2020 Research Day

Design and implementation of a Hopfield network in living cells

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Background and Motivation

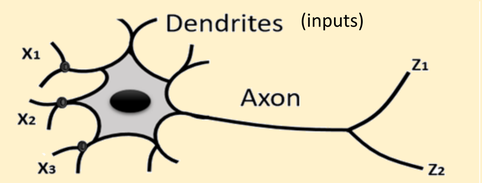
The branch of Synthetic biology focusses on applying engineering principles in the design and assembly of biological components

The three main design paradigms:

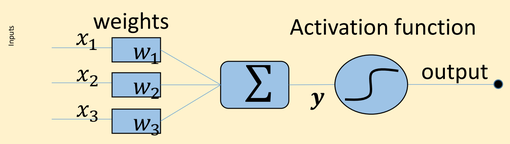
Analog | digital | Neural network

The cell's noisy and limited resources poses difficulties in implementing Analog and digital designs and their scaling
Neural networks on the other hand are inspired from biology, and their use in associative memory and pattern recognition has proven they are capable of efficiently handling noisy signals with relatively few computing units

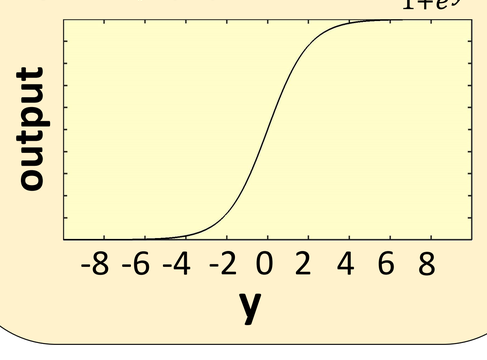
Neuron



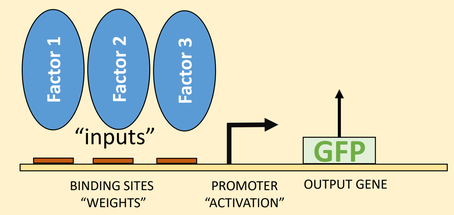
Artificial Neuron (perceptron)



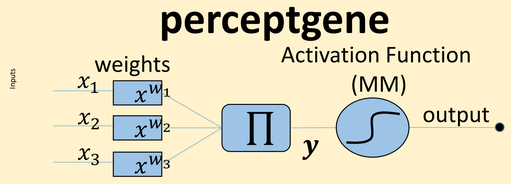
$y = \sum_i x_i w_i$ $\quad out = \frac{e^y}{1+e^y}$



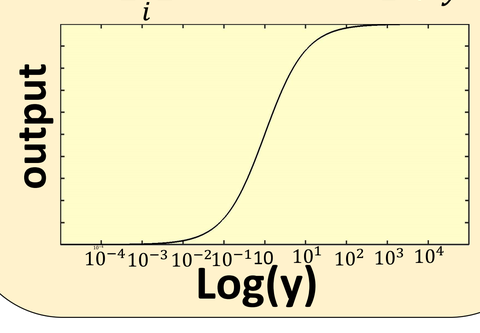
Gene regulation



perceptgene



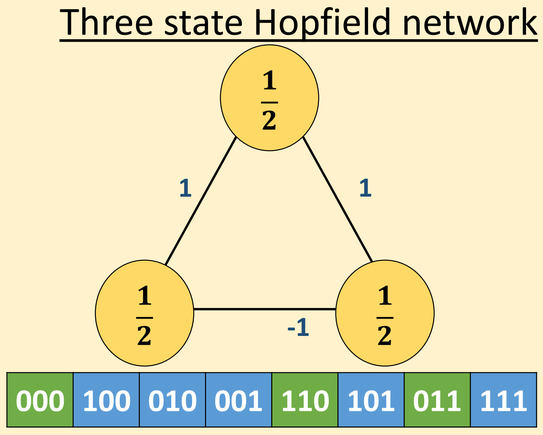
$y = \prod_i x_i^{n_i}$ $\quad out = \frac{y}{1+y}$

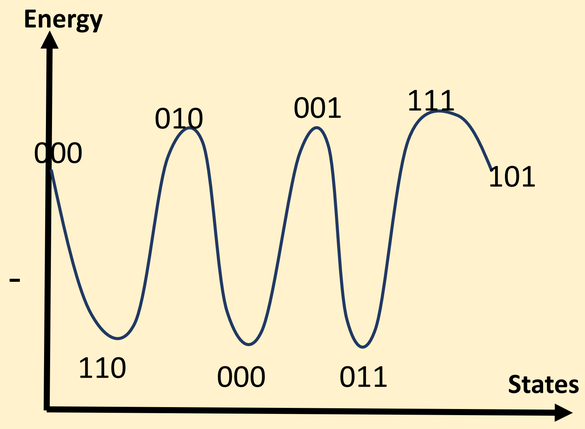


Hopfield Neural Network
Content addressable memory

Our aim is to implement Hopfield networks in living cells, these system are unique in relying on an energy function to implement associative memory, spontaneous changing in the network's state-space always result in reducing the network's energy, and so memory states (steady-states) will always be found in a local minima of the energy [1] [2].

Three state Hopfield network





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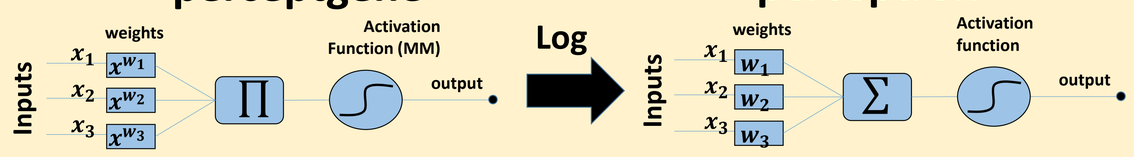
Networks states (steady ones in green)

Perceptgene and perceptron are connected by a simple log transform, which transforms the weighted power law to a multiplication, and the integration of the signal from a product to a summation, additionally the activation function in biology (Michaels-Menten) is sigmoid in the log domain:

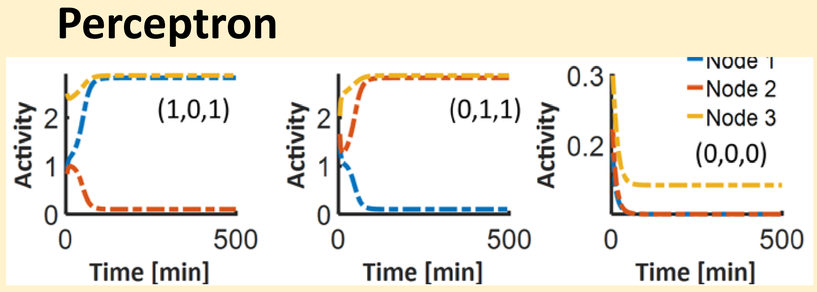
perceptgene **perceptron**



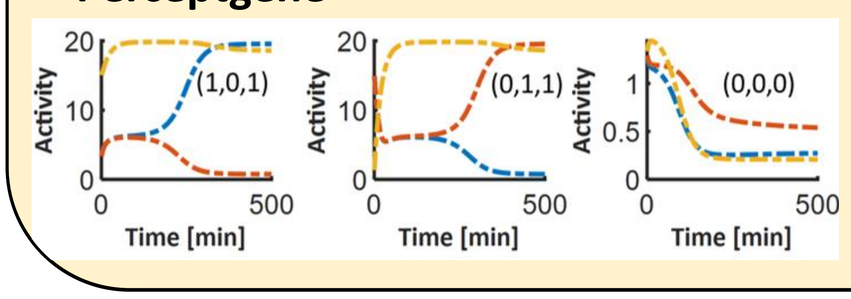
This implies that perceptron-based neural networks can be taken and mapped to perceptgene networks

Simulation results

Perceptron



Perceptgene



The biological system has 3 steady states that correspond to the stored states in the original Hopfield network [3]. Signifying that biological networks could be designed via this procedure.

Conclusions

- Hopfield networks were used to inspire a design in genetic networks
- Simulations displayed behaviour similar to the original Hopfield network

Future (current) work

- LCheck if other aspects (optimization) of Hopfield networks hold in the perceptgene networks
- Implement the network in living cells

References

[1] Hopfield, J. J. (1982) "Neural networks and physical systems with emergent collective computational abilities" Proc. Natl. Acad. Sci. USA 79, 2554- 2558.
[2] J.J. Hopfield, Neurons with graded response have collective computational properties like those of two sate neurons, Proc. Nat. Acad. Sci. USA 81 (1984)
[3] Sinni, R. A., & Daniel, R. (2019, October). Biophysical Analysis for Implementing Genetic Associative Memory Using Hopfield Networks. In 2019 IEEE Biomedical Circuits and Systems Conference (BioCAS) (pp. 1-4). IEEE.