

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

Zenke et al. 2015

Ankur Sinha @ UoB

16/11/2016

Zenke 2015

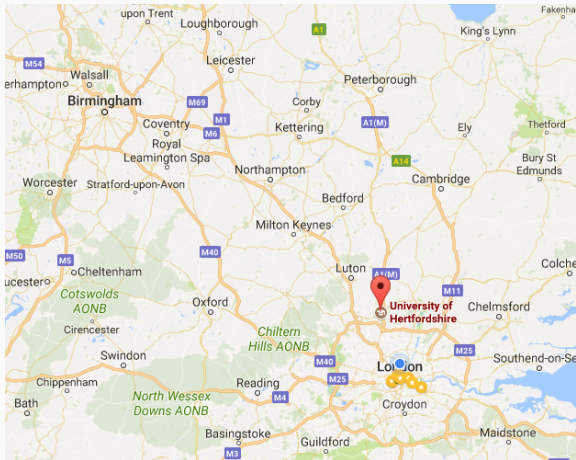
2017-11-16

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?



PhD candidate (final year!) @
UH Biocomputation at Hatfield

Zenke 2015

└ Acquainting one's self

└ \$whoami?

2017-11-16

\$whoami?



PhD candidate (final year!) @
UH Biocomputation at Hatfield

\$whoami?

UH Biocomputation Group

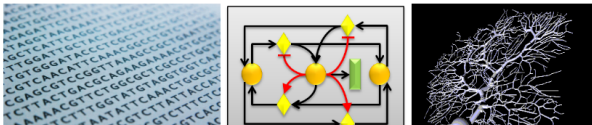
Home News Research People Publications Seminars Collaborators

Home



Latest news post - Firing patterns in the adaptive exponential integrate-and-fire model.

The [Biocomputation Research Group](#) forms part of the [Centre for Computer Science and Informatics Research \(CCSIR\)](#) at the [University of Hertfordshire](#). Research in the Biocomputation Research Group involves the development of computational models to study biological systems, and the application of biologically-inspired machine learning algorithms for the analysis of real-world data. Members of the Biocomputation Group analyse and simulate computational models at different levels of complexity, and collaborate closely with leading experimentalists in the UK and abroad.



<http://biocomputation.herts.ac.uk>

Zenke 2015

Acquainting one's self

\$whoami?

2017-11-16

\$whoami?

UH Biocomputation Group

Home

Latest news post - Firing patterns in the adaptive exponential integrate-and-fire model.

The Biocomputation Research Group forms part of the Centre for Computer Science and Informatics Research (CCSIR) at the University of Hertfordshire. Research in the Biocomputation Research Group involves the development of computational models to study biological systems, and the application of biologically-inspired machine learning algorithms for the analysis of real-world data. Members of the Biocomputation Group analyse and simulate computational models at different levels of complexity, and collaborate closely with leading experimentalists in the UK and abroad.



<http://biocomputation.herts.ac.uk>

Memory research?

Zenke 2015

2017-11-16

└ Acquainting one's self

└ Memory research?

Functional effects of structural plasticity in a balanced spiking neural network

2017-11-16

Zenke 2015

└ Acquainting one's self

└ Memory research?

Memory research?

Functional effects of structural plasticity
in a balanced spiking neural network

Functional effects of structural plasticity in a balanced spiking neural network

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

2017-11-16

Zenke 2015

└ Acquainting one's self

└ Memory research?

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

2017-11-16

Zenke 2015

└ Acquainting one's self

└ Zenke et al. 2015

... a **well-orchestrated** combination

... a **well-orchestrated** combination
of a plausible **Hebbian plasticity** model

Zenke 2015

└ Acquainting one's self

└ Zenke et al. 2015

2017-11-16

... a **well-orchestrated** combination
of a plausible **Hebbian plasticity** model

... a **well-orchestrated** combination
of a plausible **Hebbian plasticity** model
together with **non-Hebbian forms of**
plasticity, and

Zenke 2015

2017-11-16

└ Acquainting one's self

└ Zenke et al. 2015

... a **well-orchestrated** combination
of a plausible **Hebbian plasticity** model
together with **non-Hebbian forms of**
plasticity, and

... a well-orchestrated combination
of a plausible Hebbian plasticity model
together with non-Hebbian forms of
plasticity, and
globally modulated inhibitory plasticity

Zenke 2015

2017-11-16

└ Acquainting one's self

└ Zenke et al. 2015

... a well-orchestrated combination
of a plausible Hebbian plasticity model
together with non-Hebbian forms of
plasticity, and
globally modulated inhibitory plasticity

... 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

Zenke 2015

2017-11-16

└ Acquainting one's self

└ Zenke et al. 2015

... 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

Hebbian plasticity

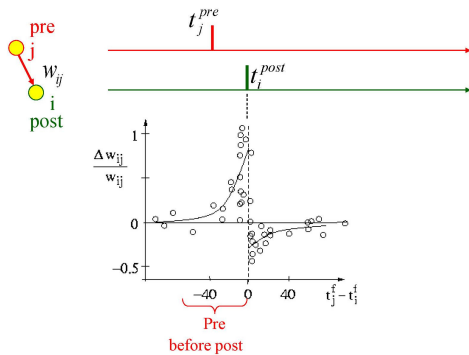


Figure 1: Classic asymmetric STDP learning rule¹.

¹Guo-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

Zenke 2015

└ Acquainting one's self

└ Hebbian plasticity

2017-11-16

Hebbian plasticity

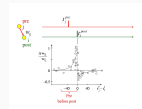


Figure 1: Classic asymmetric STDP learning rule¹.

¹Guo-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

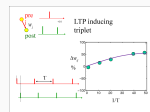


Figure 2: Triplet STDP learning rule used in this paper².
²Jean-Pascal Pfister and Wulfram Gerstner. "Triplets of spikes in a model of spike timing-dependent plasticity". In: *Journal of Neuroscience* 26.38 (2006), pp. 9673–9682

Hebbian plasticity

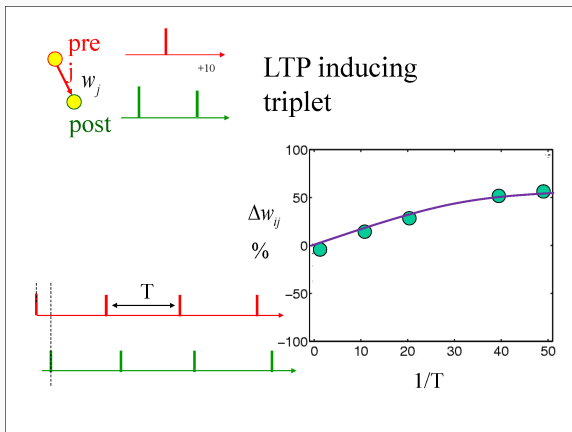


Figure 2: Triplet STDP learning rule used in this paper².

²Jean-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

Zenke 2015

2017-11-16

└ Acquainting one's self

└ Hebbian plasticity

Zenke 2015
└ Acquainting one's self

└ Effect of Hebbian plasticity

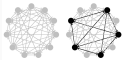


Figure 3: Cell assembly

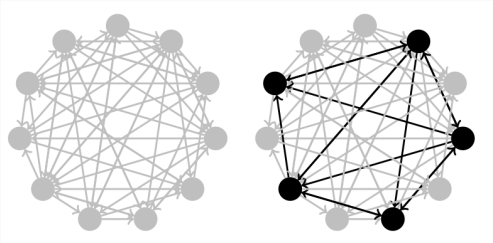


Figure 3: Cell assembly

$$\frac{d}{dt}w_{ij}(t) = H(\dots) \quad (1)$$

Zenke 2015

└ Acquainting one's self

└ Effect of Hebbian plasticity

$$\frac{d}{dt}w_{ij}(t) = H(\dots) \quad (1)$$

Effect of Hebbian plasticity: recall

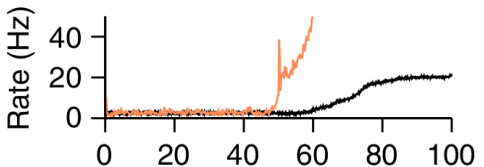
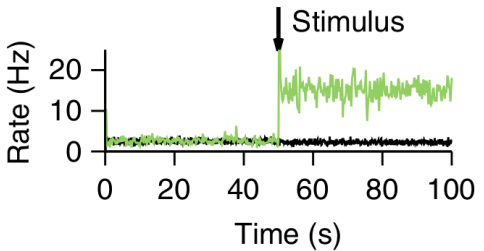


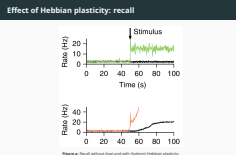
Figure 4: Recall without (top) and with (bottom) Hebbian plasticity.

Zenke 2015

└ Acquainting one's self

└ Effect of Hebbian plasticity: recall

2017-11-16



Effect of Hebbian plasticity: dynamics

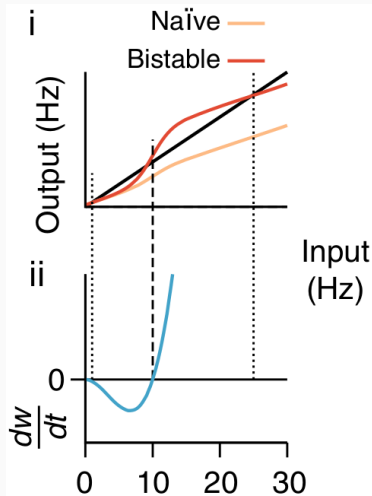
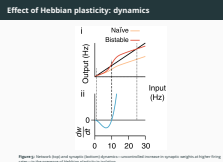


Figure 5: Network (top) and synaptic (bottom) dynamics—uncontrolled increase in synaptic weights at higher firing rates—in the presence of Hebbian plasticity in isolation.

Zenke 2015

└ Acquainting one's self

└ Effect of Hebbian plasticity: dynamics



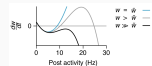


Figure 6: Synaptic dynamics vary depending on their relation to the reference weight—preventing unlimited potentiation

Zenke 2015

└ Acquainting one's self

└ Addition of non-Hebbian plasticity I:
heterosynaptic plasticity

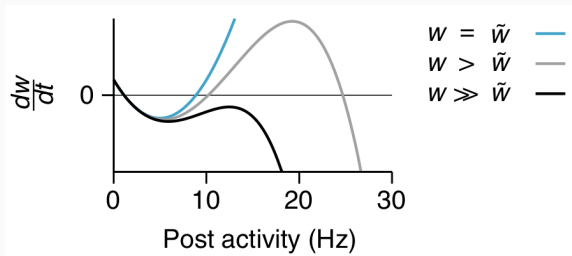


Figure 6: Synaptic dynamics vary depending on their relation to the reference weight—preventing unlimited potentiation

Addition of non-Hebbian plasticity I: heterosynaptic plasticity

$$\frac{d}{dt}w_{ij}(t) = H(\dots) - G(\dots) \quad (2)$$

2017-11-16

Zenke 2015

└ Acquainting one's self

└ Addition of non-Hebbian plasticity I:
heterosynaptic plasticity

$$\frac{d}{dt}w_{ij}(t) = H(\dots) - G(\dots) \quad (2)$$

Addition of non-Hebbian plasticity II: transmitter induced plasticity

$$\begin{aligned} \frac{d}{dt}w_{ij}(t) = & H(\dots) \\ & - G(\dots) \\ & + T(S_{pre}) \end{aligned} \quad (3)$$

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

2017-11-16

Zenke 2015

└ Acquainting one's self

└ Addition of non-Hebbian plasticity II:
transmitter induced plasticity

Addition of non-Hebbian plasticity II: transmitter induced plasticity

$$\begin{aligned} \frac{d}{dt}w_{ij}(t) = & H(\dots) \\ & - G(\dots) \\ & + T(S_{pre}) \end{aligned} \quad (3)$$

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

Resultant dynamics

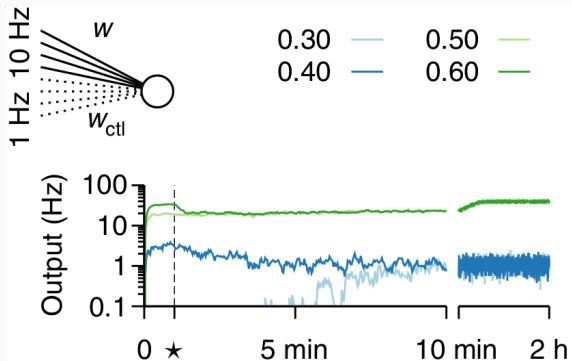


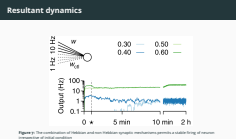
Figure 7: The combination of Hebbian and non Hebbian synaptic mechanisms permits a stable firing of neuron irrespective of initial condition

Zenke 2015

2017-11-16

└ Acquainting one's self

└ Resultant dynamics



Global inhibition further stabilises network

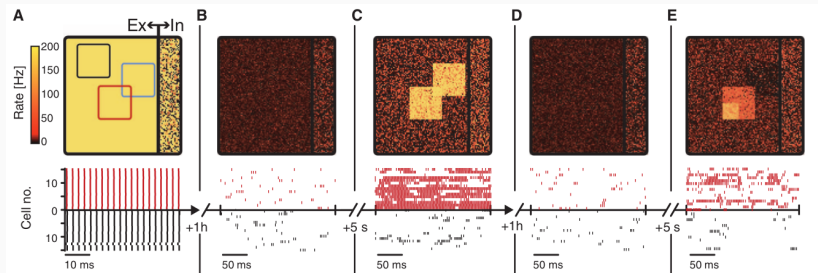


Figure 8: Homoeostatic inhibitory synaptic plasticity balances excitation to limit a network to an asynchronous irregular state³. Based on experimental observations⁴.

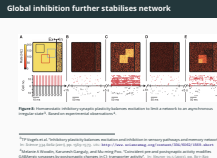
³TP Vogels et al. "Inhibitory plasticity balances excitation and inhibition in sensory pathways and memory networks". In: *Science* 334.6062 (2011), pp. 1569–1573. URL: <http://www.sciencemag.org/content/334/6062/1569.short>

⁴Melanie 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

Zenke 2015

└ Acquainting one's self

└ Global inhibition further stabilises network



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

2017-11-16

Zenke 2015

└ Acquainting one's self

└ Resultant behaviours

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

- Successful assembly **formation and** (in most cases) **recall**.
- The network **retained the ability to form more assemblies** after initial sets.

Zenke 2015

2017-11-16

└ Acquainting one's self

└ Resultant behaviours

- Successful assembly **formation and** (in most cases) **recall**.
- The network **retained the ability to form more assemblies** after initial sets.

- 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

2017-11-16

Zenke 2015

└ Acquainting one's self

└ Takeaway: requirements for memory formation and recall

- Multiple plasticity mechanisms:

- Multiple plasticity mechanisms:

Takeaway: requirements for memory formation and recall

2017-11-16

Zenke 2015

└ Acquainting one's self

└ 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)

- 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)