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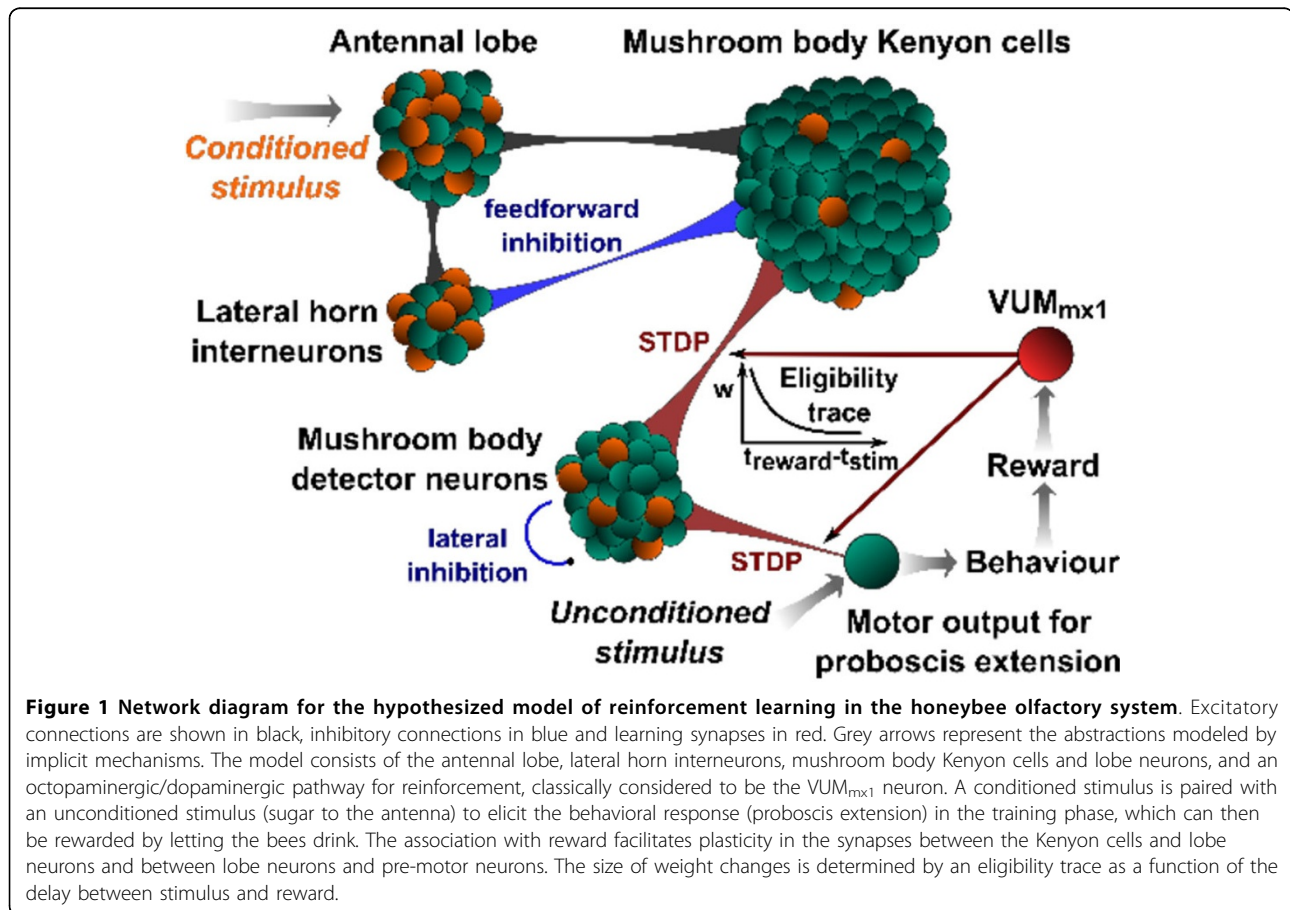
# Spiking neural network model of reinforcement learning in the honeybee implemented on the GPU

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From 24th Annual Computational Neuroscience Meeting: CNS\*2015  
Prague, Czech Republic. 18-23 July 2015

Honeybees can learn and perform complex behavioral tasks despite their small brains that contain less than a million neurons. At the same time they are accessible to

physiological experiments and the relatively small number of neurons in their brain lends itself to quite detailed numerical simulations. Bees therefore are a



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good model system for studying sensory cognition and reinforcement learning.

We have shown in earlier work [1] that the anatomy and known electrophysiological properties of the olfactory pathway of insects in combination with spike-timing dependent plasticity (STDP) and lateral inhibition lend themselves to an unsupervised self-organization of synaptic connections for the recognition of odors. Here we extend this model by adding mechanisms of reinforcement learning, as suggested by [2] (see Figure 1). We employ a three factor learning rule where plasticity is governed by pre-synaptic and post-synaptic activity and a global octopaminergic/dopaminergic reinforcement signal, triggered by a reward. We investigated the role of feed-forward and feedback mechanisms, as well as the role of the connectivity initially achieved by unsupervised STDP.

Our model is implemented in the GeNN [3] framework, which facilitates the use of GPUs for spiking neural network simulations using a code generation framework. Because of the massive parallelism provided by GPUs, we can simulate tens of thousands of neurons in real time in the sparse firing regime relevant here. We investigated optimization strategies and neuron and synapse model choices for a better performance on the GPU. The model presented here is a stepping-stone to more sophisticated learning models and multi-sensory integration in the Green Brain Project [4], in which we aim to control a flying robot with a simulation of learning and decision making mechanisms in the honeybee related both to the olfactory and visual pathways.

#### Acknowledgements

This project is supported by the EPSRC (Green Brain Project, grant number EP/J019690/1).

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Published: 18 December 2015

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doi:10.1186/1471-2202-16-S1-P181

**Cite this article as:** Yavuz et al.: Spiking neural network model of reinforcement learning in the honeybee implemented on the GPU. *BMC Neuroscience* 2015 **16**(Suppl 1):P181.

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