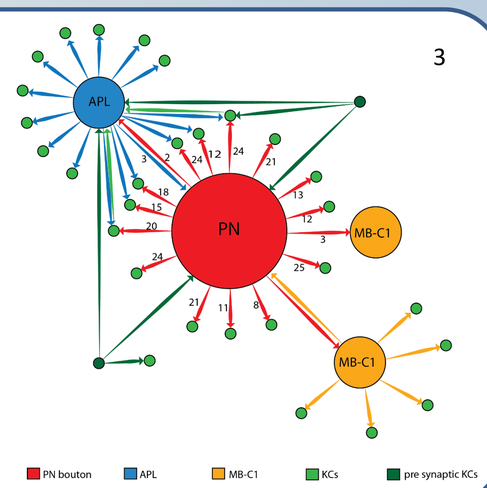
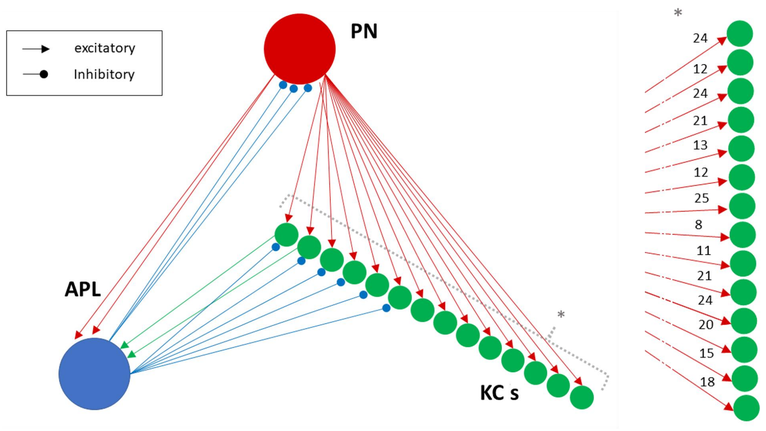


Figure 1,2,3 provided by G.Tavosanis

Model

Connectome



The model consists of 15 excitatory spiking neurons (1 PN, 14 KCs) and 1 inhibitory non-spiking APL neuron. Left: Connectome with all excitatory and inhibitory connections found. Right: Number of synaptic contacts between PN bouton and individual KCs.

The model is realised in Brian2, a python extension package, which works equation based.

Neuron Model

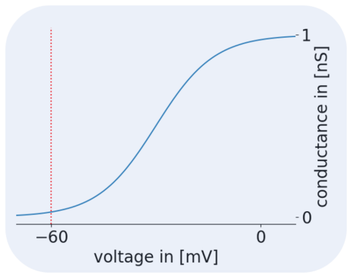
A leaky integrate-and-fire neuron model was used together with conductance-based synapses. Based on a fire-and-reset rule a spike is elicited at -40/ -50 mV in PN/ KC, followed by a reset of the membrane potential to -70 mV. The APL neuron is non-spiking and the conductance of its synapses depends on the membrane potential of the APL neuron (blue box). For the KCs a spike frequency adaption mechanism was introduced by adding an adaption current (green).

PN $$C_m^{PN}\frac{d}{dt}v = g^L(E_L - v) - g^{APL}(E_i - v)$$

APL $$C_m^{APL}\frac{d}{dt}v = g^L(E_L - v) + g^{PN}(E_E - v) + g^{KC}(E_E - v)$$

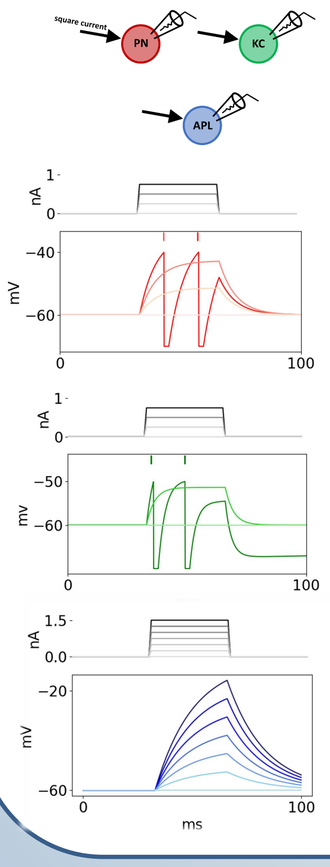
KC $$C_m^{KC}\frac{d}{dt}v = g^L(E_L - v) + g^{PN}(E_E - v) - g^{APL}(E_I - v) - g^A(E_A - v)$$

Cm : membrane capacitance *v : voltage* *g : conductance* *E : reversal potential* *adaption current*

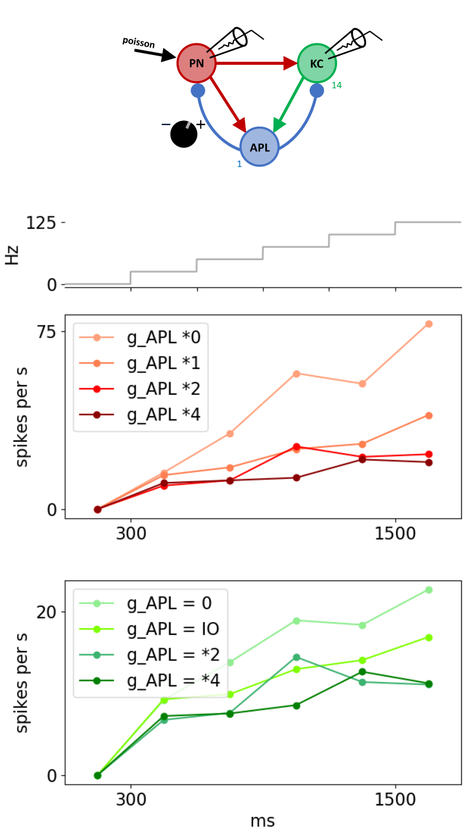


Experimental Results

Neuron Analysis



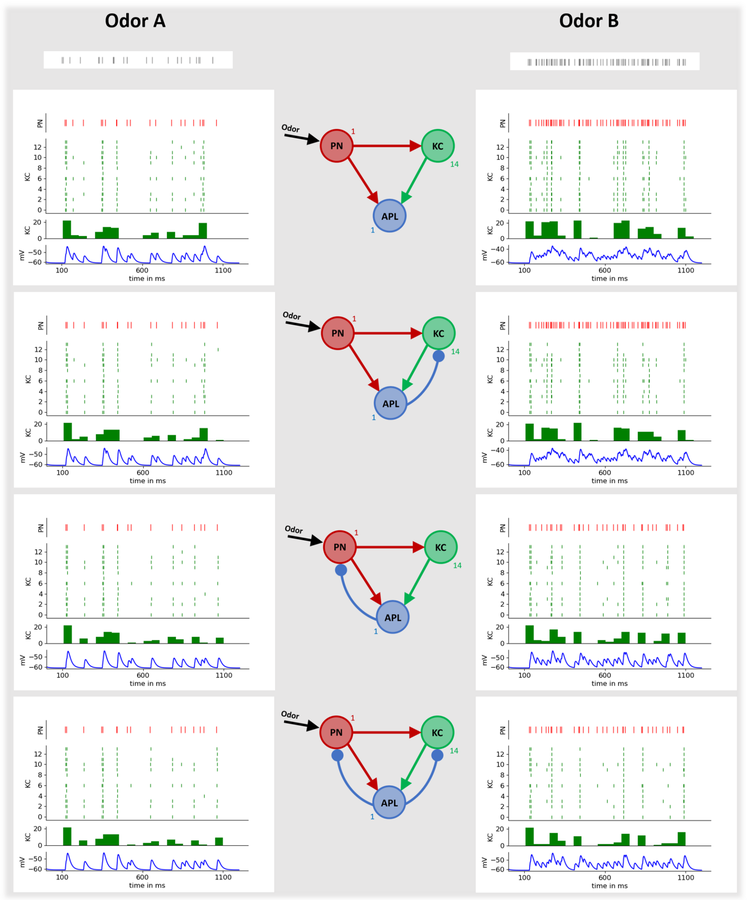
A single cell current clamp analysis shows the varying behavior of the cell potentials. On top are the current injections shown in grading colors, responsible for the change in the membrane potential beneath. The time constants vary, depending on the membrane capacity, the effect of the adaption current in KC is visible and no spikes in APL neuron.



Network Analysis

Left: Spikes per second during rising Poisson input (grey) to the PN cell. The four graded colors indicate increasing synapse strengths of the inhibitory APL synapses (red: PN; green: KC)

Right: Network analysis comparing two odors with low/high input . The four trials, shown in each row vary through the inhibitory APL influence. From top to bottom in each panel: PN spikes, KC spike pattern, KC spike histogram and membrane potential of the APL neuron. As expected, the KC pattern is sparser than the PN spike-train and a temporal shift is visible



Conclusion

- MG- model with a mix of spiking/non-spiking neurons produces biologically realistic outcome/ sparse KC pattern
- The non-spiking APL neuron has a local inhibitory and a temporal effect on the KC spike pattern

Outlook

- Network of multiple MG-models for appropriate modeling of the APL neuron in calycal space should be involved
- Include MG-model in a complete olfactory pathway model

Acknowledgement

This research is supported by the German Research Foundation (grant no. 403329959) within the Research Unit 'Structure, Plasticity and Behavioral Function of the Drosophila mushroom body' (DFG-FOR 2705)

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