Universität Bielefeld Cognitive Interaction Technology Center of Excellence

CITEC

Learning in Silicon Beyond Spike-Timing-Dependent-Plasticity

Elisabetta Chicca

Neuromorphic Behaving Systems

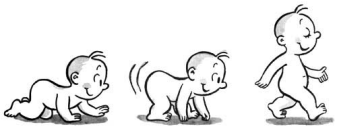
Faculty of Technology and Cognitive Interaction Technology Center of Excellence (CITEC)

Bielefeld University

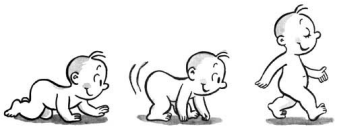
BioComp 2017 - Roscoff, June 26, 2017

Learning

Learning motor skills



Learning motor skills



Learning

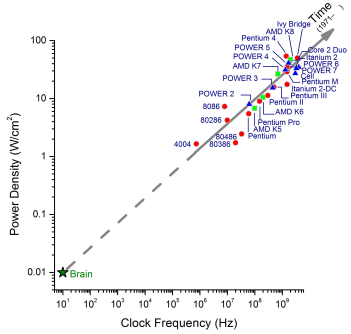
Learning

Learning

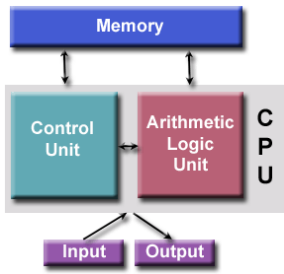
Synapses

Credit: Graham Johnson, Graham Johnson Medical Media

Computer vs Brain



Source: `http://www.research.ibm.com`



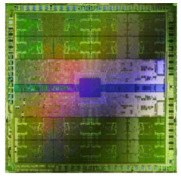
Source: `https://www.quora.com/`

Motivation for a paradigm shift

"*[...] programming is basically planning and detailing the enormous traffic of words through the von Neumann bottleneck*[1]*, and much of that traffic concerns not significant data itself but where to find it.*" John Backus, 1978

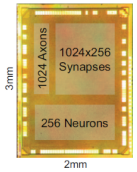
[1] Channel used for the communication between the Central Processing Unit (CPU) and the memory.

Neuro-computing

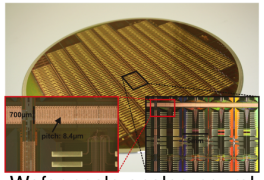


SW simulated neural networks (CPUs, GPUs).

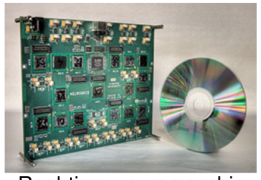
Real-time ARM-based neural network simulator (SpiNNaker).



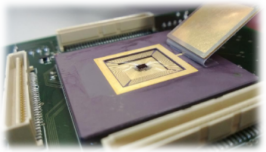
Fully digital *cognitive computing* chips (IBM).



Wafer-scale analog neural accelerators (BrainScaleS).



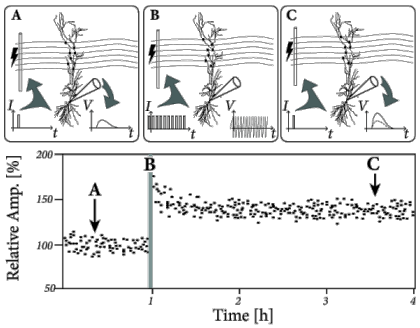
Real-time neuromorphic multi-chip emulator (NeuroGrid).



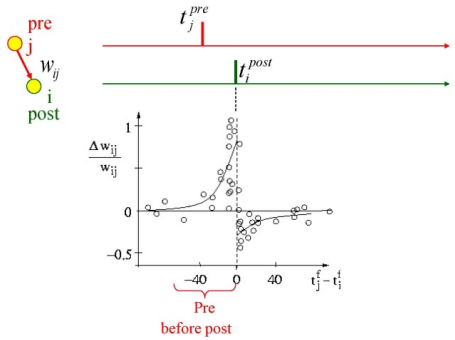
Real-time multi-neuron chip with plastic synapse neuron circuits (neuroP).

Learning in analog sub-threshold VLSI circuits

Long term plasticity in biological systems



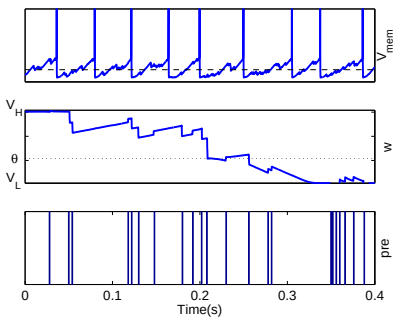
Paradigm of long-term potentiation induction(1).



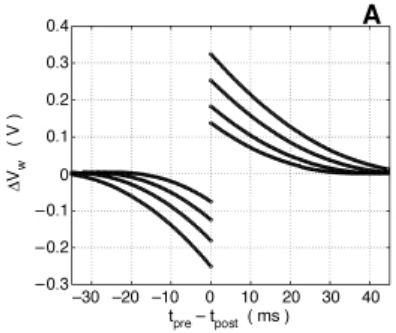
Induction of synaptic potentiation and depression(2).

(1) Reproduced from Neural Dynamics. W. Gerstner, W. Kistler, R. Naud and L. Paninski (2014). (2002).
(2) Reproduced from STDP article on scholarpedia, which is based on original from Bi and Poo (1998).

Long-term plasticity in analog sub-threshold circuits

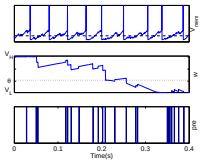


Chicca et al. 2014



Bofill-i-Petit and Murray, 2004

Long-term plasticity in analog sub-threshold circuits



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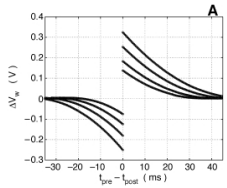

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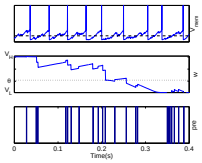

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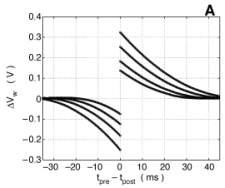

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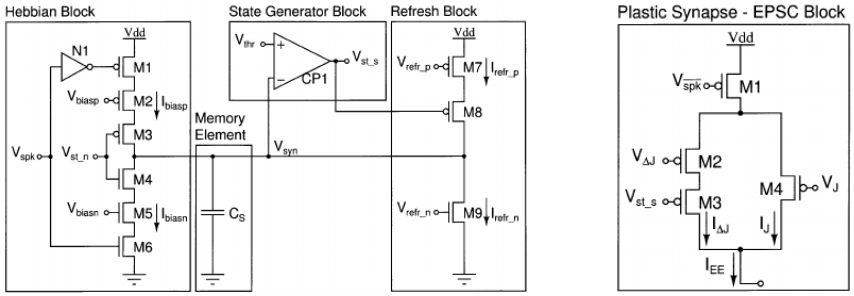
A VLSI recurrent network of Integrate-and-Fire neurons connected by plastic synapses with long-term memory

Chicca et al. 2003



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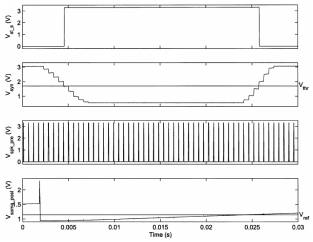

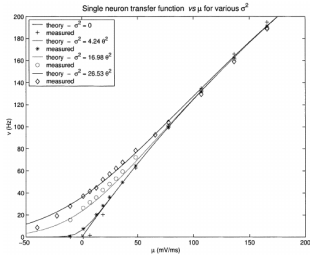

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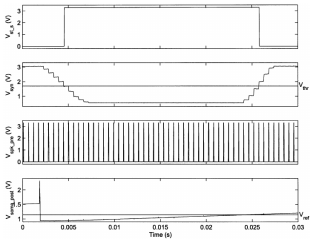
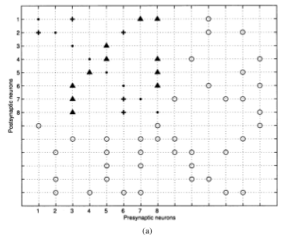
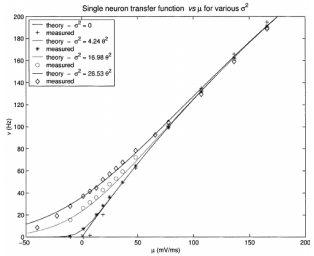
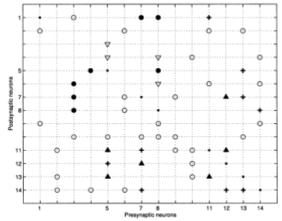
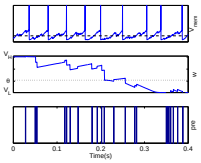








Long-term plasticity in analog sub-threshold circuits



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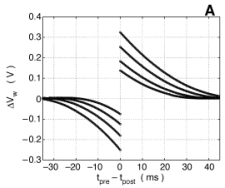

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Synchrony detection and amplification by silicon neurons with STDP synapses

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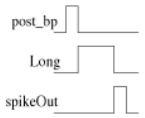

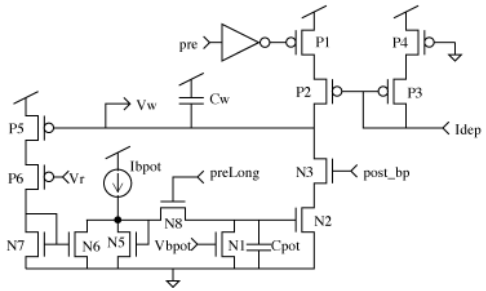

Synchrony detection and amplification by silicon neurons with STDP synapses

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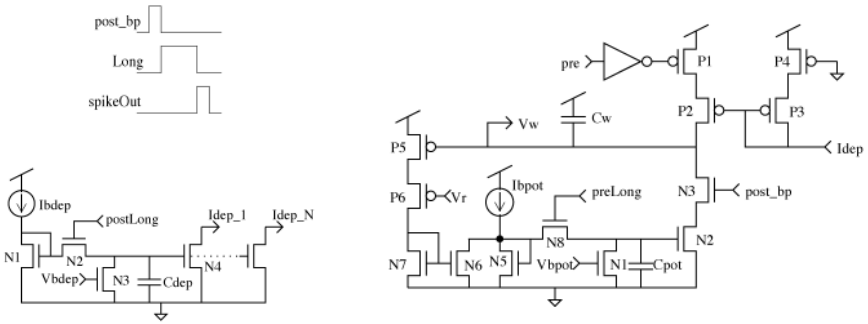

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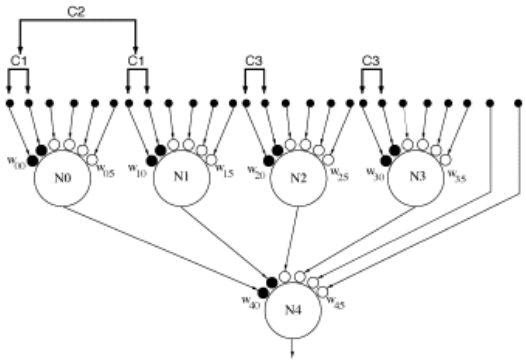

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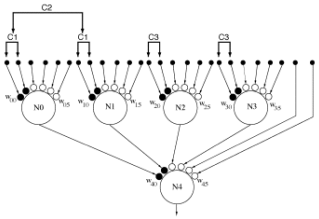

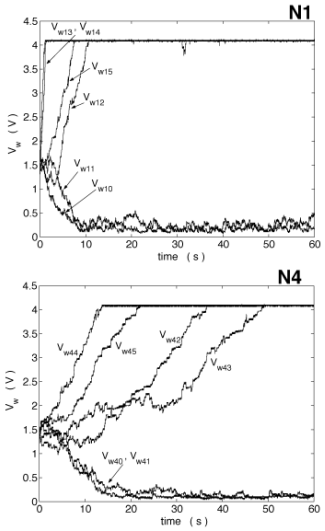

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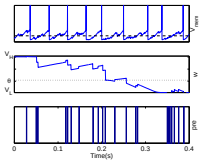

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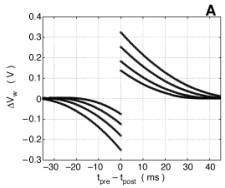

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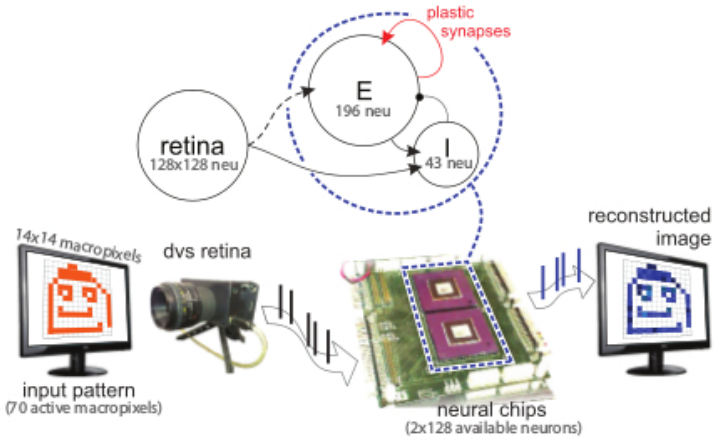
Real time unsupervised learning of visual stimuli in neuromorphic VLSI systems

Giulioni, Corradi, Dante, del Giudice, *arXiv preprint arXiv*:1506.05427 (2015).



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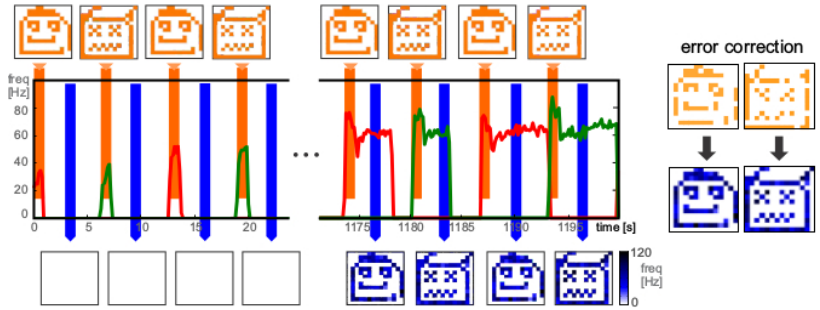
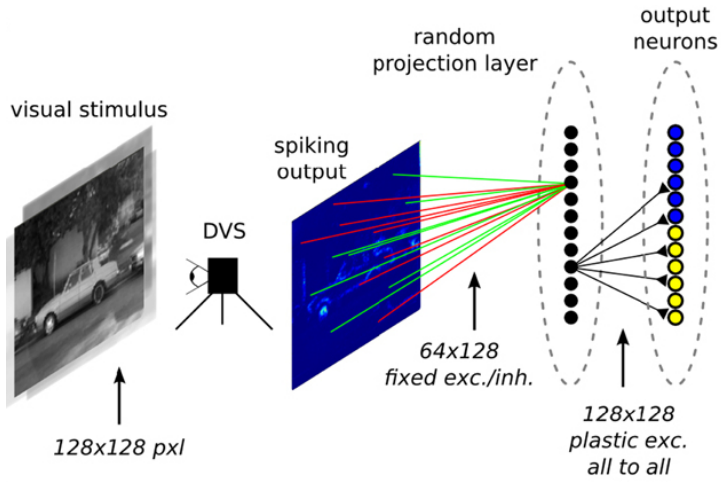


A reconfigurable on-line learning spiking neuromorphic processor comprising 256 neurons and 128K synapses

Qiao, Mostafa, Corradi, Osswald, Stefanini, Sumislawska, Indiveri, *Frontiers in neuroscience* 9 (2015): 141.



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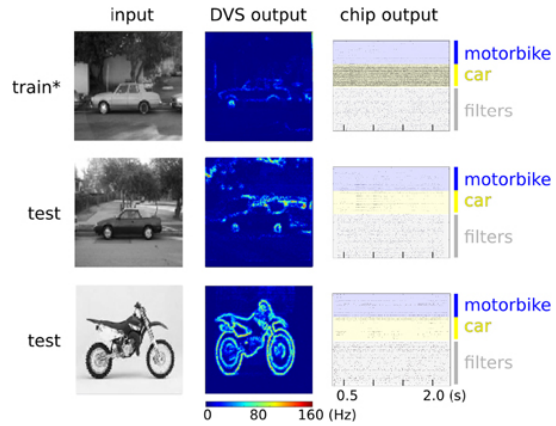

Test car: car pop. 11.1 Hz vs. motorbike pop. 7.1 Hz; Test motorbike: motorbike pop. 7.4 Hz vs. car pop. 4.9 Hz.

Merging the two approaches
(Mean firing rate + STDP)

PNAS

Calcium-based plasticity model explains sensitivity of synaptic changes to spike pattern, rate, and dendritic location

Michael Graupner[a,b,1] and Nicolas Brunel[a]

[a]Laboratory of Neurophysics and Physiology, Unité Mixte de Recherche 8119, CNRS and Université Paris Descartes, 75270 Paris Cedex 06, France; and [b]Center for Neural Science, New York University, New York, NY 10003-6603

Edited by Terrence J. Sejnowski, Salk Institute for Biological Studies, La Jolla, CA, and approved January 20, 2012 (received for review June 10, 2011)

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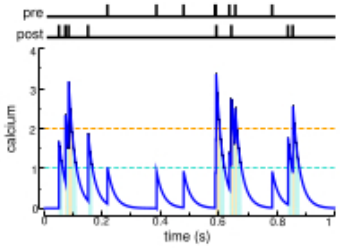

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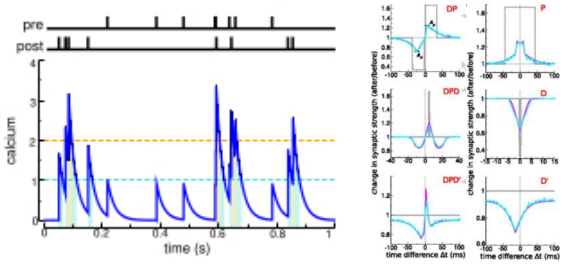

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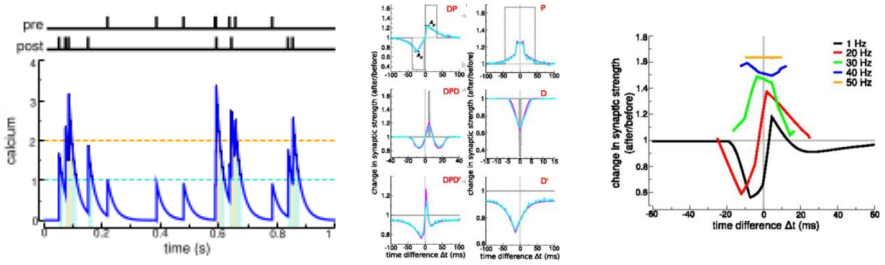
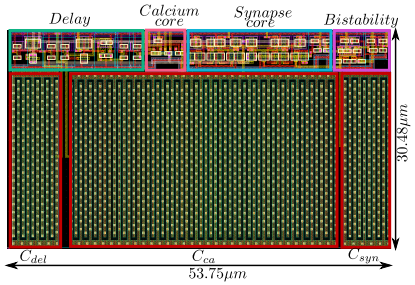
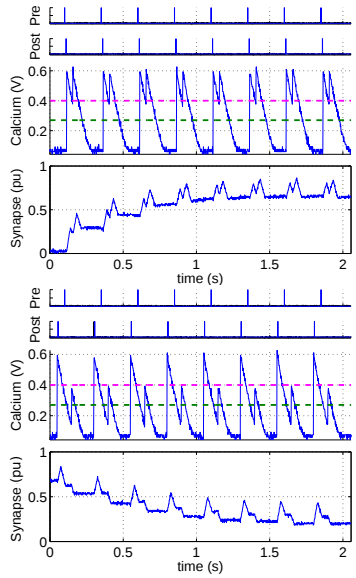


Chip data - Long term potentiation and depression

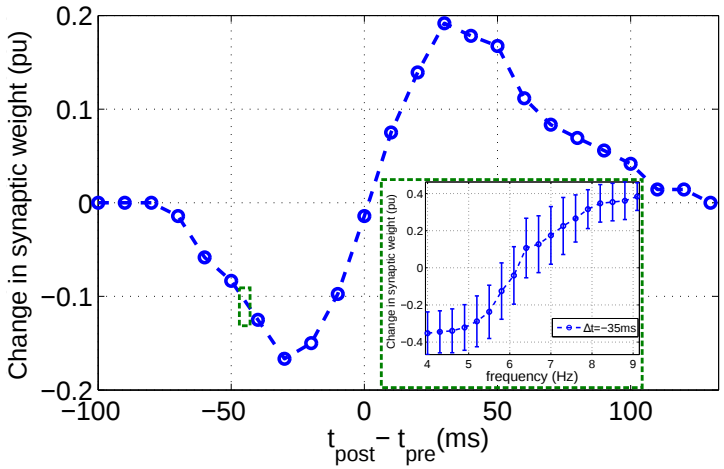
Maldonado et al., *IEEE Trans. on Circ. and Sys. I*, 2016





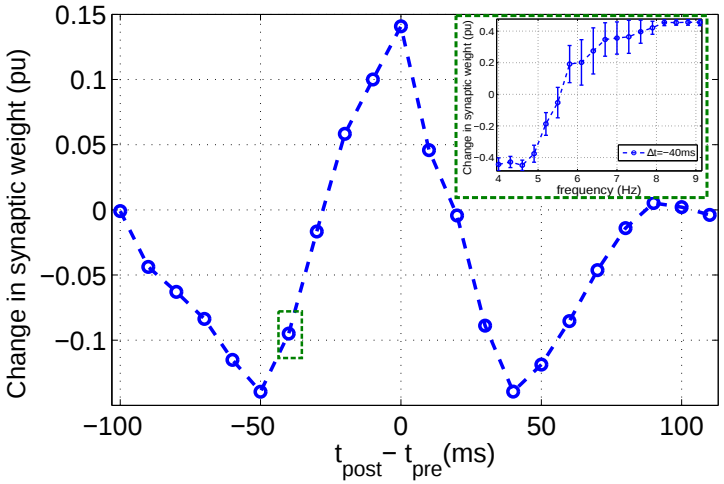
Chip data - Classical STDP

Maldonado et al., *IEEE Trans. on Circ. and Sys. I*, 2016



Chip data - Another form of STDP

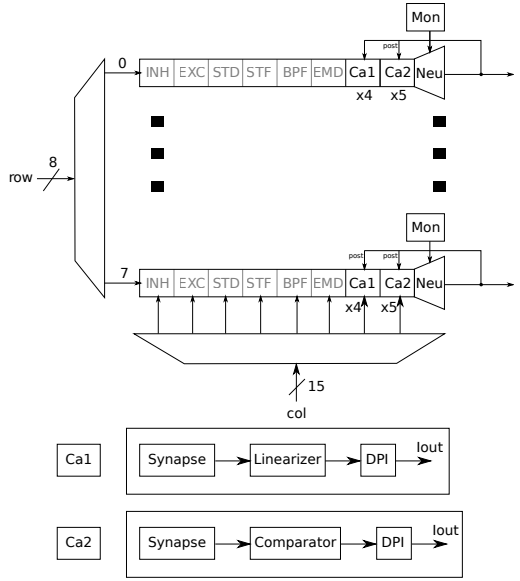
Maldonado et al., *IEEE Trans. on Circ. and Sys. I*, 2016



Small network on chip

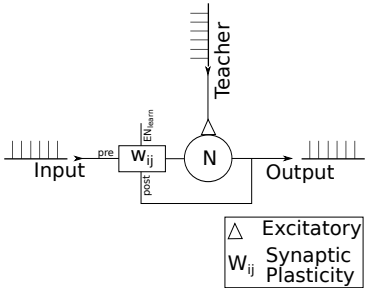
From single synapse to neural array

Unpublished data



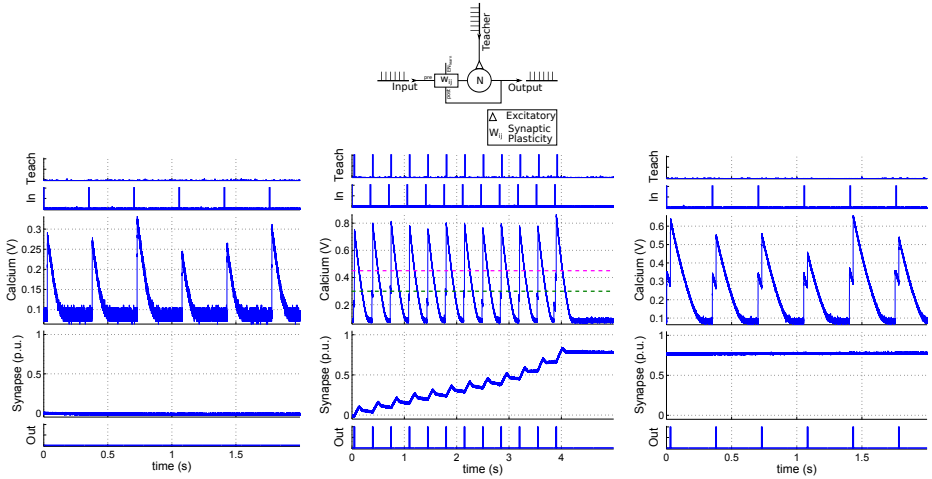
Chip data - Interaction with neurons

Single synapse experiment - unpublished data



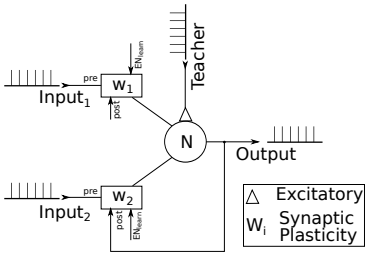
Chip data - Interaction with neurons

Single synapse experiment - unpublished data



Chip data - Interaction with neurons

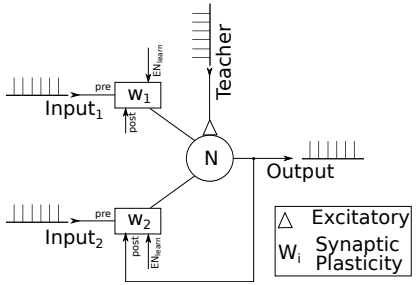
Two synapses experiment - unpublished data



	Pattern1	Pattern2
Input1	2.86 Hz	4 Hz
Input2	4 Hz	2.86 Hz
Teacher	2.86 Hz	4 Hz

Chip data - Interaction with neurons

Two synapses experiment - unpublished data



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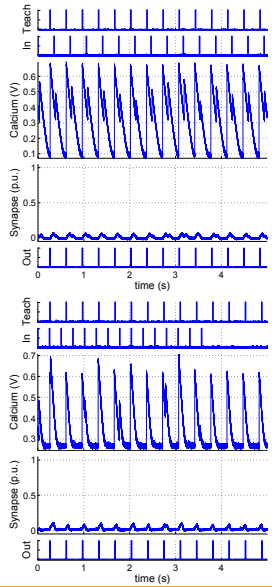
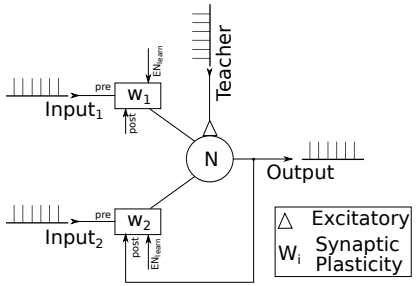


Chip data - Interaction with neurons

Two synapses experiment - unpublished data



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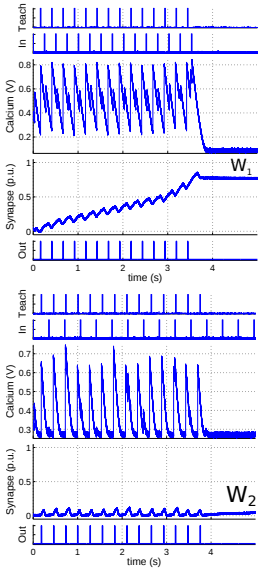
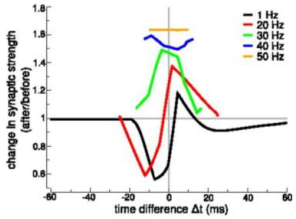
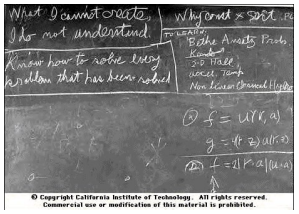


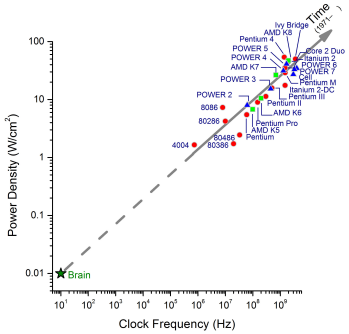
Conclusions

Toward a general learning model in silico





Source: `https://www.quora.com/`



Source: `http://www.research.ibm.com`

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WE ARE HIRING!

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