Smelling with Silicon

Performing computation with limited synaptic precision

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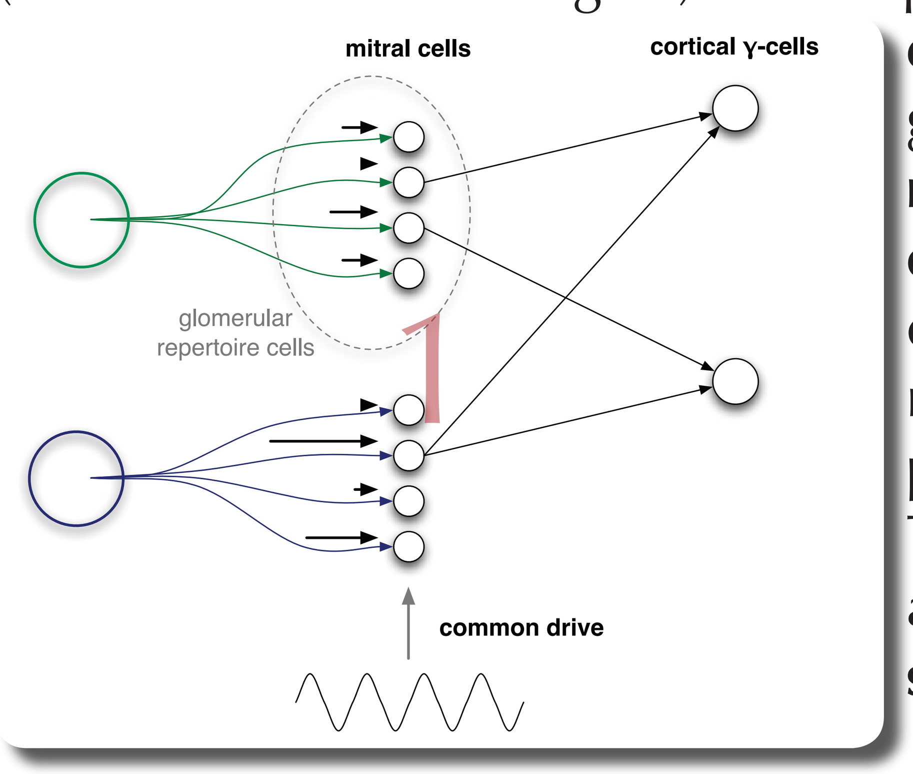
Introduction

Previous studies have shown that complex and **sophisticated information processing** can occur in **spike-based** computational systems using only **binary (potentiated or depressed) synapses** [Hopfield & Brody 2003, Floreano 2004]. We present an implementation of an **olfactory bulb model** using binary synapses and network structure and dynamics to perform highly selective **odour recognition**.

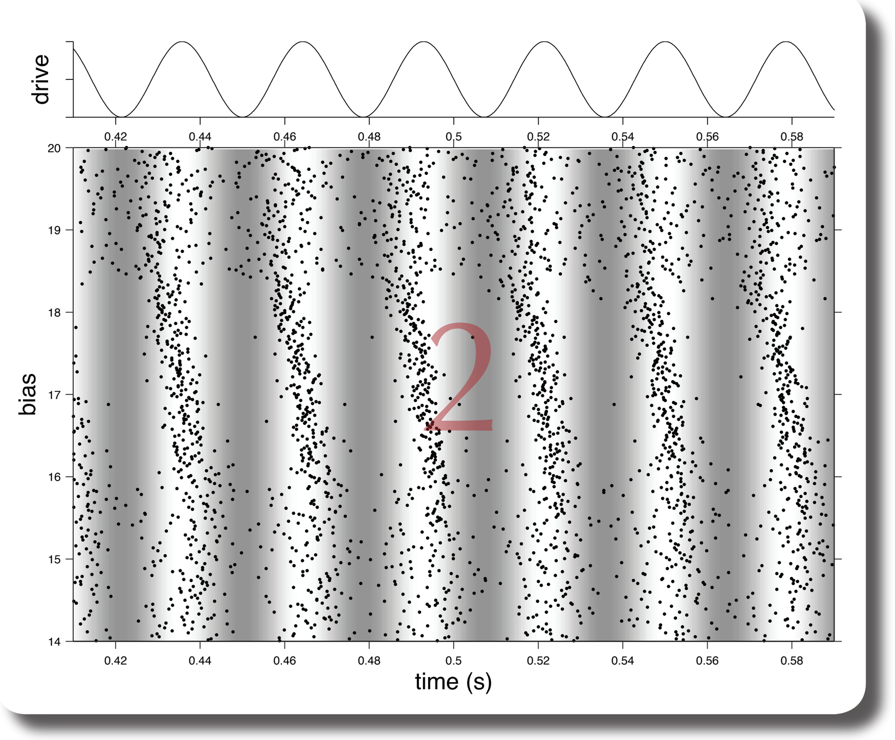
Olfactory model

Figure 1 shows the Hopfield/Brody olfactory bulb model. **Glomeruli** (left-most circles in the figure) activate proportionally to a particular



odour component. Each glomerulus activates several **mitral cells** with a degree of **randomness**. **Gamma cells** detect **synchrony** in mitral cell activity, and perform **odour detection**. The mitral cell population also recieves a **common sinusoidal input**.

Figure 2 shows the effect of this common input. These spike trains have been sorted by the bias current injected into the cell. The **sinusoidal drive** induces **soft synchronisation** within the mitral population. For a **range** of **input currents**, the mitral cell population fires in **tight synchrony**.



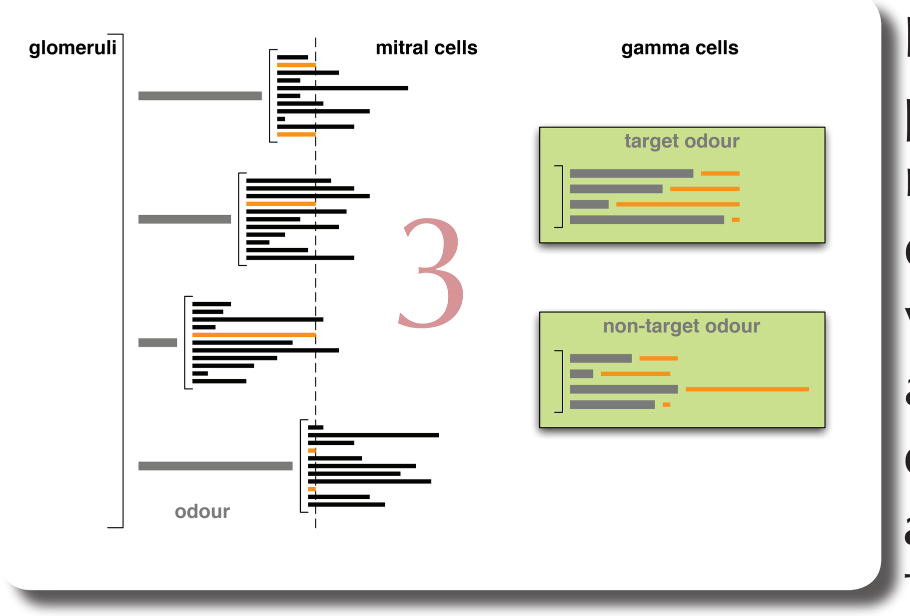
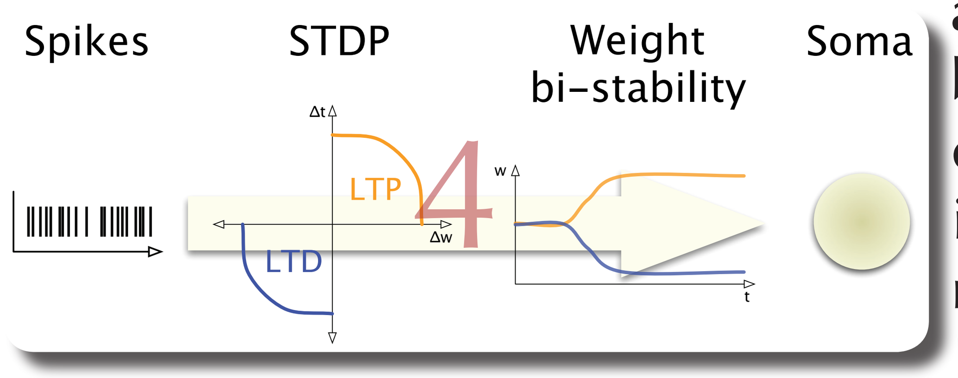


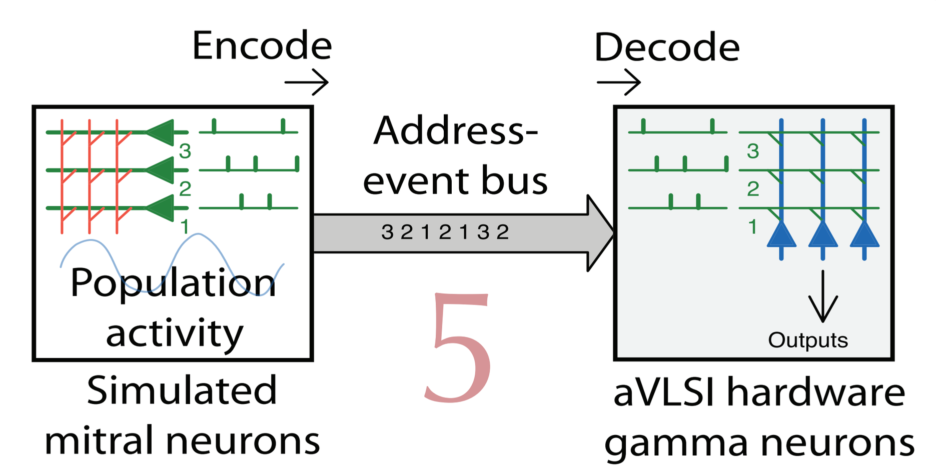
Figure 3 illustrates odour presentation in the olfactory model. **Odour components** drive the glomeruli with varying strengths. These activations cause a **subset** of the **mitral cells** to fire in **approximate synchrony**. This subset is connected to a **gamma cell** which acts as a **synchrony detector**. Non-target odours will not cause synchrony in the same mitral cells, and therefore the gamma cell will not fire.

Hybrid model

We implemented this model in a **hybrid hardware-software** simulation. **Odour generation**, **glomerular activity** and **mitral cell activity** were simulated by software. **Gamma cells** were implemented in an **analog VLSI** neuron model developed at the INI [Indiveri, Chicca, Douglas 2004] (See **figure 4**). The **synapses** in this neuron model perform learning using **spike-time-dependent plasticity**. The **weights** of the synaptic connections are **binary** over long time scales. The neuron adopts a simple **integrate-and-fire** model.

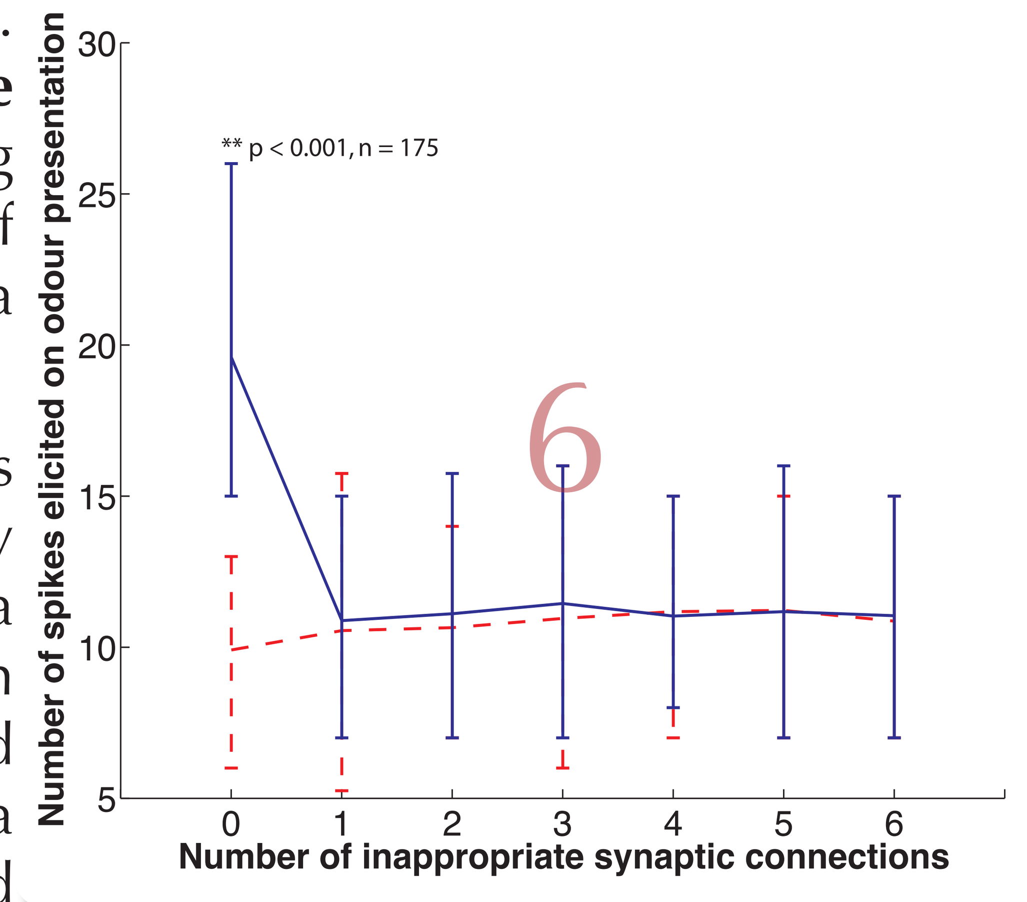


The **software / hardware interface** was made with the **Address Event Protocol** developed at INI. Custom workstation-based hardware **communicates spike events** between the software mitral cell neurons and the on-chip aVLSI gamma neurons, and **monitors the gamma cell response**.



Results

Figure 6 shows the results of the odour presentation trials. We **presented an odour** to the model, and **measured the number of gamma cell spikes**. We **degraded the network** by connecting an increasing number of **random mitral cells** to a gamma cell.



The solid line shows a gamma cell initially engineered for a target odour and then degraded. The dashed line shows a gamma cell initially connected randomly. Error bars show the upper and lower quartiles.

The **selectivity of the model** is compares the response to a target odour with the response to a random odour. For our implementation, this **selectivity was 1.98:1**.

STDP learning in gamma cell synapses **supresses** the response to **near-target odours**, by depressing inappropriate mitral cell connections. This gives **sharp odour selectivity** when degrading te network. **Odour selectivity between target and near-target odours was 1.78:1.**

The success of this scheme shows that **sophisticated computation** is possible in **noisy networks** of spiking neurons relying only on the **neuron dynamics** and the **network structure**. Precise analog synaptic weights are not necessary for computation.

References

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