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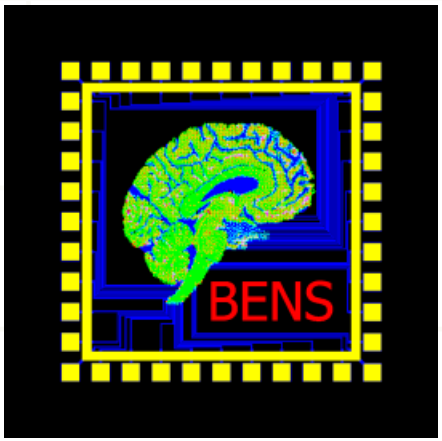
Neuromorphic Engineering: Computational Paradigms Inspired by the Brain



Tara Julia Hamilton
Biomedical Engineering and Neuroscience Group
The MARCS Institute,
University of Western Sydney

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Artificial Intelligence

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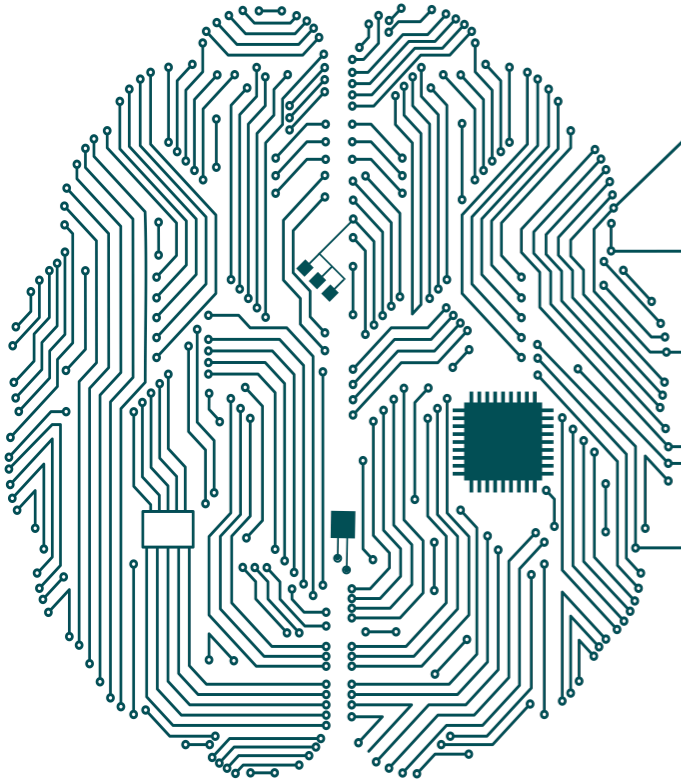

- It is self-learning
- It assumes
- It adapts
- It predicts
- It finds typical and untypical patterns
- It analyses and suggests the most valuable decisions for the user

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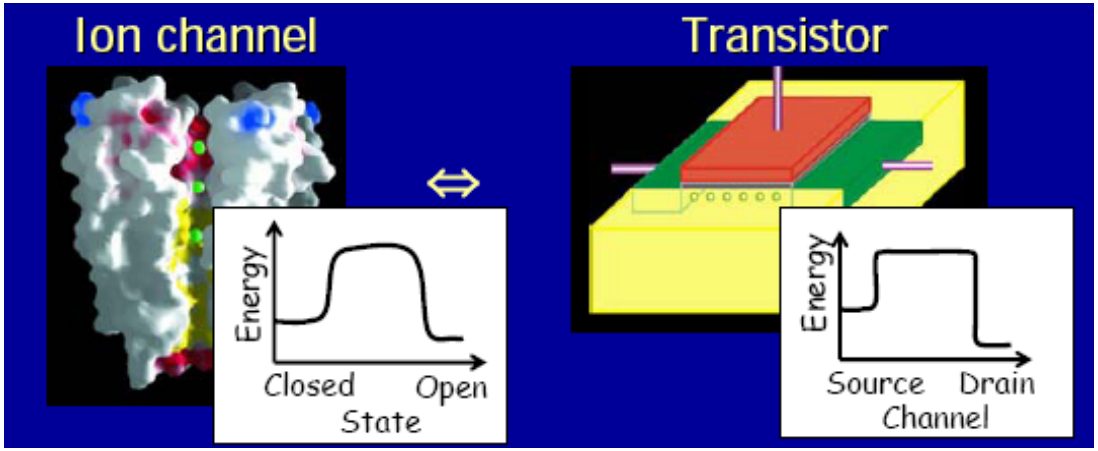

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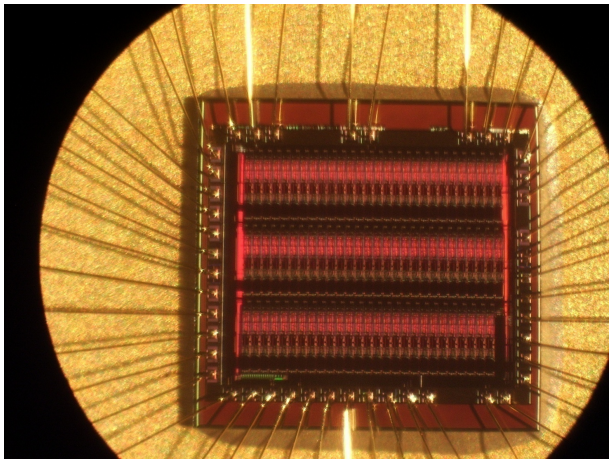

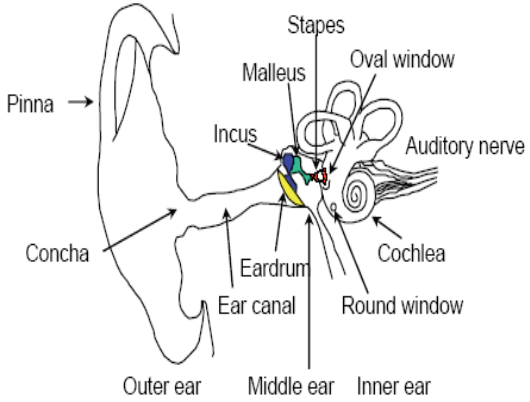

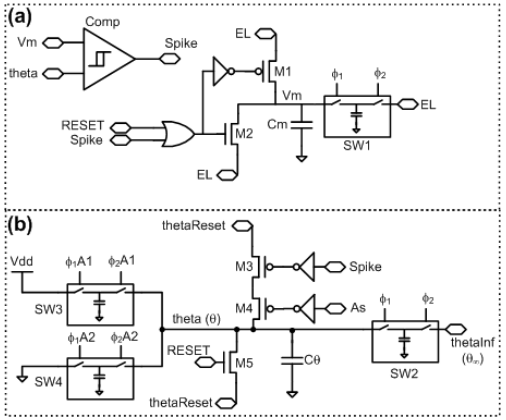

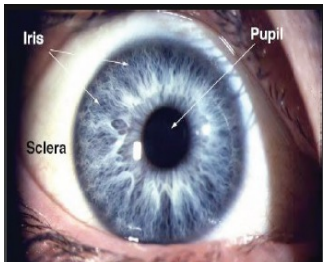

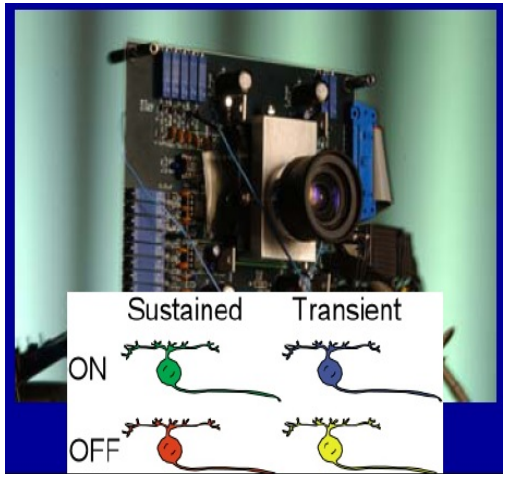

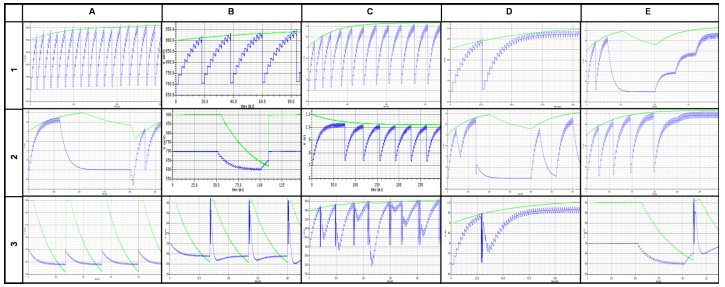

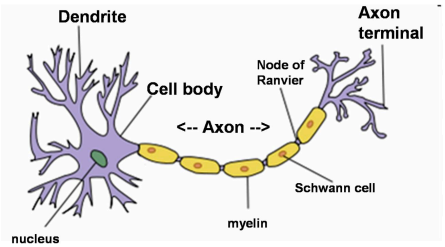

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Neuromorphic Engineering

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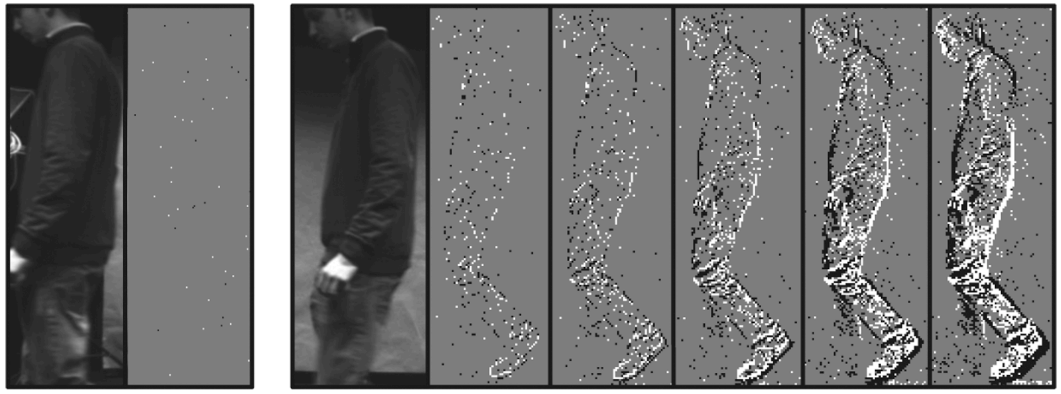
earSmart by Audience



(a) (b) (c) (d) (e) (f) (g) (h)

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Neuromorphic Chips

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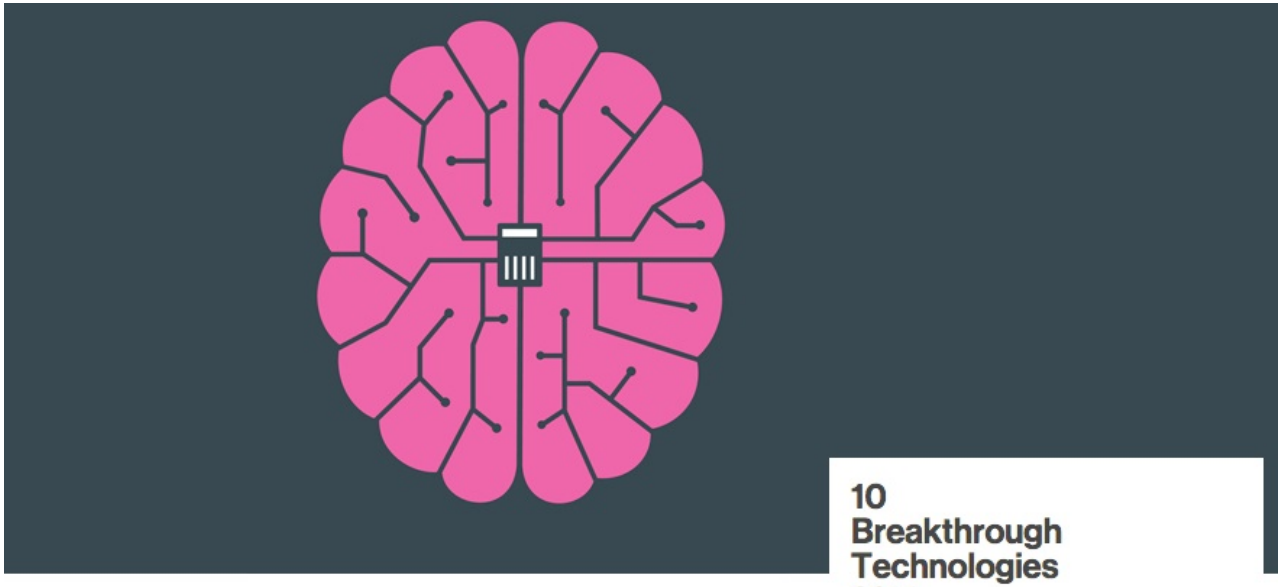

Neuromorphic Chips

Microprocessors configured more like brains than traditional chips could soon make computers far more astute about what's going on around them.

Breakthrough

An alternative design for computer chips that will enhance artificial intelligence.

Why It Matters

Traditional chips are reaching fundamental performance limits.

Key Players

+ Qualcomm
+ IBM
+ HRL Laboratories
+ Human Brain Project

10 Breakthrough Technologies 2014

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Neuromorphic Processors

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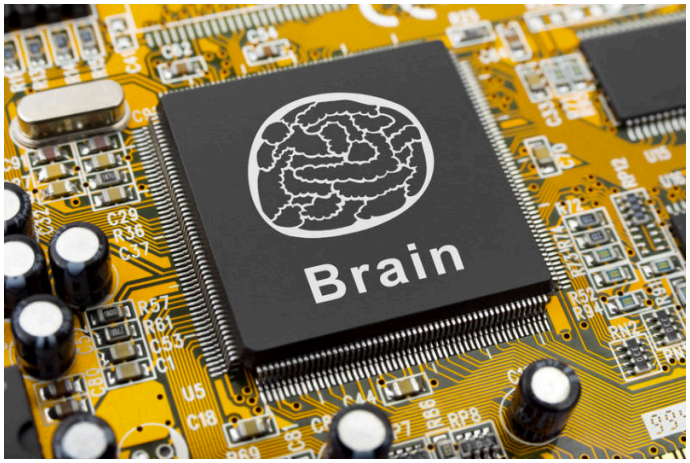
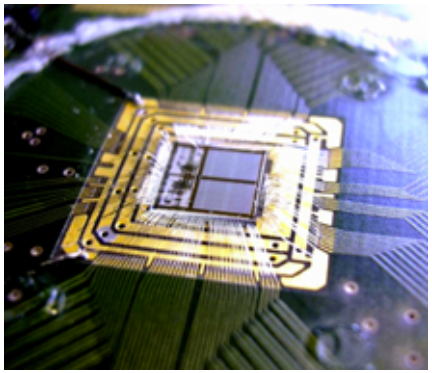
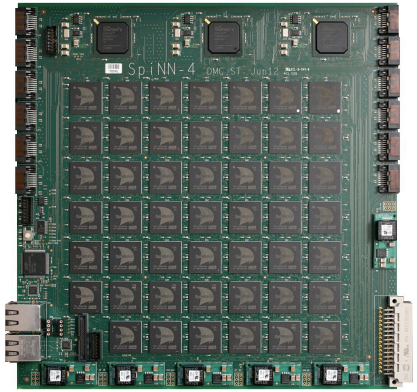
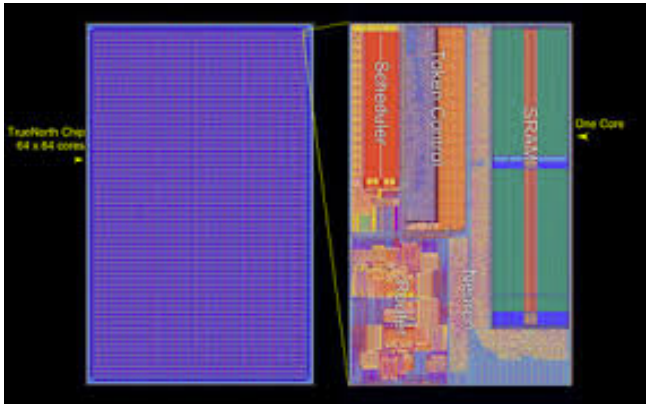




FACETS



SpiNNaker



IBM TrueNorth

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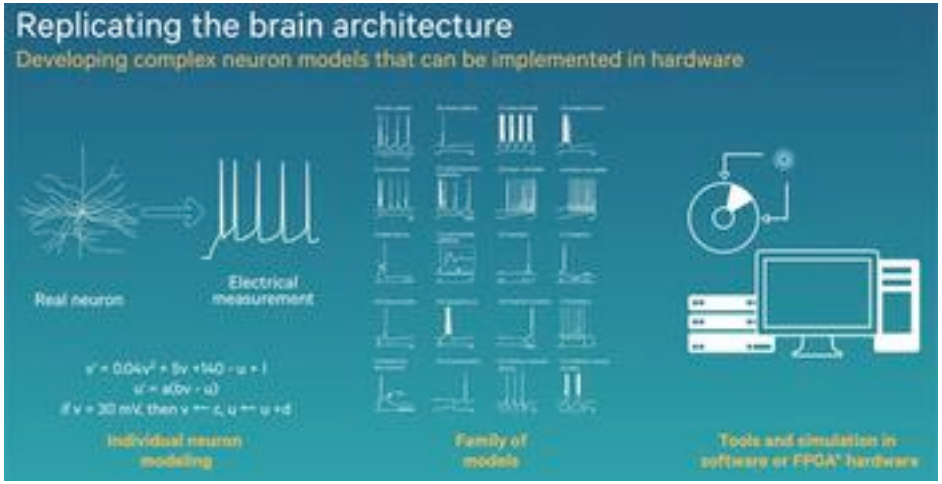
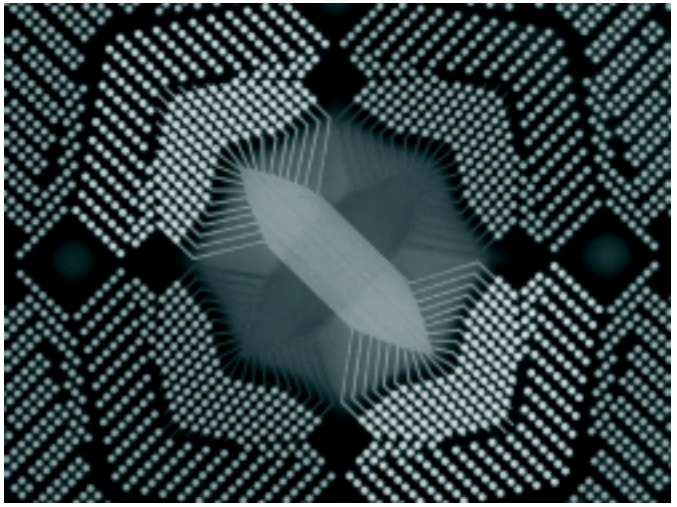


Qualcomm Zeroth Chip



HP SyNAPSE Memristors

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Neuromorphic Engineering

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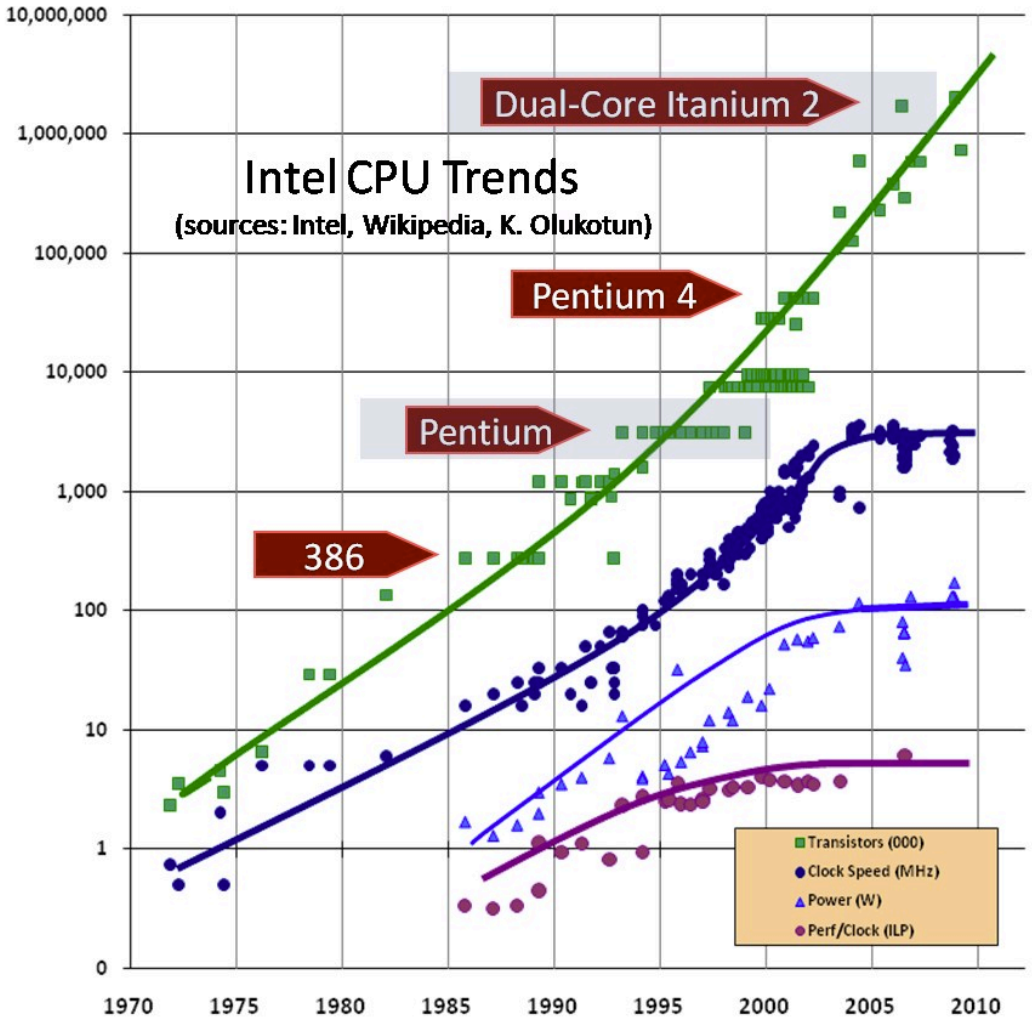

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Stochastic Electronics

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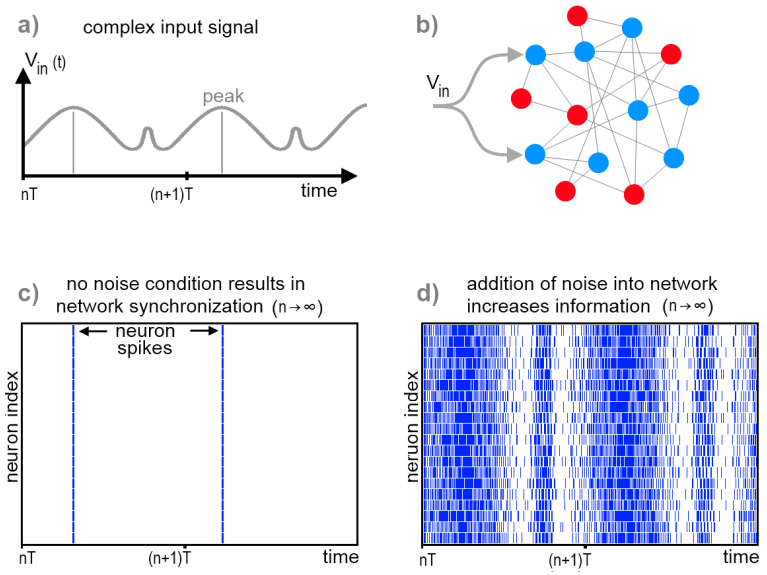

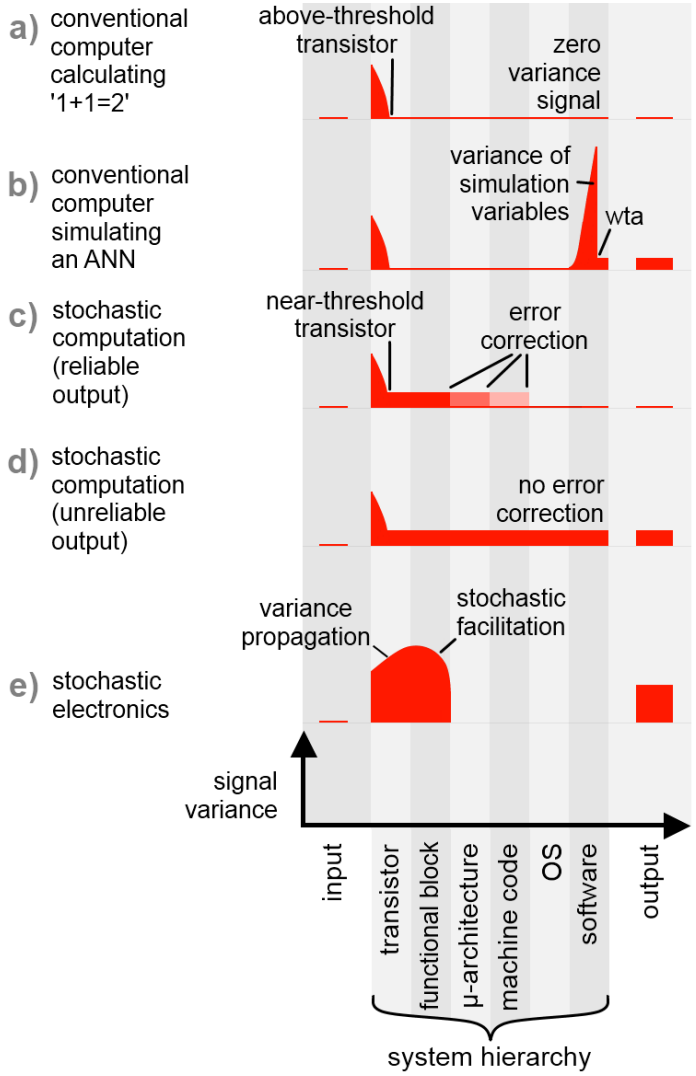

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Computation

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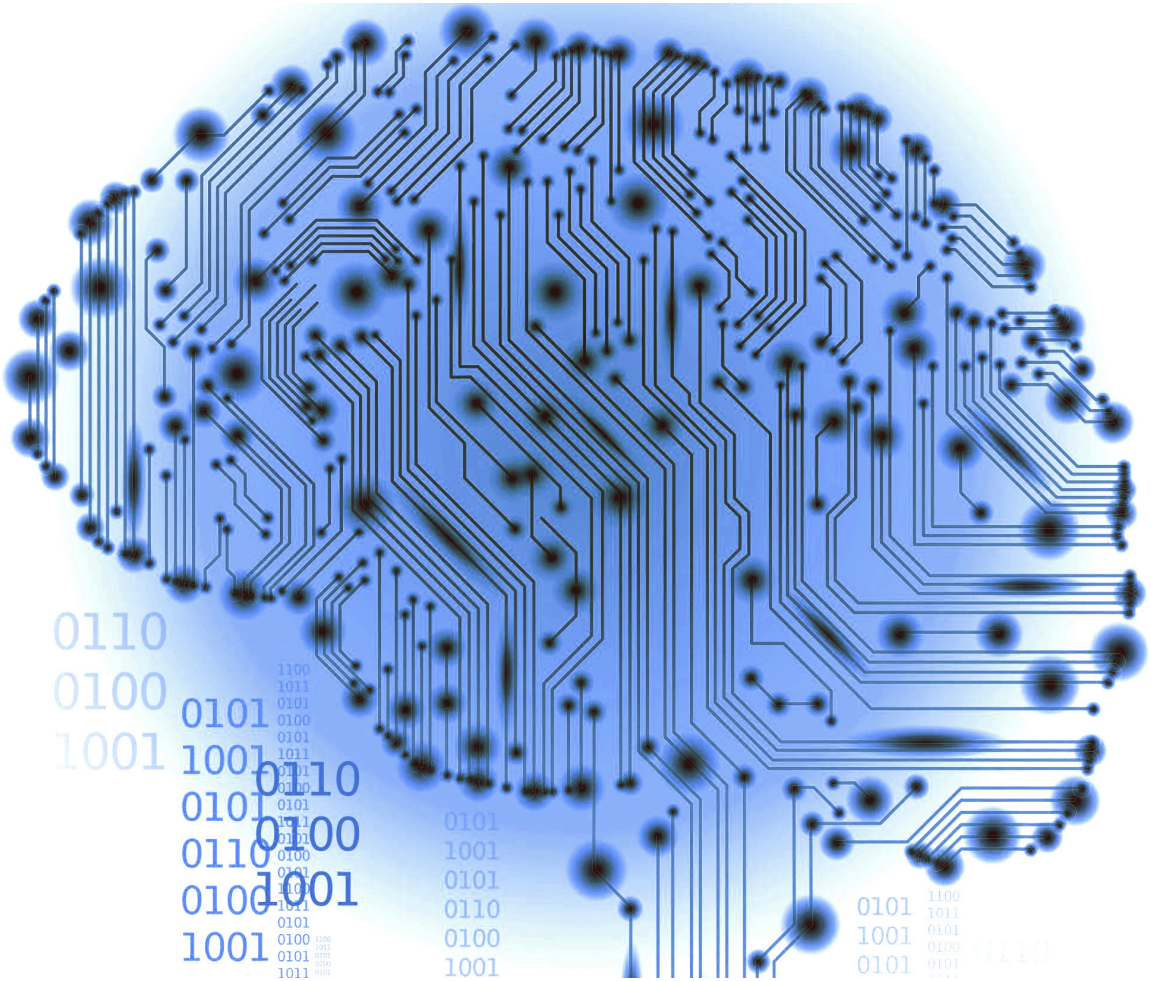
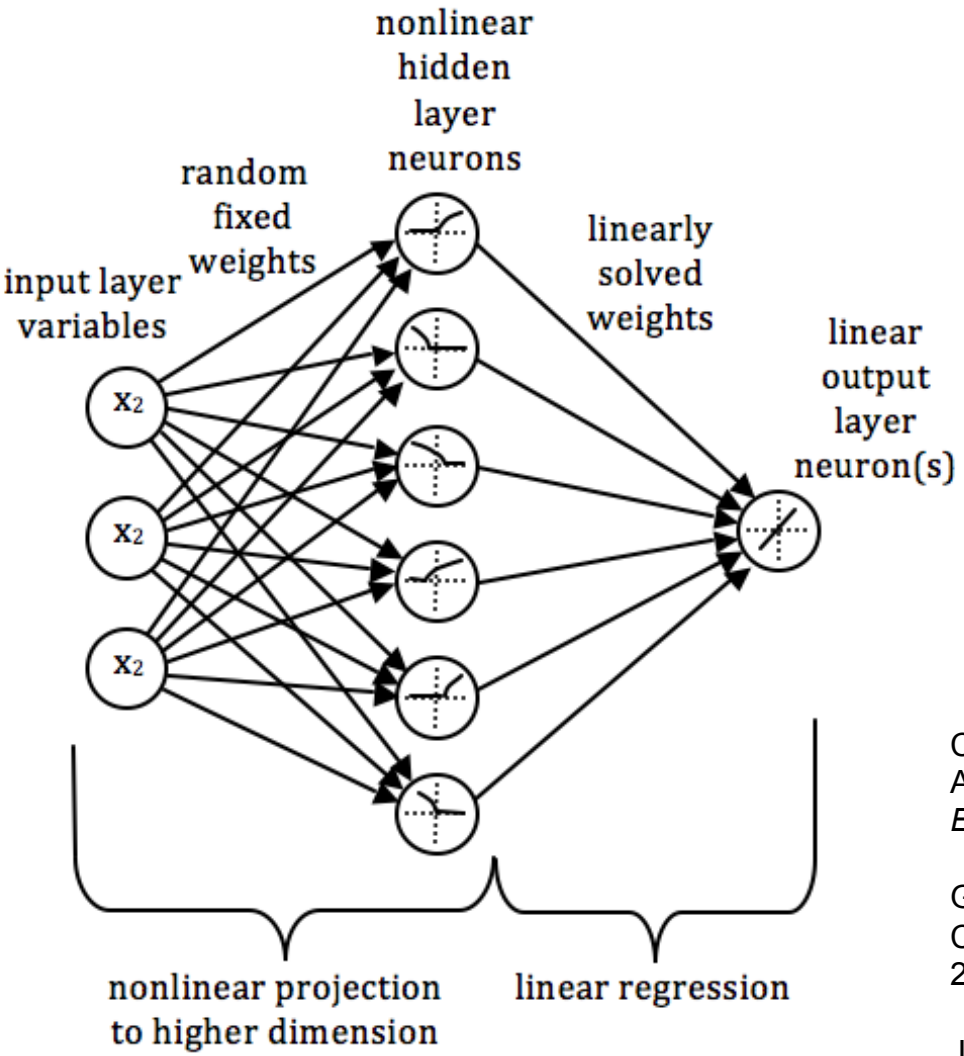


Linear Solutions of Higher Dimensional Interlayers



C. Eliasmith and C. Anderson, *Neural Engineering*, 2003.

G.-B. Huang, Q.-Y. Zhu, and C.-K. Siew *Neurocomputing*, 2006.

J. Tapson and A. van Schaik, *Neural Networks*, 2013.

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Example: Extreme Learning Machine - definition

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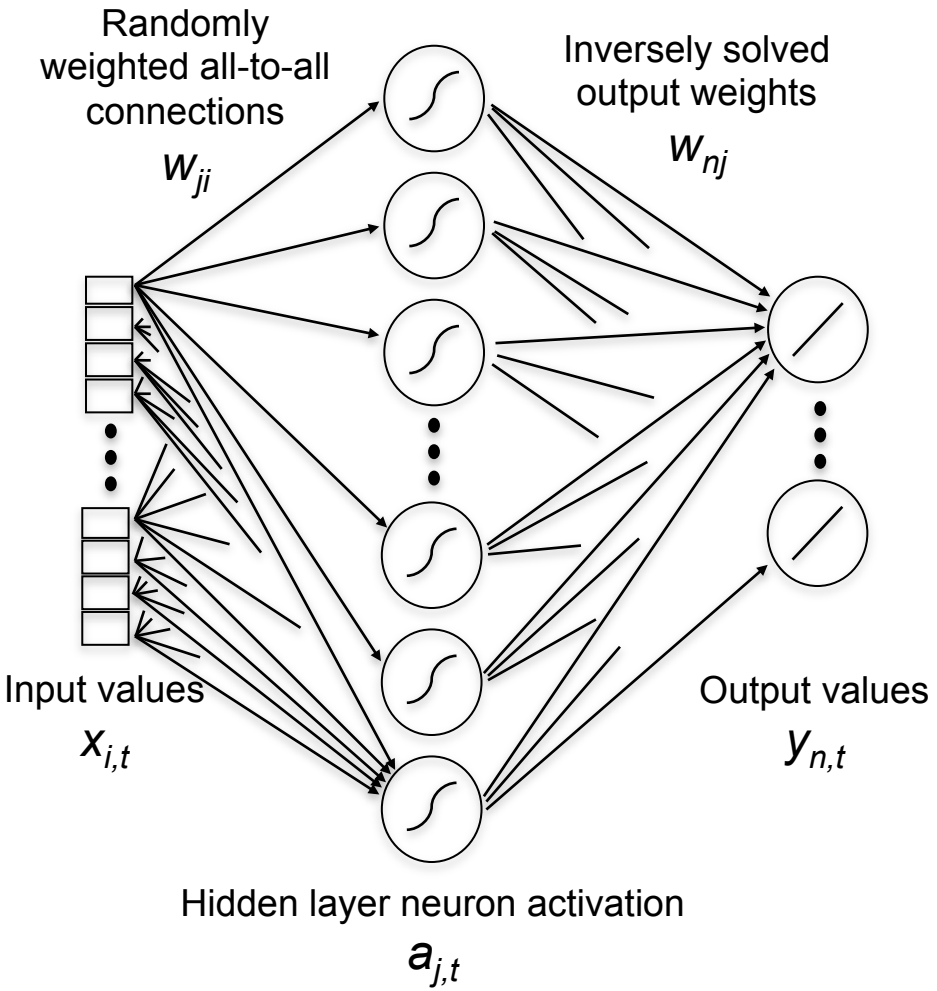
$$y_{n,t} = \sum_{j=1}^{M} w_{nj}^{(2)} f\left(\sum_{i=1}^{L} w_{ji}^{(1)} x_{i,t}\right)$$

$$a_{j,t} = f\left(\sum_{i=1}^{L} w_{ji}^{(1)} x_{i,t}\right)$$

$$WA = Y$$

$$W = YA^{+}$$



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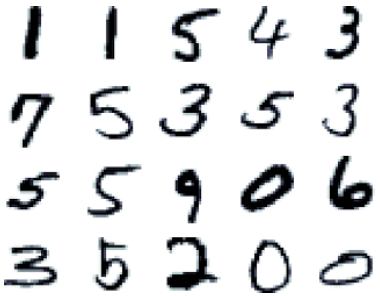
Results on MNIST



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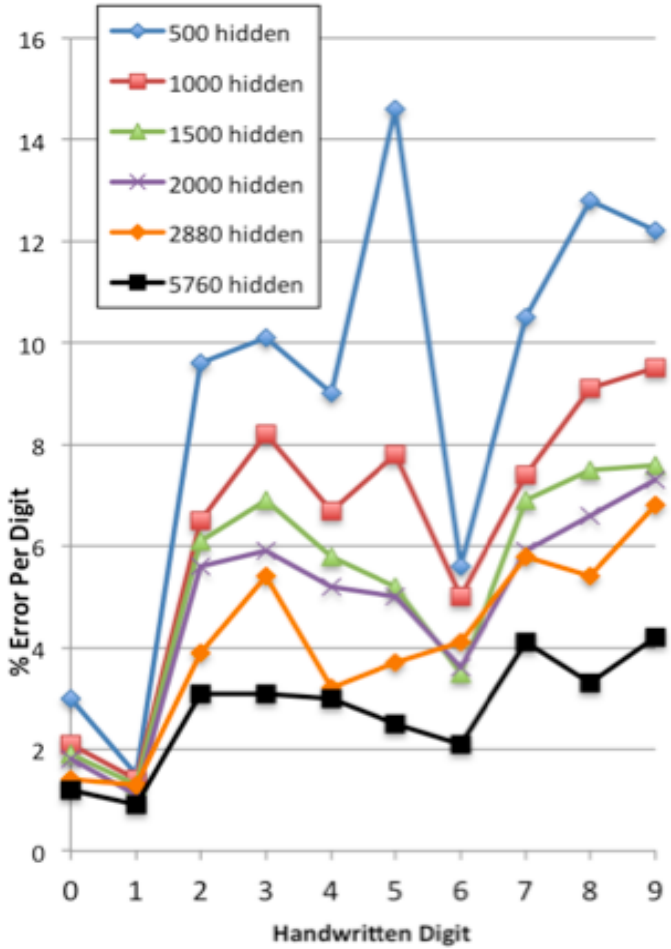

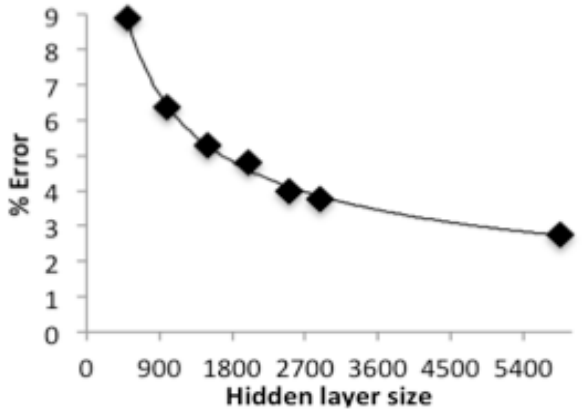

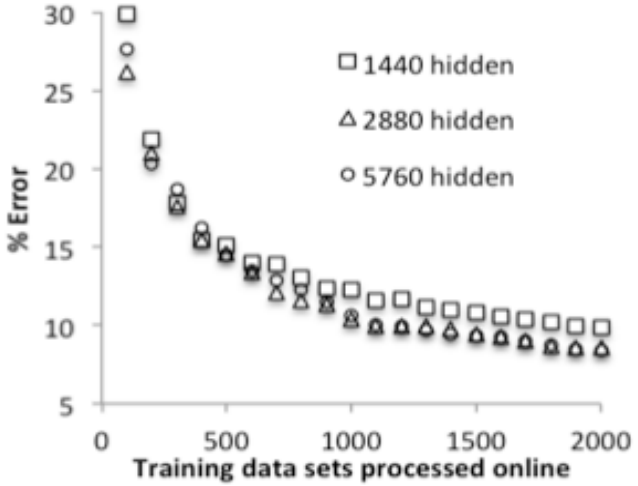

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The Synaptic Kernel Inverse Method (SKIM)

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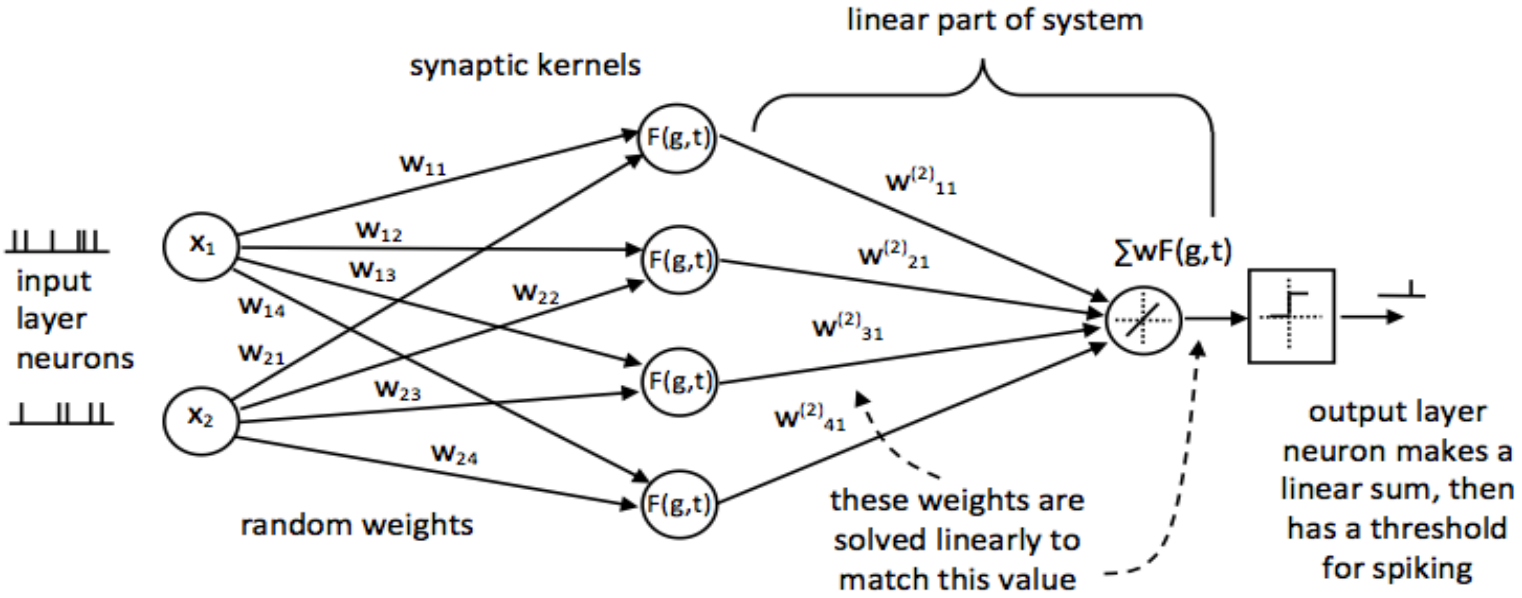

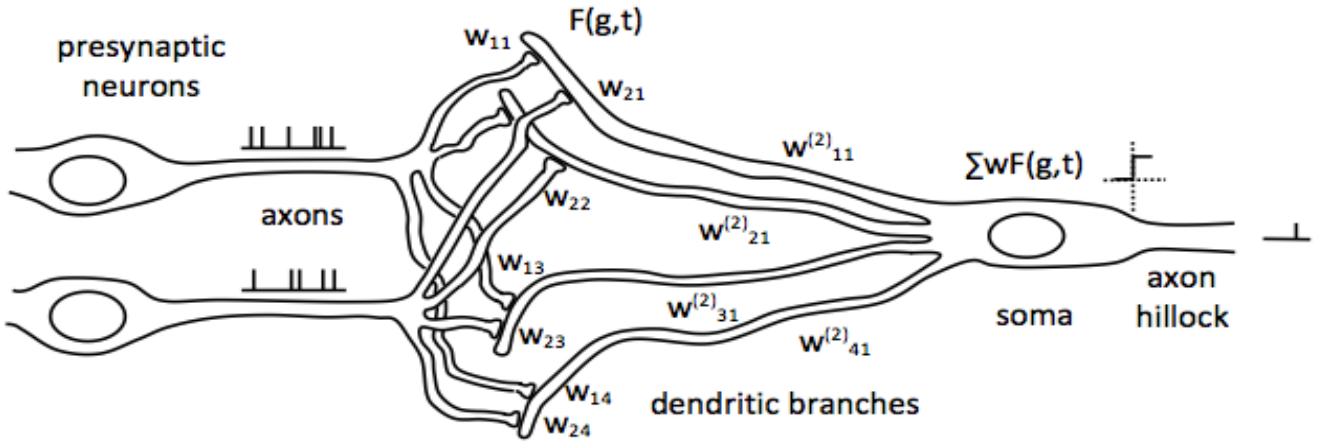

J. Tapson et al., *Frontiers in Neuroscience*, 2013.

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The Synaptic Kernel Inverse Method (SKIM)

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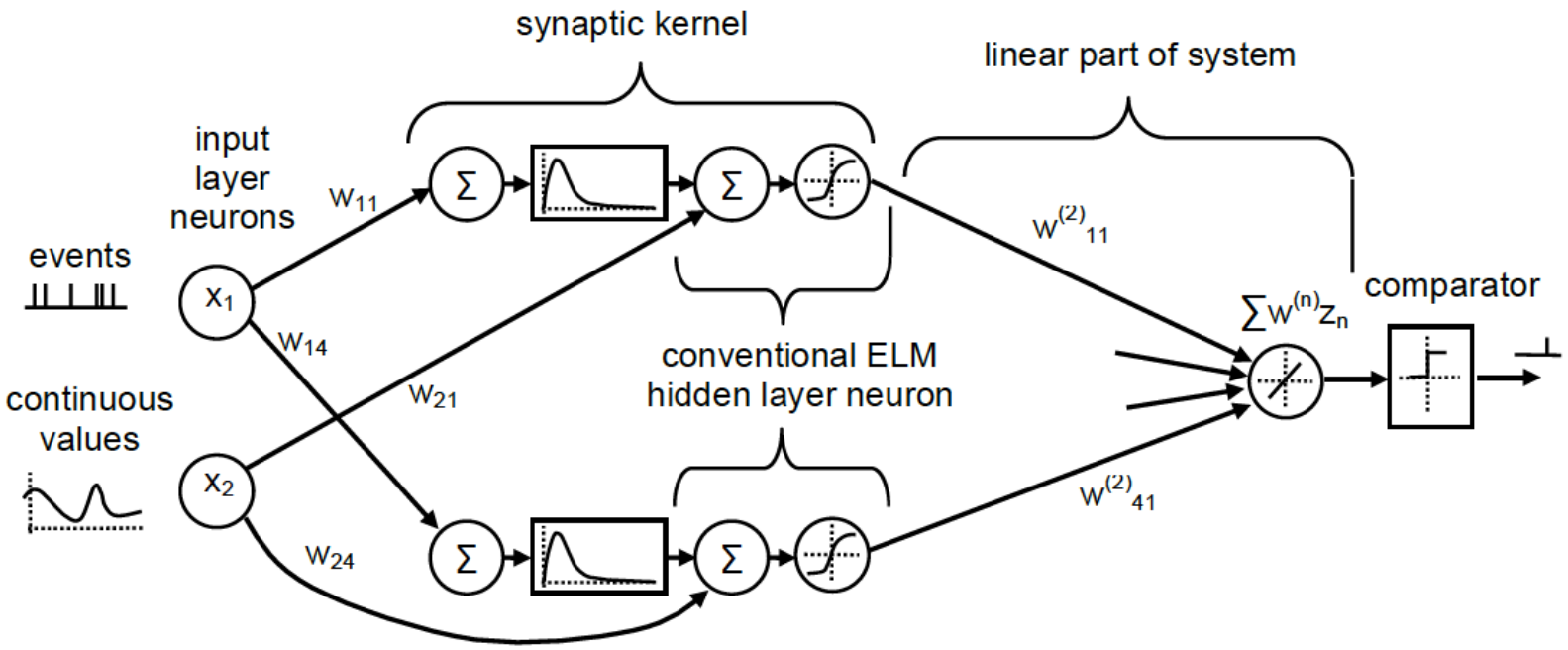
- We copy the way mammalian neurons work:
  - We convert the spike event into a continuous-time function, at the synapses
  - We weight the inputs from different synapses and sum them at the soma
  - We learn the correct weights with which to combine the synaptic signals



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Implementation on silicon

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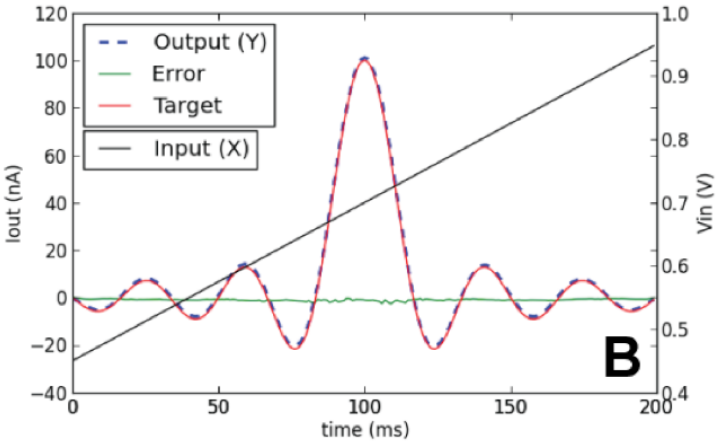
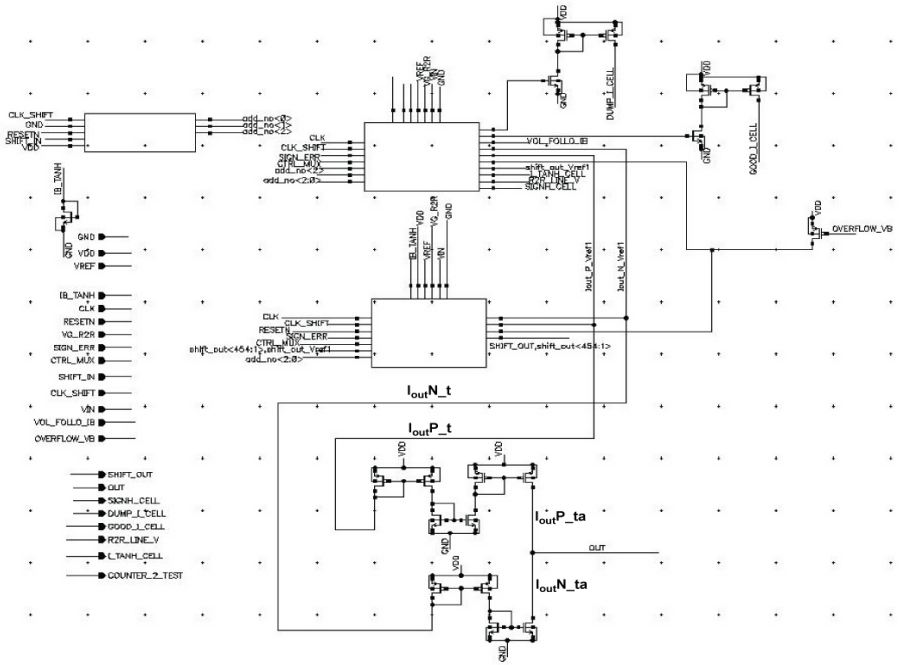
Issues:

Random connections
-> process mismatch
Tunable weights
-> multiplying DACS
Pseudoinverse computation
-> gradient descent



A.



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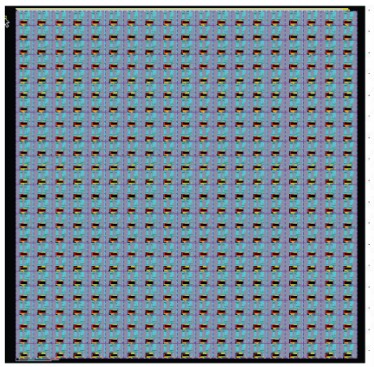

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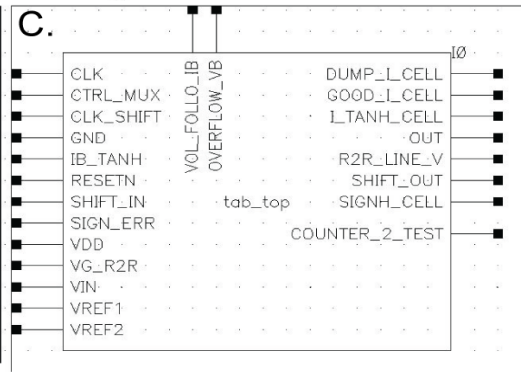

Custom aVLSI circuit

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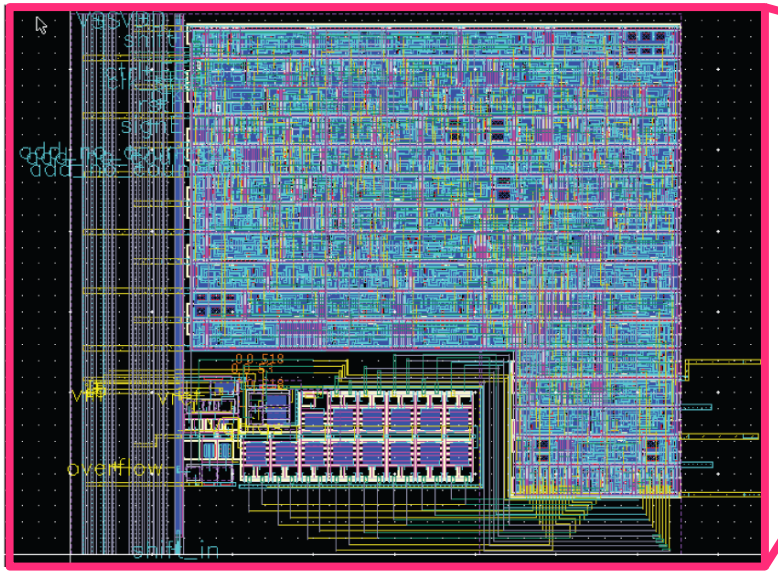
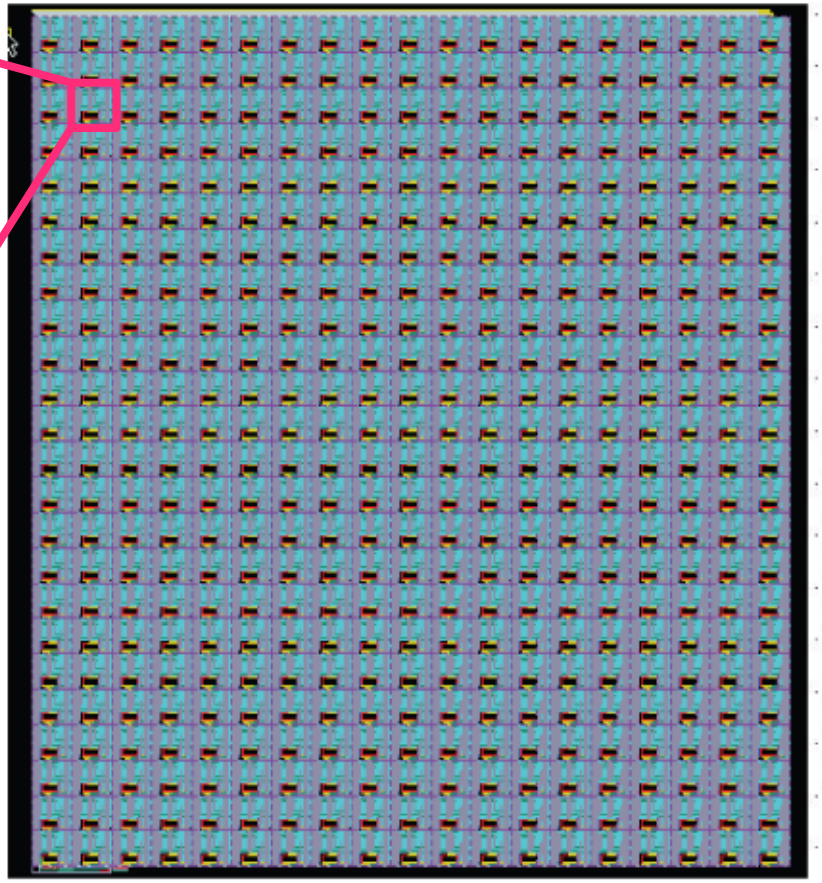
Neuron block



Top Level Tab



SISO TAB IC fabricated in TSMC65nm technology (1 mm^2)
Total 456 neurons.

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Trainable Analog Block

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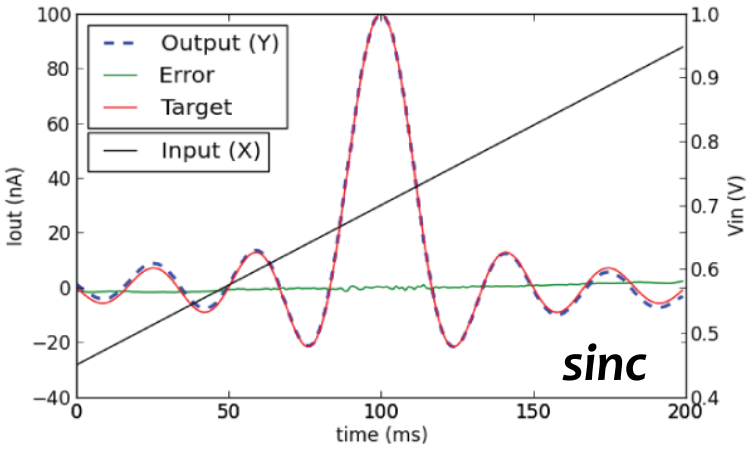
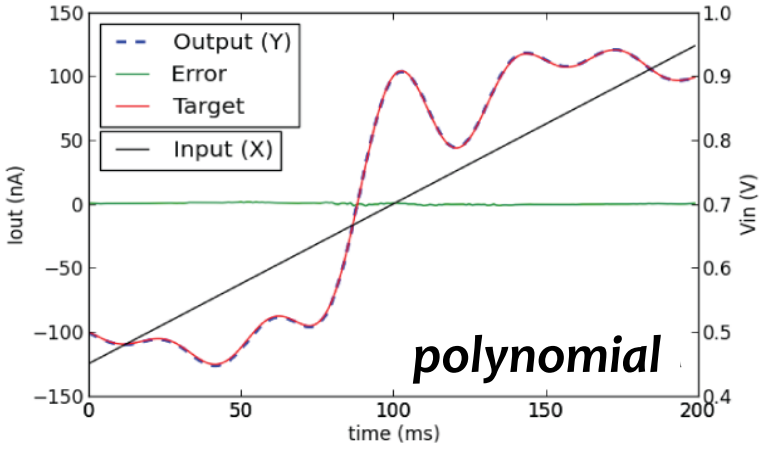
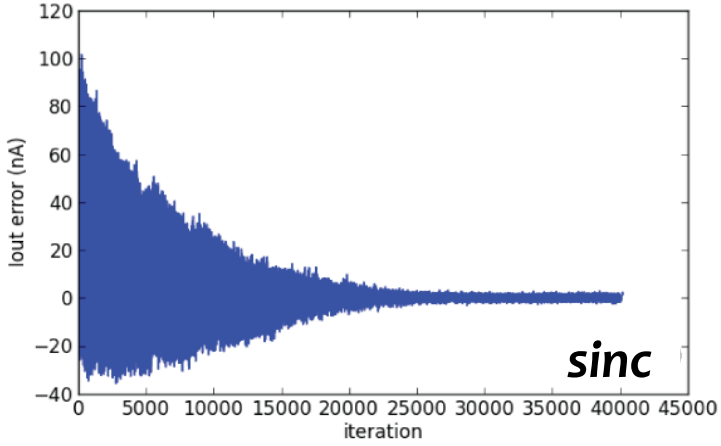
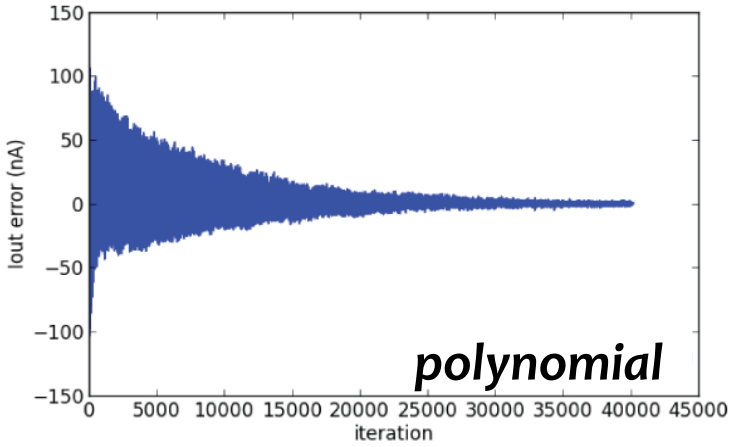
Trained function (*dashed curve*) predicts the correct output value (*red curve*)





Error converges to minimum over the learning process





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FPGA Approach

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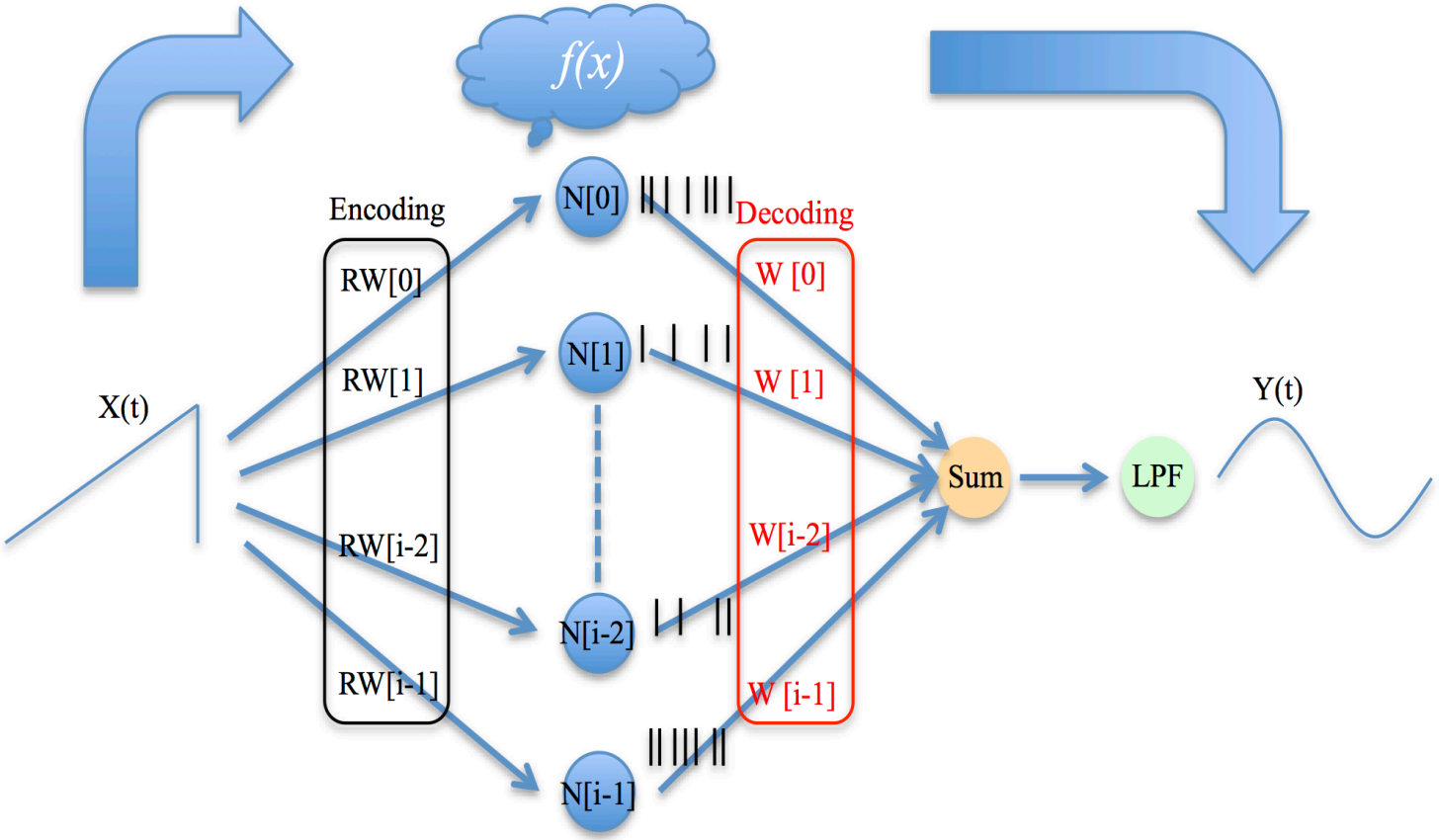

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FPGA results

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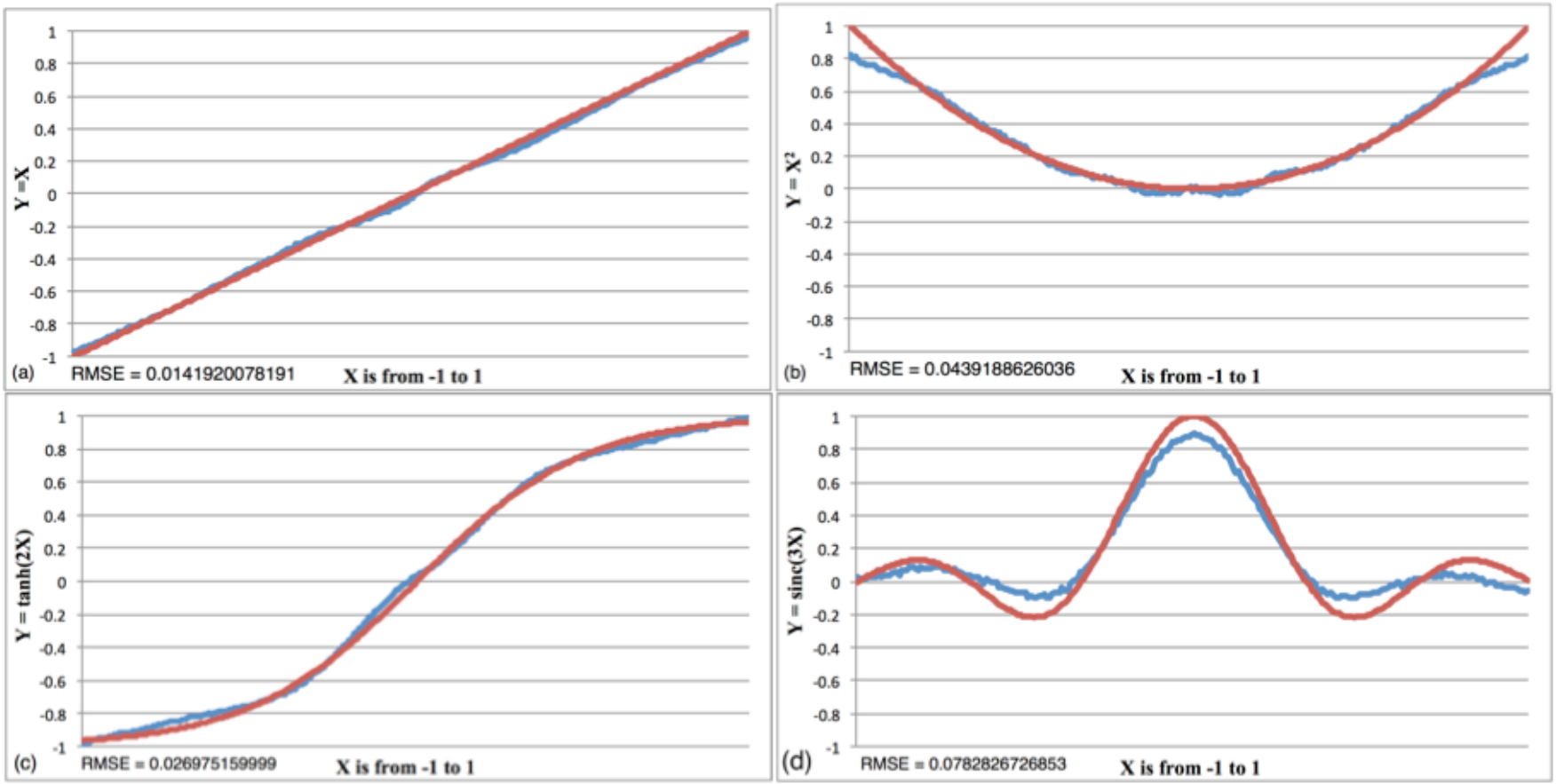

Clockwise from top left: $y = k.x$, $y = x^2$, $y = \tanh(x)$, $y = \mathrm{sinc}(x)$

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Neural Simulator

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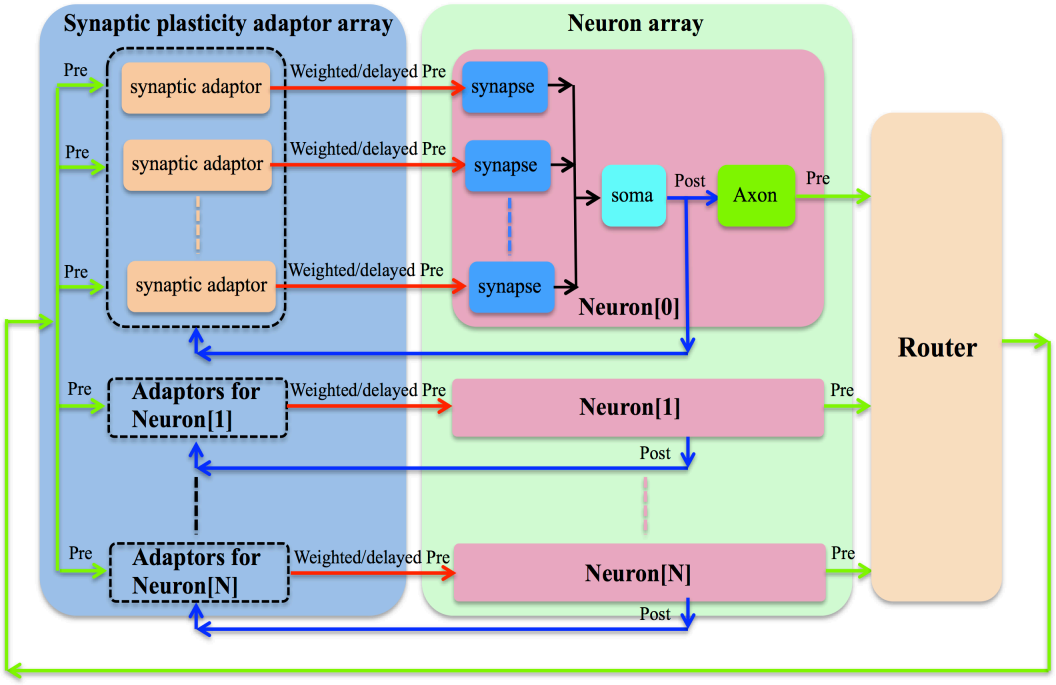
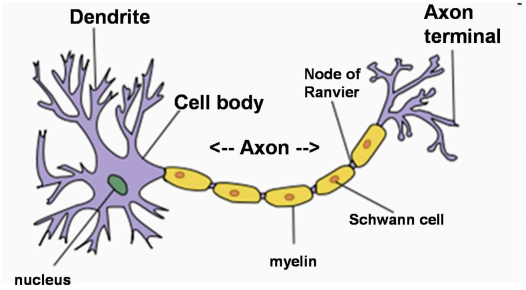
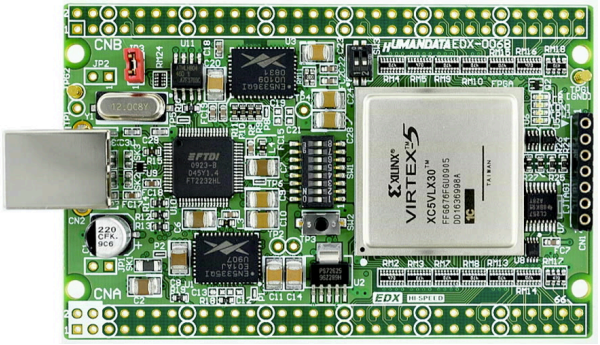


MegaSimulator:
64×10^9 Synapses





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Smart Sensing

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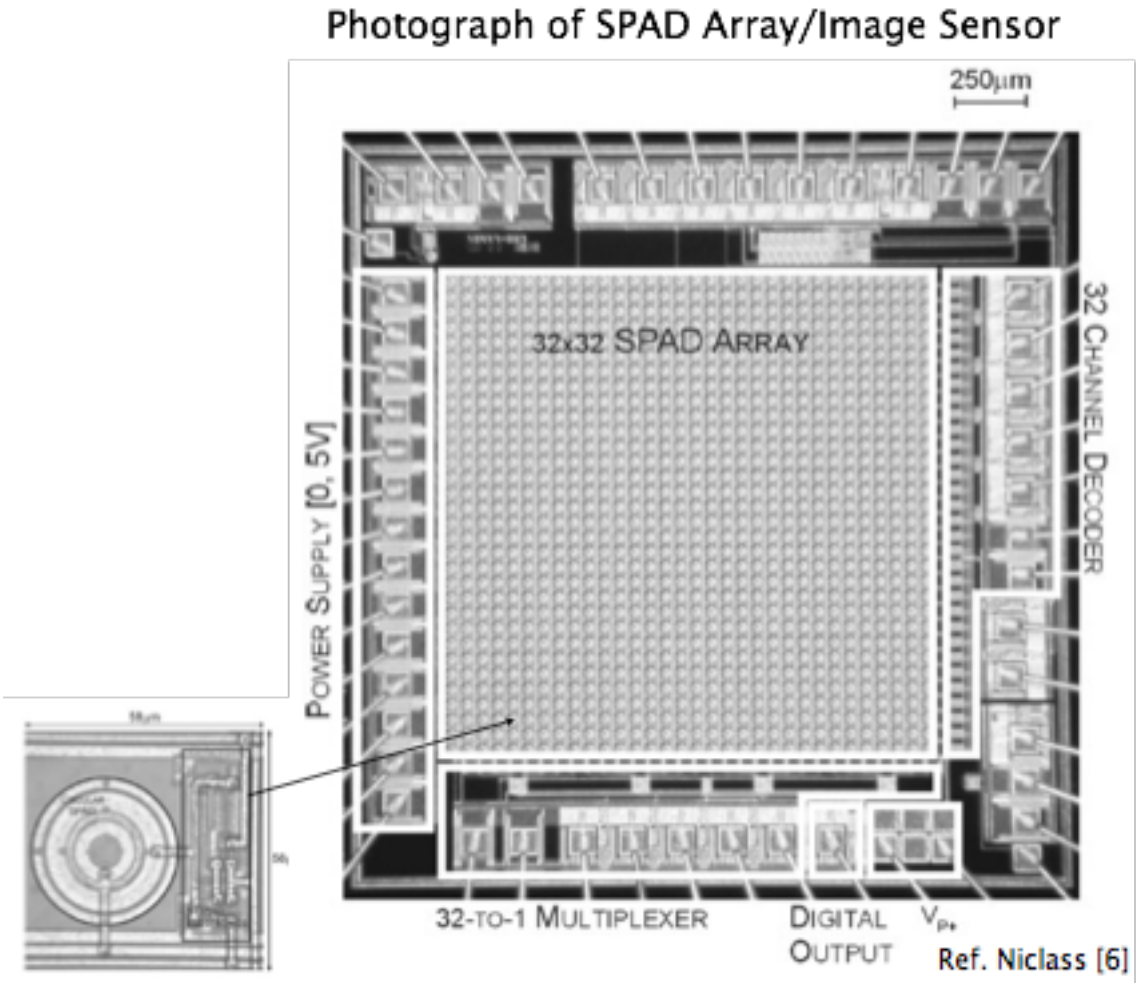

Source: Dr. Dennis Delic, DSTO

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LIDAR with SPAD

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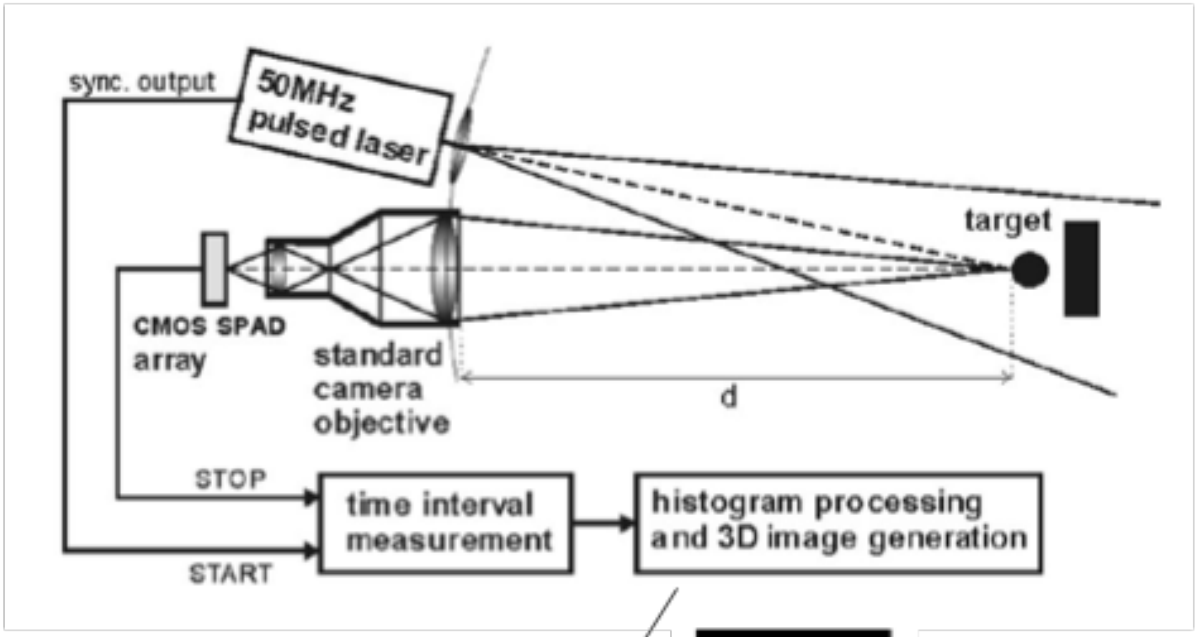
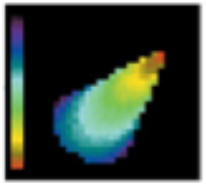
Basic Setup: Photon Timing.

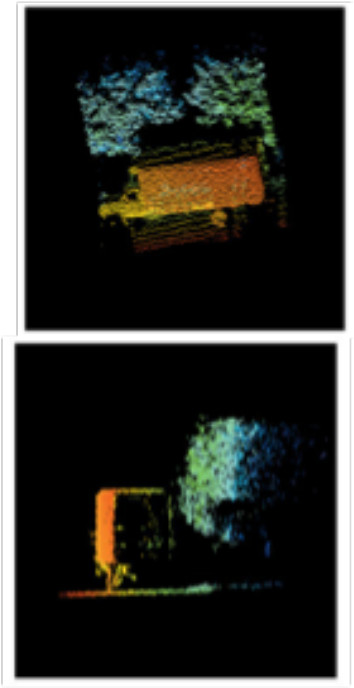
Source: Dr. Dennis Delic, DSTO

Using Ranging Mode (TOF) as opposed to Time-Correlated Single Photon Counting (TCSPC).



Pixels are color-coded with range





Example target: truck next to a tree.

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SPAD array processing

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Traditional Approach

spatio-temporal pattern
generated by SPAD array
is encoded into pixel values

16 bit pixels

16 bit bus

off-chip processing

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Spatio-Temporal Pattern Recognition

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- There are ongoing debates about the information content (coding) in spikes
  - Rate codes
  - Time or interval codes
  - Place codes
  - Population codes

- Spatio-temporal pattern recognition offers a method for processing all of these types of codes

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SPAD array processing

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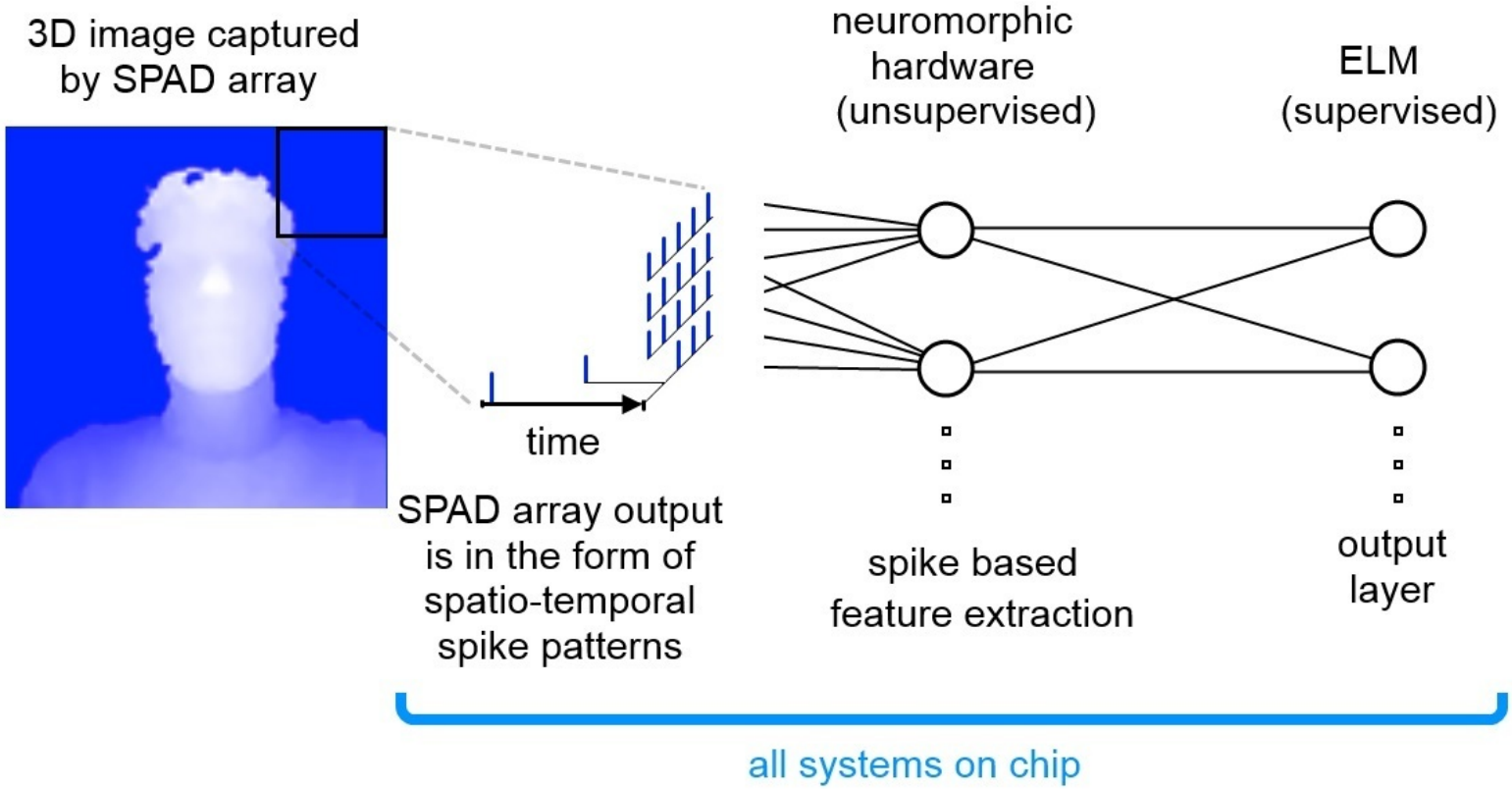
Our Approach



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Synaptic Kernel Adaptation Neuron (SKAN)

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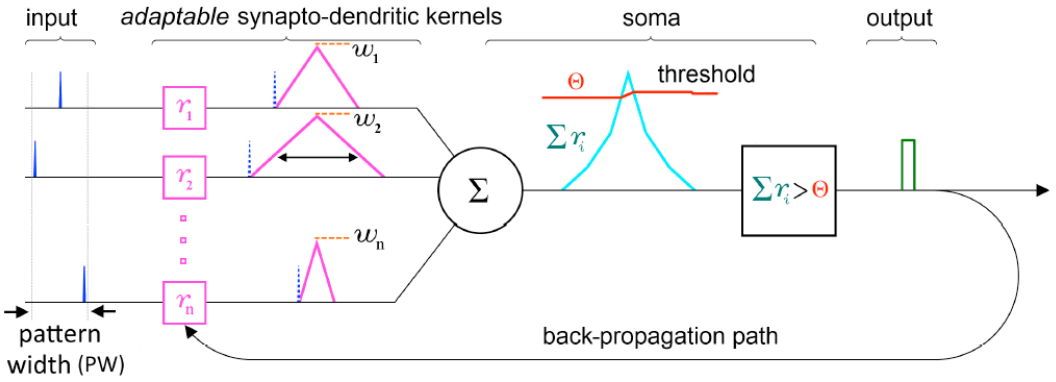

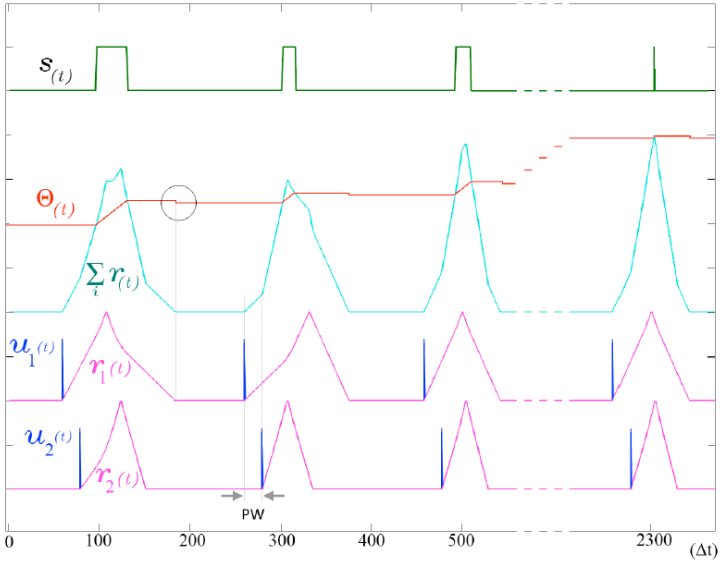

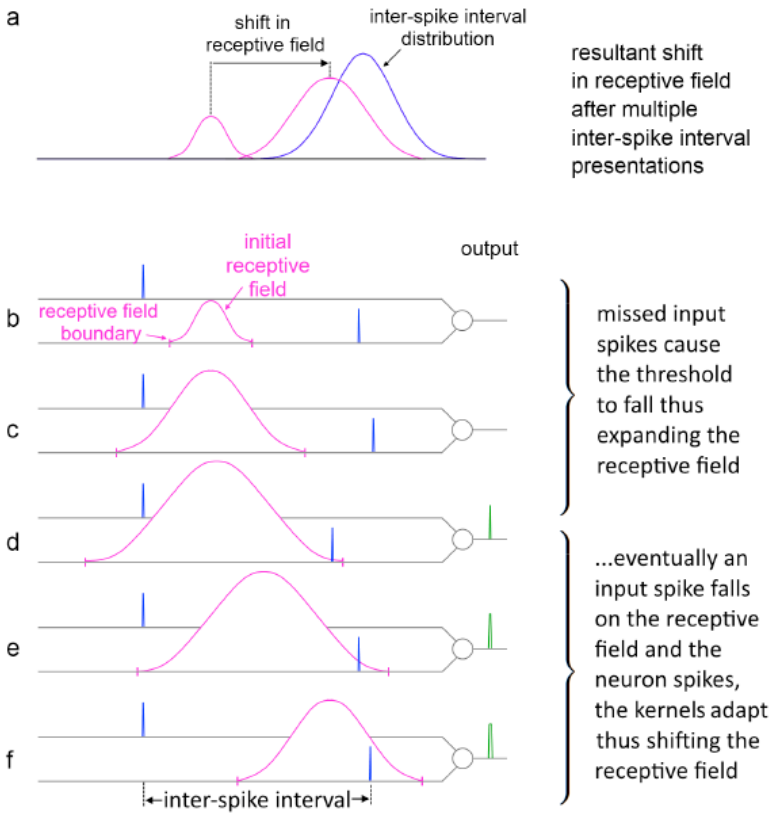

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3D recognition with an ELM

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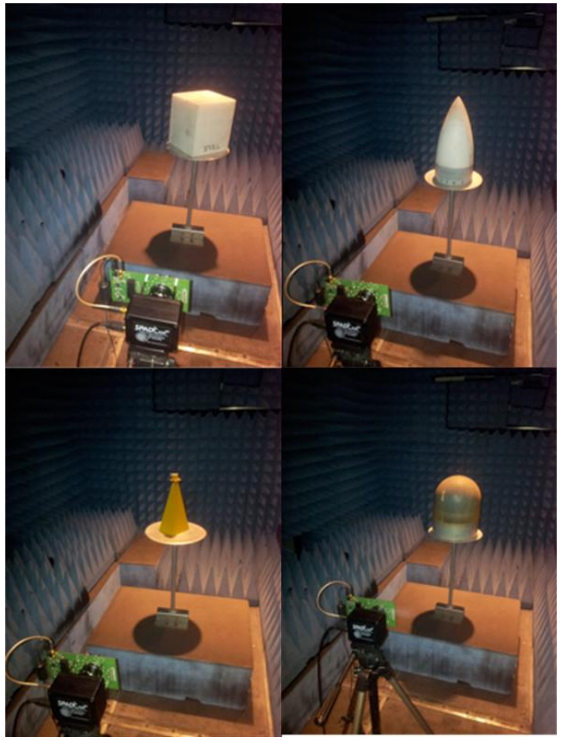

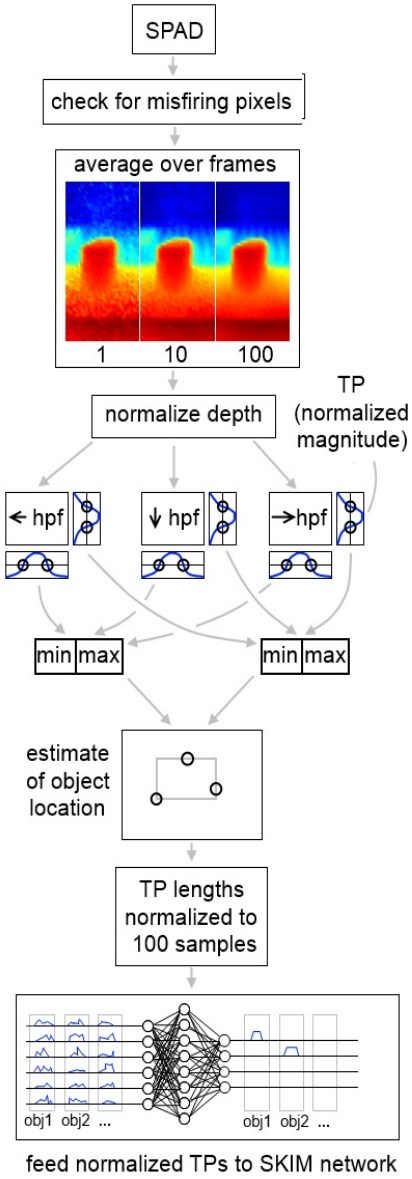

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3D recognition with an ELM

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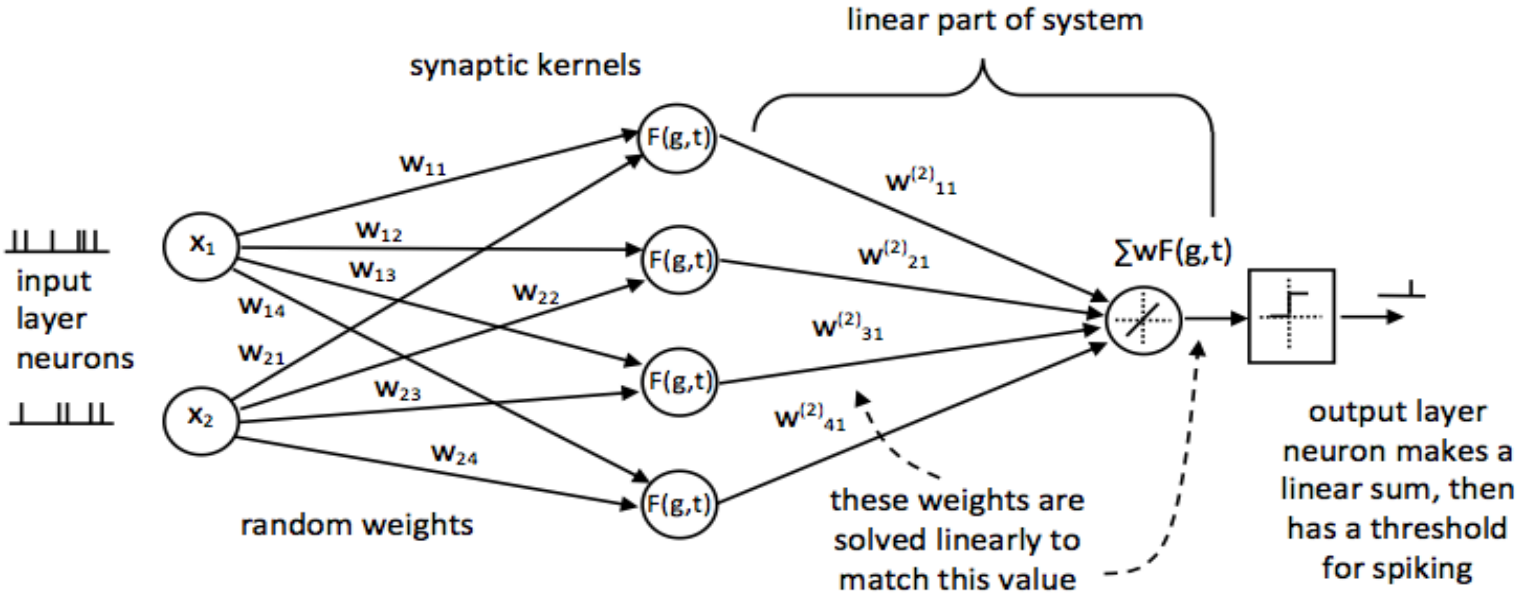

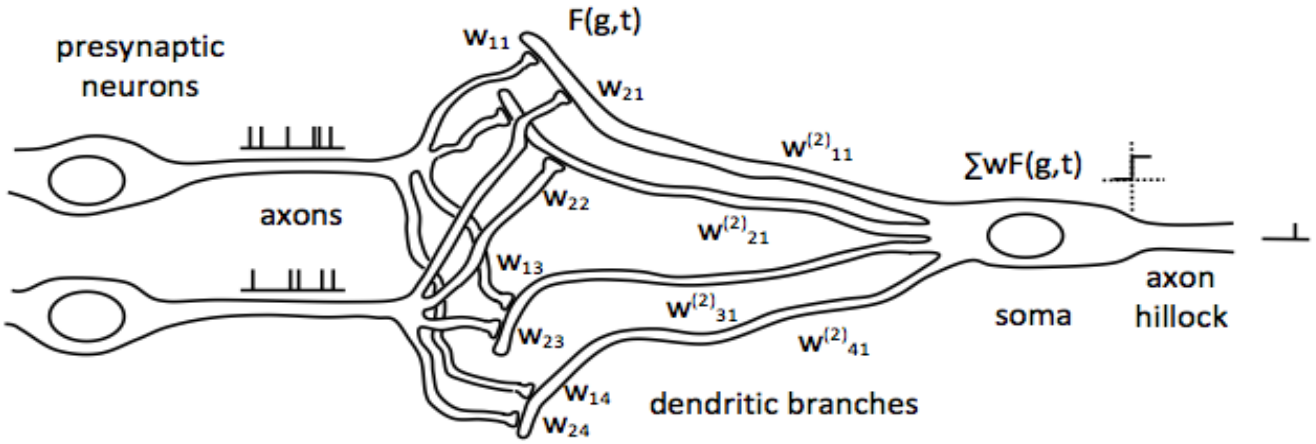

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Extension to Deep Networks

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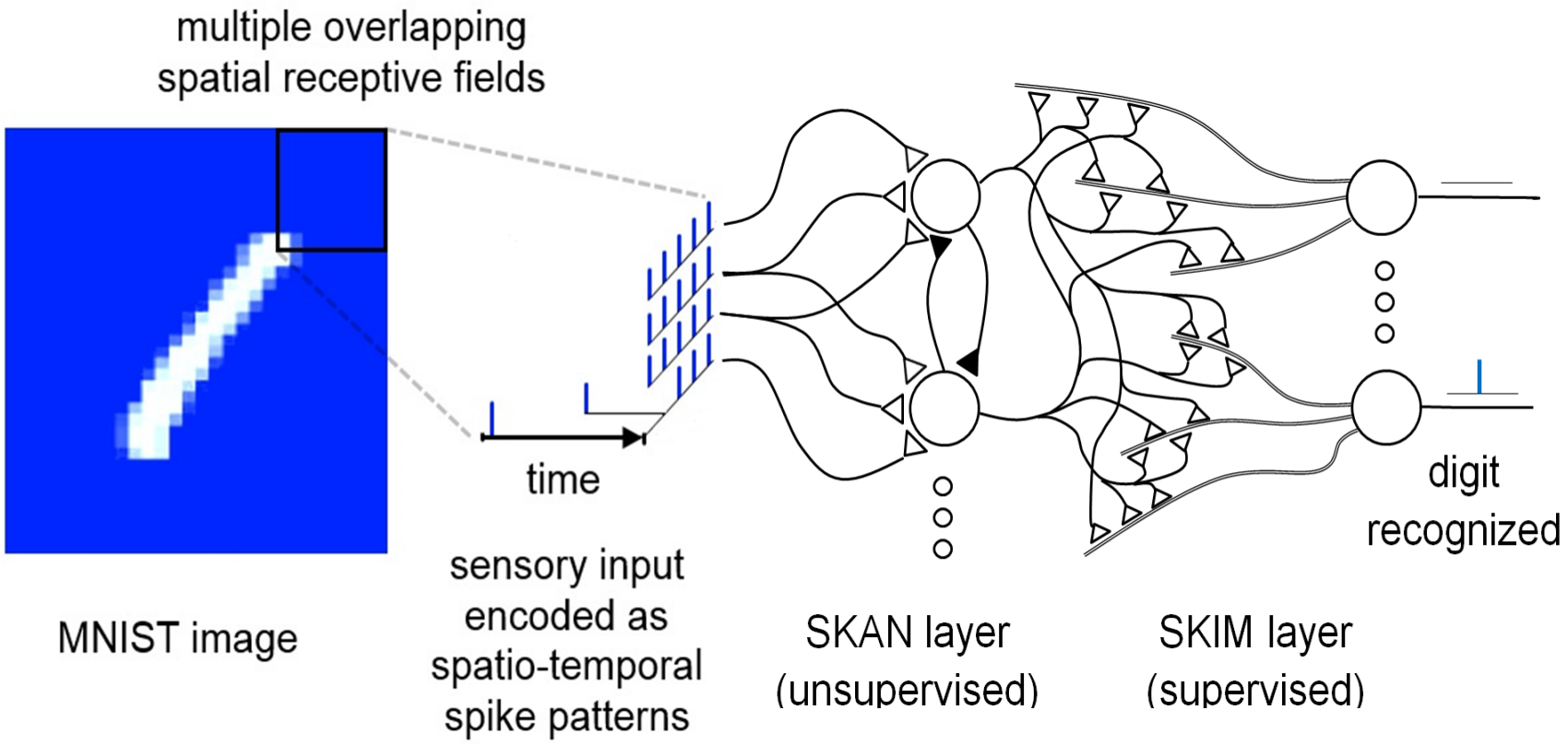

SKAN – see Afshar et al., *Frontiers in Neuroscience*, 2014

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Conclusions

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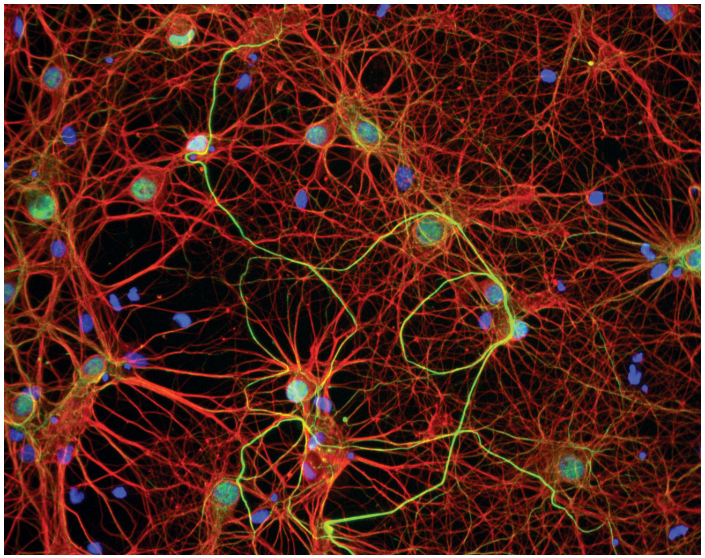

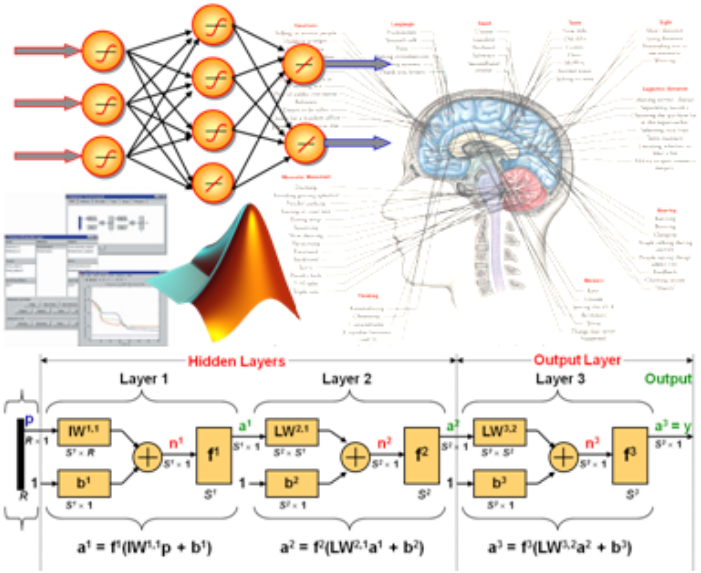

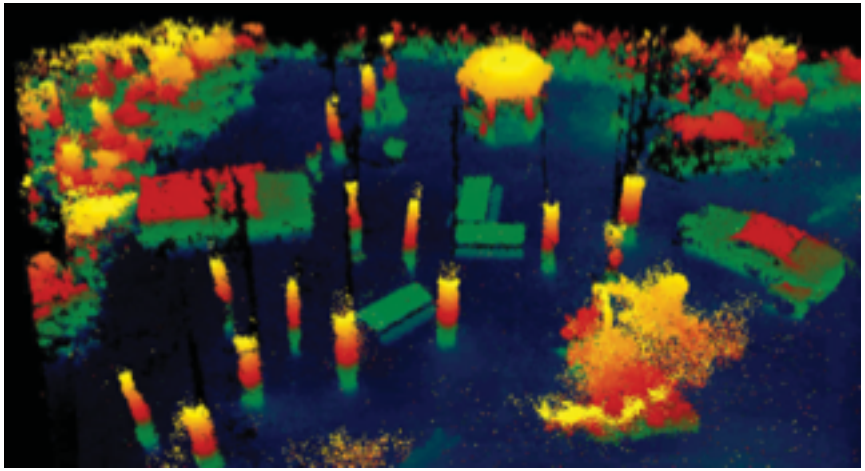

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Thank you!

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Reassuring

Title text: 'At least humans are better at quietly amusing ourselves, oblivious to our pending obsolescence' thought the human, as a nearby Dell Inspiron contentedly displayed the same bouncing geometric shape screensaver it had been running for years.

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Acknowledgements

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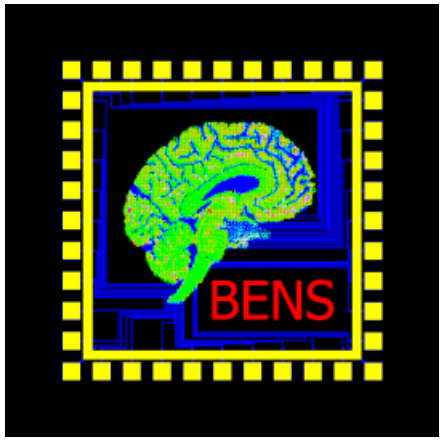

Saeed Afshar, PhD Student, BENS
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Dennis Delic, Fellow, DSTO

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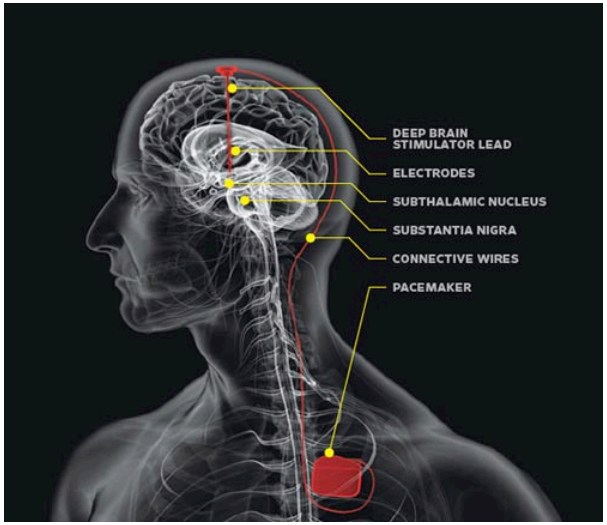

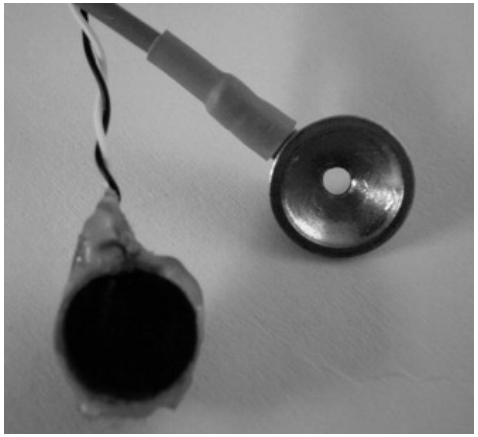

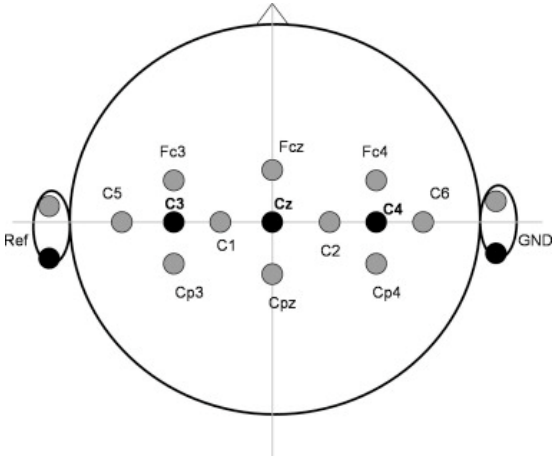

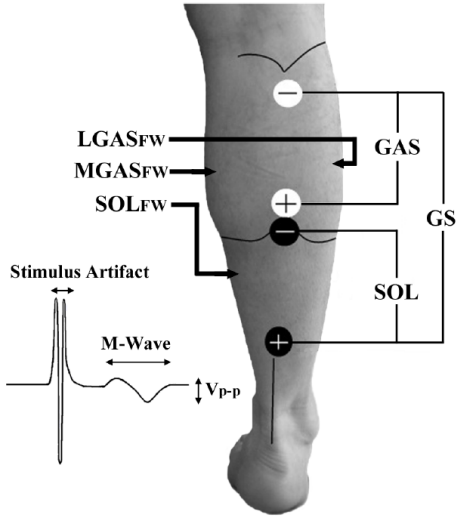

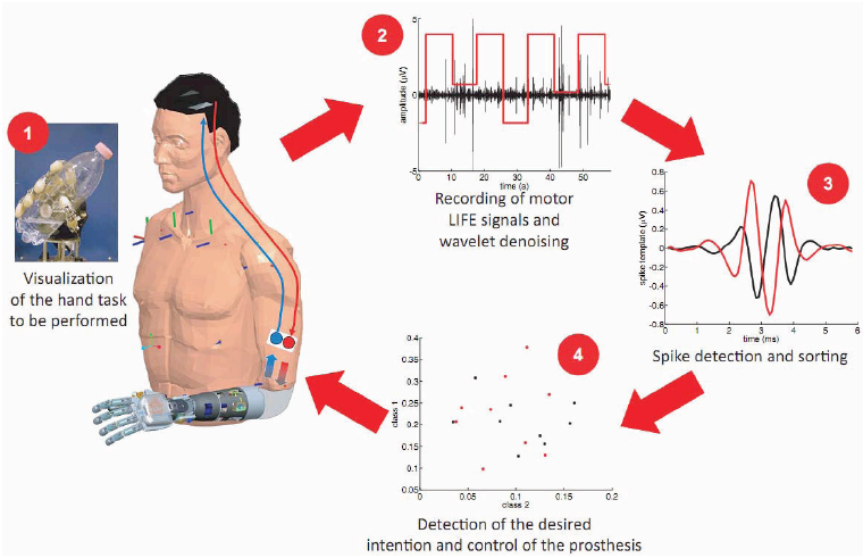

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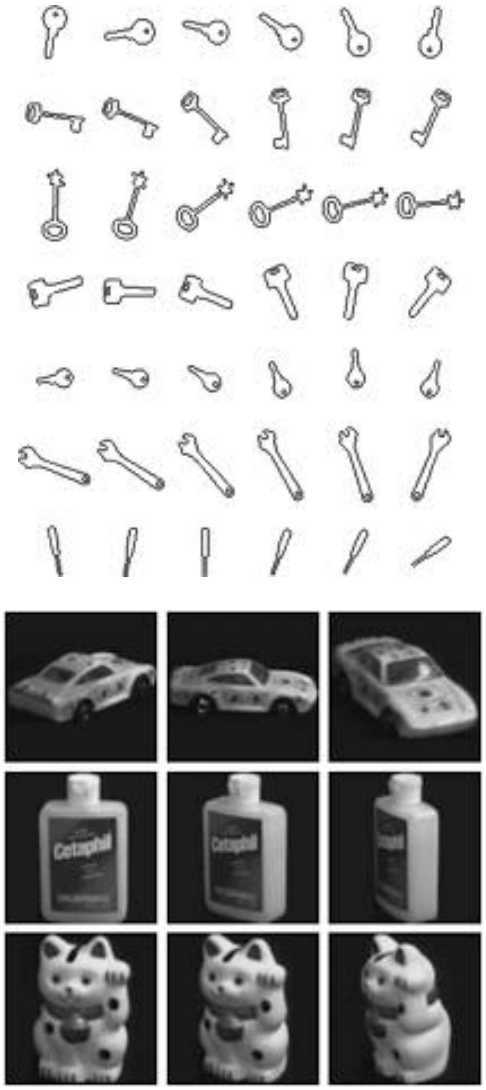

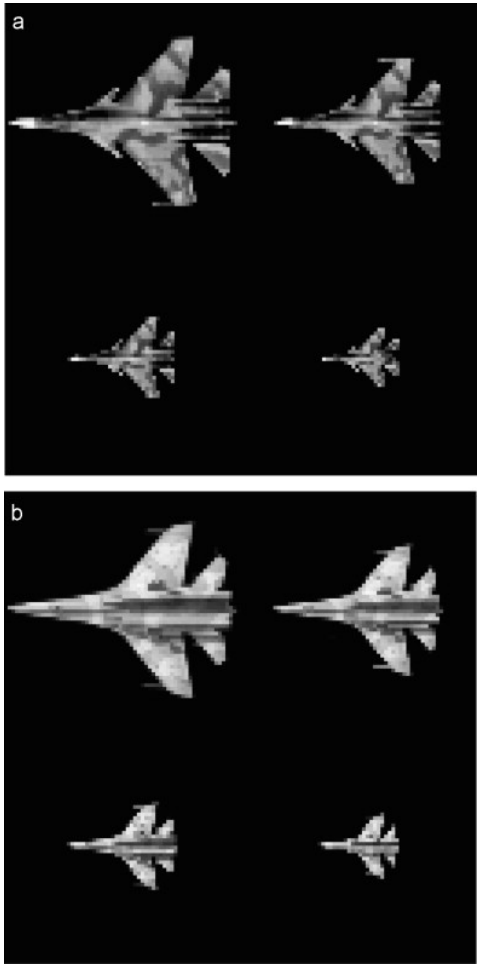

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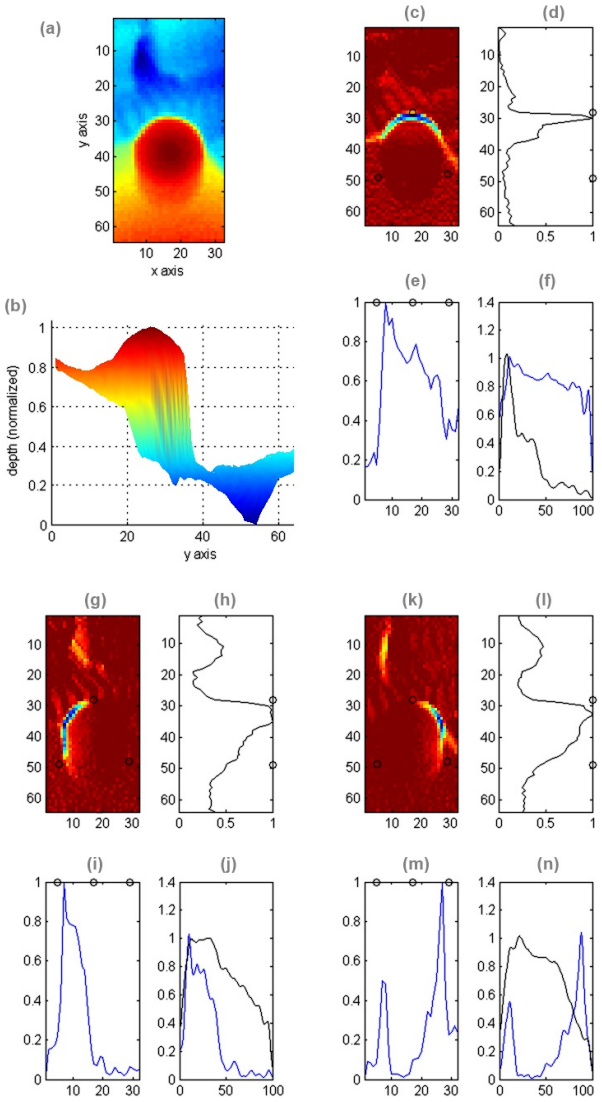

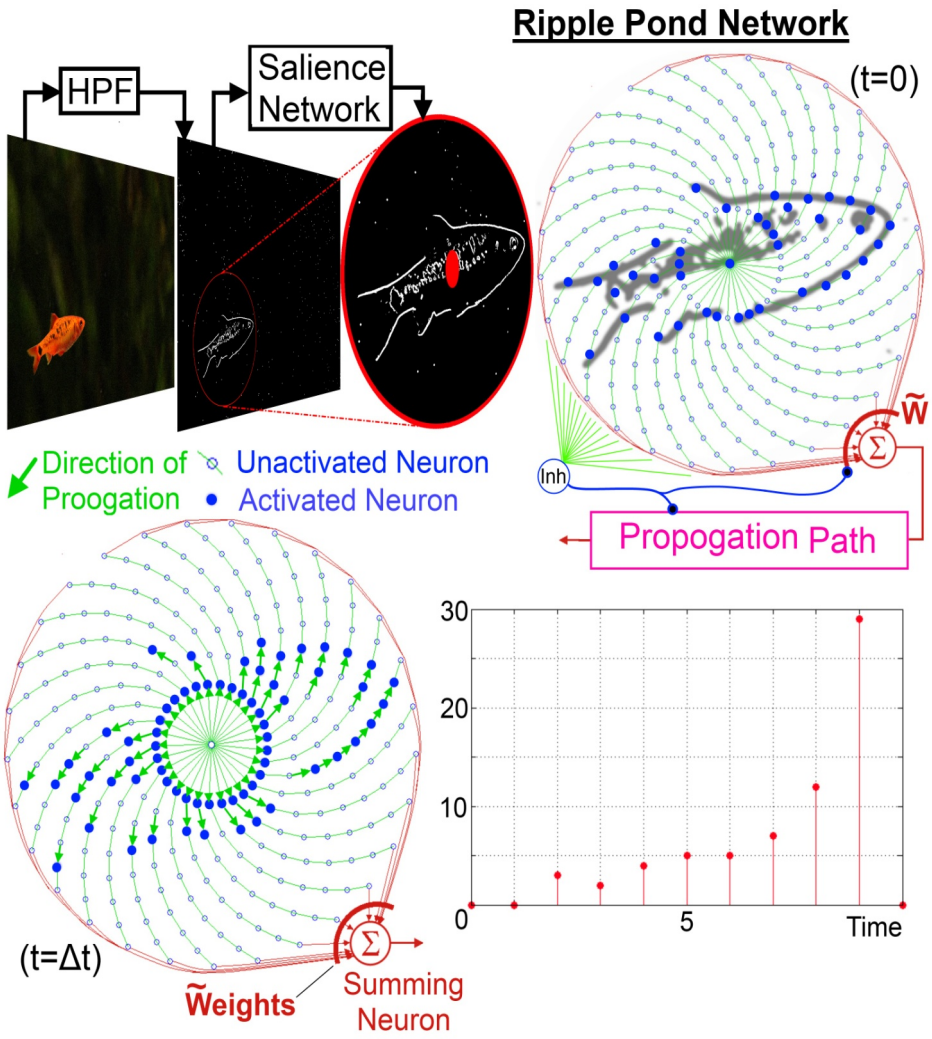

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