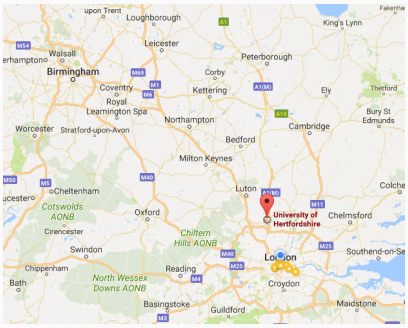
Diverse synaptic plasticity mechanisms orchestrated to form and retrieve memories in spiking neural networks

Zenke et al. 2015

Ankur Sinha @ UoB
16/11/2016

Notes

$whoami?



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Notes

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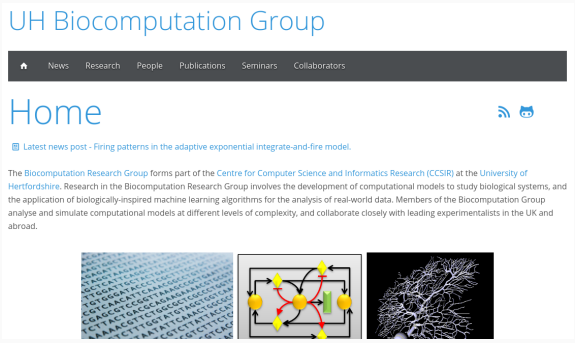

http://biocomputation.herts.ac.uk

Notes

Memory research?

Functional effects of structural plasticity in a balanced spiking neural network

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

Notes

Zenke et al. 2015

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. . . a well-orchestrated combination of a plausible Hebbian plasticity model together with non-Hebbian forms of plasticity, and globally modulated inhibitory plasticity leads to the formation of cell assemblies

Notes

Hebbian plasticity

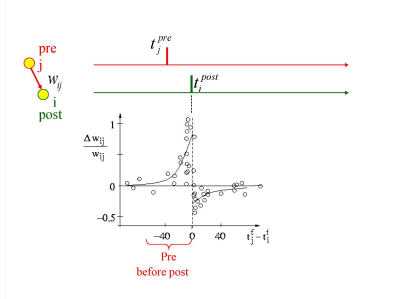

Figure 1: Classic asymmetric STDP learning rule[1].

[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

Notes

Hebbian plasticity

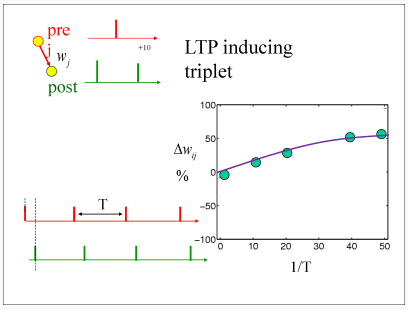

Figure 2: Triplet STDP learning rule used in this paper[2].

[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

Notes

Effect of Hebbian plasticity

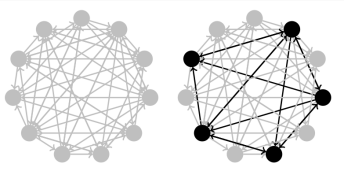

Figure 3: Cell assembly

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Effect of Hebbian plasticity

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

Notes

Effect of Hebbian plasticity: recall

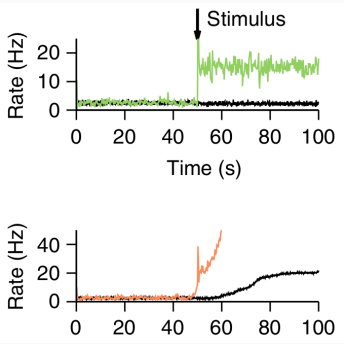

Figure 4: Recall without (top) and with (bottom) Hebbian plasticity.

Notes

Effect of Hebbian plasticity: dynamics

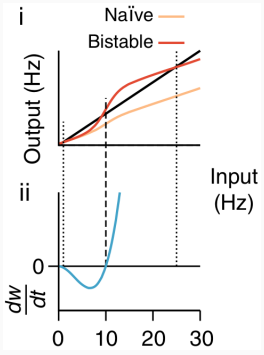

Figure 5: Network (top) and synaptic (bottom) dynamics—uncontrolled increase in synaptic weights at higher firing rates—in the presence of Hebbian plasticity in isolation.

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Addition of non-Hebbian plasticity I: heterosynaptic plasticity

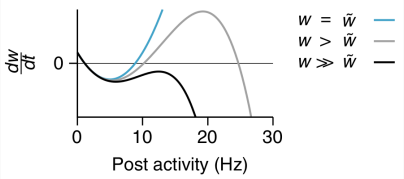

Figure 6: Synaptic dynamics vary depending on their relation to the reference weight—preventing unlimited potentiation

Notes

Addition of non-Hebbian plasticity I: heterosynaptic plasticity

$$\frac{\mathrm{d}}{\mathrm{dt}} w_{ij}(t) = \mathrm{H}(\ldots) - \mathrm{G}(\ldots) \tag{2}$$

Notes

Addition of non-Hebbian plasticity II: transmitter induced plasticity

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

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

Notes

Resultant dynamics

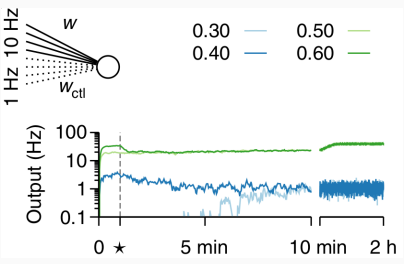

Figure 7: The combination of Hebbian and non Hebbian synaptic mechanisms permits a stable firing of neuron irrespective of initial condition

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Global inhibition further stabilises network

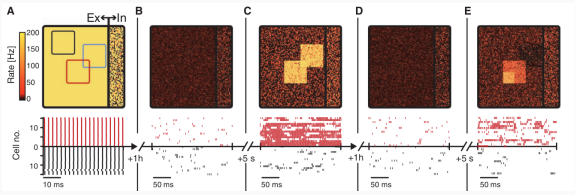

Figure 8: Homoeostatic inhibitory synaptic plasticity balances excitation to limit a network to an asynchronous irregular state[3]. Based on experimental observations[4].

[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

Notes

Resultant behaviours

- 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.

Notes

Takeaway: requirements for memory formation and recall

- 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)

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