Ratiometric Chemical Blend Processing with a Neuromorphic Model of the Insect Macroglomerular Complex

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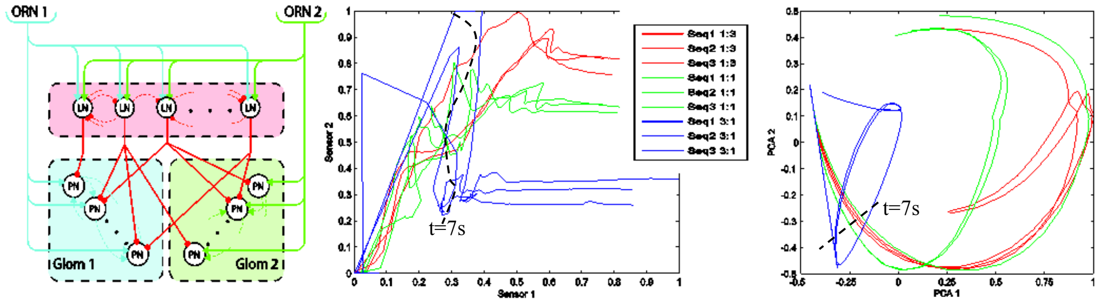
Abstract. We present a dynamical spiking neuromorphic model constrained by the known biology of the insect antennal lobe (AL) macroglomerular complex (MGC)[1] implemented in a field programmable gate array (FPGA). When driven by polymer coated quartz-crystal microbalance (QCM) chemosensors at its input, the dynamical trajectories of the model's projection neuron (PN) output population activity encode the concentration ratios of binary odour mixtures. We demonstrate that it is possible to recover blend ratio information from the early transient phase of QCM responses that would otherwise be difficult to separate directly from chemosensor data using classical approaches. Our results demonstrate the potential of insect-based neuromorphic signal processing methods for the rapid and efficient classification of ratiometrically encoded chemical blends.

Keywords: Electronic Nose, Antennal Lobe Model, FPGA, QCM, Ratiometric Decoding.
PACS: 07.05.Mh, 07.05.Tp, 07.07.Df.

METHODS AND RESULTS

The model architecture in Fig. 1a was constructed using biologically plausible assumptions taken from morphological and physiological studies of moth MGC area, which is known to be critical for pheromone blend processing in males.[1] Our model contains two specialized MGC glomeruli and ORNs connected to every local interneuron (LN) via excitatory synapses. In contrast, the PNs of each glomerulus, which comprise the key output of the MGC area only receive input from a particular ORN type. LNs have a probability to form inhibitory interconnections to other LNs. PNs make excitatory connections with other PNs of the same glomerulus, but connections to the other glomerulus are not permitted. On the other hand, LNs can make inhibitory connections with PNs of both glomeruli. Neurons within the model were implemented in programmable logic as spiking leaky integrate-and-fire soma driven by exponential decay synaptic dynamics.[2] ORN-LN and LN-LN synaptic weights were modified using a form of spike-time dependent plasticity[3] (STDP) for the purpose of unsupervised learning of blend ratios from input (ORN) time series. Learning resulted in a distribution of ORN-LN weights that evenly covered the space of possible input ratios.

Olfaction and Electronic Nose: Proceedings of the 14th International Symposium on Olfaction and Electronic Nose
AIP Conf. Proc. 1362, 77-78 (2011); doi: 10.1063/1.3626312



(a) (b) (c)

FIGURE 1. (a) Schematic of the AL MGC model comprising two ORNs (15 PNs in each of the two glomeruli and a total of 30 LNs were used in the FPGA implementation. Arrows and circles represent excitatory and inhibitory synapses respectively), (b) Trajectory plot of Sensor 1 versus Sensor 2 data for three repeat measurement trials (Seq1-3). The average Euclidean distances between the three ratios of the sensor data trajectory plot for Seq1:0.1947, Seq2: 0.184 and Seq3: 0.1902. The red, green and blue traces represent mixture ratios 1:3, 1:1 and 3:1 respectively, (c) PCA plot of the AL model PN firing rate trajectories post-training for each measurement sequence of the three blend ratios (95% of variance explained). The average Euclidean distances between the three ratios of the model output PCA trajectory plot for Seq1:0.2762, Seq2: 0.2681 and Seq3: 0.3006.

In this way, the activity of a particular LN becomes dominant for a specific input ratio of the stimulus at a given instant in time. After the network was trained with a set of ORN time series representing different chemical concentration ratios, it was able to perform a successful classification over a broad band of unknown ratios. The capability of the model was first tested with a set of synthetic ORN data in order to understand the resulting network dynamics, before introducing the chemosensor time series depicted in Fig. 1b. Chemosensor time series were obtained by sampling the responses of two 30 MHz QCMs (spray coated with different 1%wt polymer solutions), which were applied directly to the ORN input after normalization (as a driving synaptic current). Three binary mixtures of ethyl acetate and isoamyl alcohol were made with different concentration ratios (3:1, 1:3 and 1:1) and evaporated into a sample chamber, generating the transient and steady state responses shown in Fig. 1b. The early transient phases of the QCM responses (before 7 seconds) were found to be closely overlapping and difficult to separate, but they become separable once the steady state QCM response is reached. Fig. 1c shows the reduced space of firing rate trajectories of the model's PN outputs to this chemosensor input. Analysis of Euclidean distances between the trajectories shows separation of blend ratios in the early transient responses of the network, which is not evident in the raw QCM sensor responses (particularly between ratio 3:1, shown in blue, and the other ratios except one ratio which was ultimately misidentified). Thus, our results show that this insect-based neuromorphic MGC model can learn and retrieve concentration ratios of chemical blends from the early transient responses of real QCM chemosensors.

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