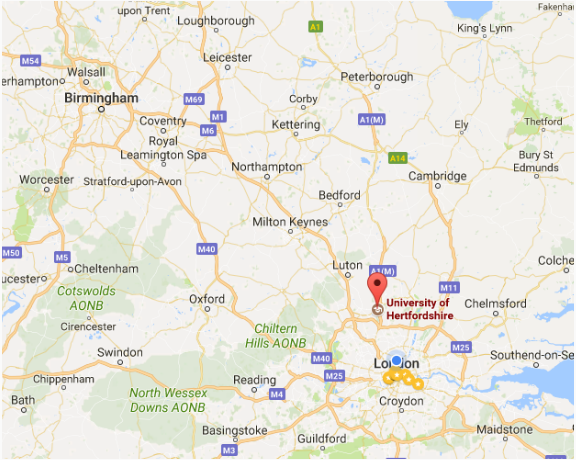
Diverse synaptic plasticity mechanisms orchestrated to form and retrieve memories in spiking neural networks

Zenke et al. 2015

Ankur Sinha @ UoB

16/11/2016

$whoami?



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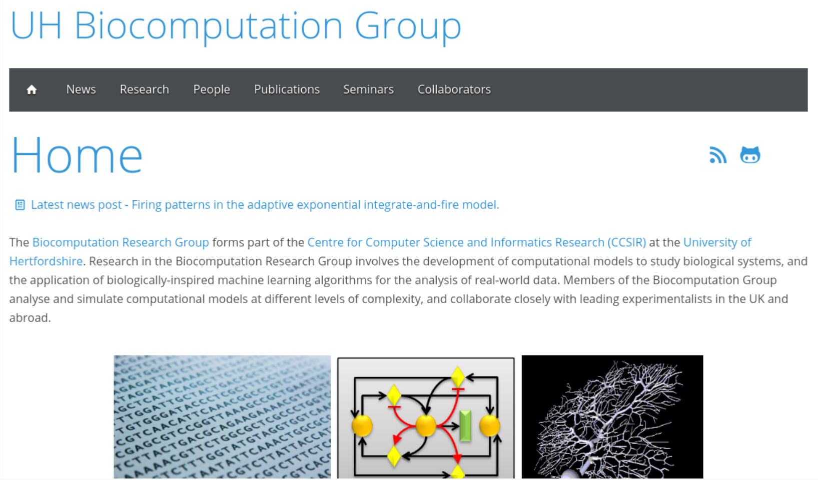

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Memory research?

Functional effects of structural plasticity in a balanced spiking neural network

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Functional effects of structural plasticity in a balanced spiking neural network

. . . where the function we're interested in is memory

Diverse synaptic plasticity mechanisms orchestrated to form and retrieve memories in spiking neural networks

. . . a well-orchestrated combination

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leads to the formation of cell assemblies

Hebbian plasticity

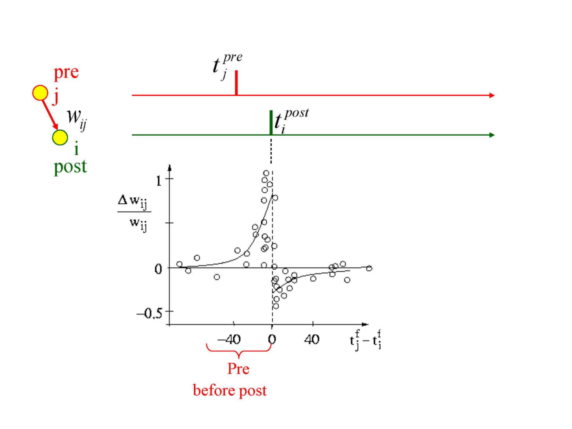

Figure 1: Classic asymmetric STDP learning rule[1].

[1] Guo-qiang Bi and Mu-ming Poo. "Synaptic modifications in cultured hippocampal neurons: dependence on spike timing, synaptic strength, and postsynaptic cell type". In: *The journal of neuroscience* 18.24 (1998), pp. 10464–10472

Hebbian plasticity

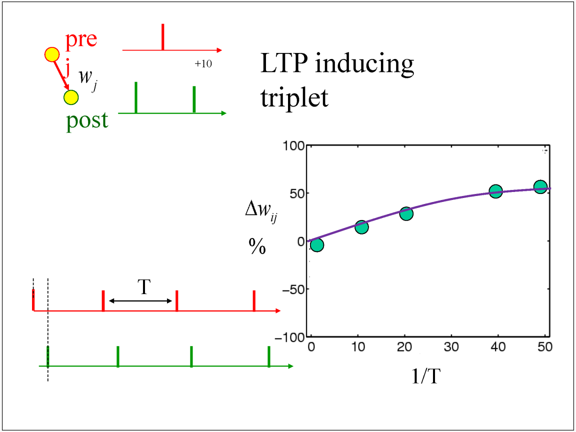

Figure 2: Triplet STDP learning rule used in this paper[2].

[2] Jean-Pascal Pfister and Wulfram Gerstner. "Triplets of spikes in a model of spike timing-dependent plasticity". In: *Journal of Neuroscience* 26.38 (2006), pp. 9673–9682

Effect of Hebbian plasticity

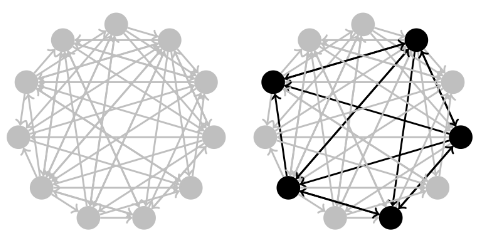

Figure 3: Cell assembly

Effect of Hebbian plasticity

$$\frac{d}{dt} w_{ij}(t) = H(\ldots) \tag{1}$$

Effect of Hebbian plasticity: recall

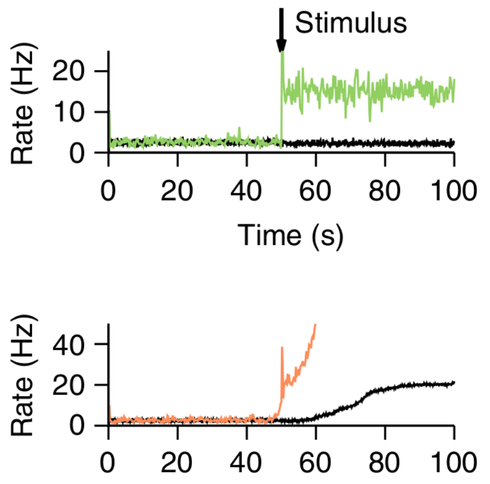

Figure 4: Recall without (top) and with (bottom) Hebbian plasticity.

Effect of Hebbian plasticity: dynamics

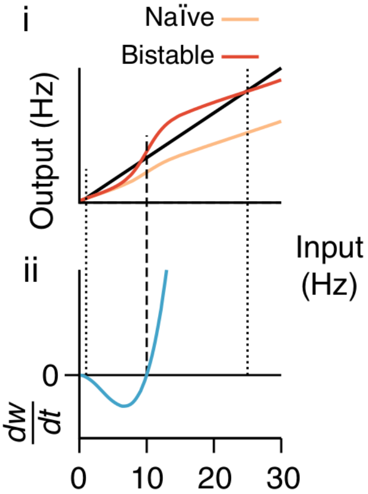

Figure 5: Network (top) and synaptic (bottom) dynamics—uncontrolled increase in synaptic weights at higher firing rates—in the presence of Hebbian plasticity in isolation.

Addition of non-Hebbian plasticity I: heterosynaptic plasticity

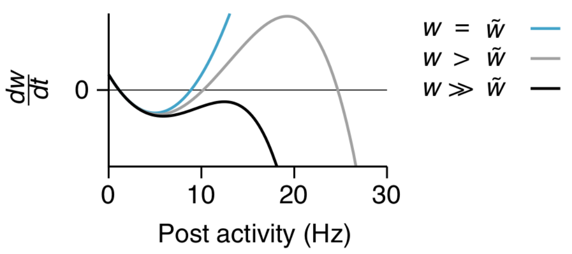

Figure 6: Synaptic dynamics vary depending on their relation to the reference weight—preventing unlimited potentiation

Addition of non-Hebbian plasticity I: heterosynaptic plasticity

$$\begin{aligned} \frac{d}{dt} w_{ij}(t) &= H(\dots) \\ &\quad - G(\dots) \end{aligned} \tag{2}$$

Addition of non-Hebbian plasticity II: transmitter induced plasticity

$$\frac{d}{dt}w_{ij}(t) = H(\ldots) - G(\ldots) + T(S_{pre}) \tag{3}$$

The transmitter induced plasticity increases weights depending on the activity of the pre-synaptic neuron, therefore, preventing uncontrolled depression.

Resultant dynamics

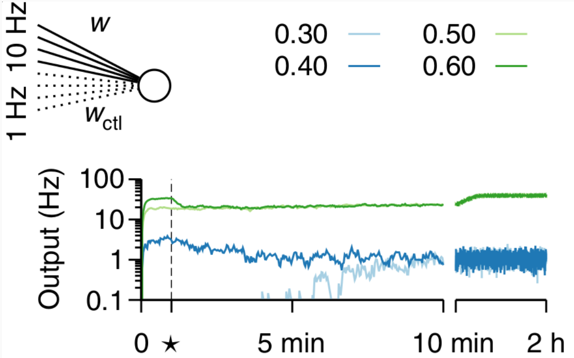

Figure 7: The combination of Hebbian and non Hebbian synaptic mechanisms permits a stable firing of neuron irrespective of initial condition

Global inhibition further stabilises network

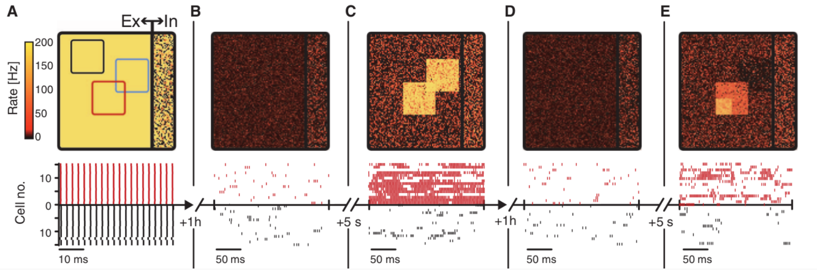

Figure 8: Homoeostatic inhibitory synaptic plasticity balances excitation to limit a network to an asynchronous irregular state[3]. Based on experimental observations[4].

[3] TP Vogels et al. "Inhibitory plasticity balances excitation and inhibition in sensory pathways and memory networks". In: *Science* 334.6062 (2011), pp. 1569–1573. URL: http://www.sciencemag.org/content/334/6062/1569.short

[4] Melanie A Woodin, Karunesh Ganguly, and Mu-ming Poo. "Coincident pre-and postsynaptic activity modifies GABAergic synapses by postsynaptic changes in Cl- transporter activity". In: *Neuron* 39.5 (2003), pp. 807–820

Resultant behaviours

- Successful assembly formation and (in most cases) recall.

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- Successful assembly formation and (in most cases) recall.
- The network retained the ability to form more assemblies after initial sets.
- Inactive memories (memory ensembles that were not stimulated for recall) decayed slightly, but no change was observed in active memories implying that the memories stored are stable over time.

Takeaway: requirements for memory formation and recall

- Multiple plasticity mechanisms:

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- Multiple plasticity mechanisms:
    - of different types (Hebbian, non-Hebbian, homosynaptic, heterosynaptic, transmitter-induced, global secretion induced)
    - at different time scales (fast Hebbian matched by fast non-Hebbian, slow compensatory)