Realizing Associative Memory Learning through Neuromorphic Circuits

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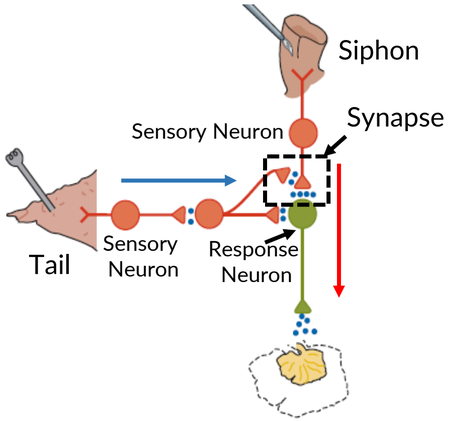
May 07, 2019

Research Motivation

Associative Memory

Invertebrates

Sea slug



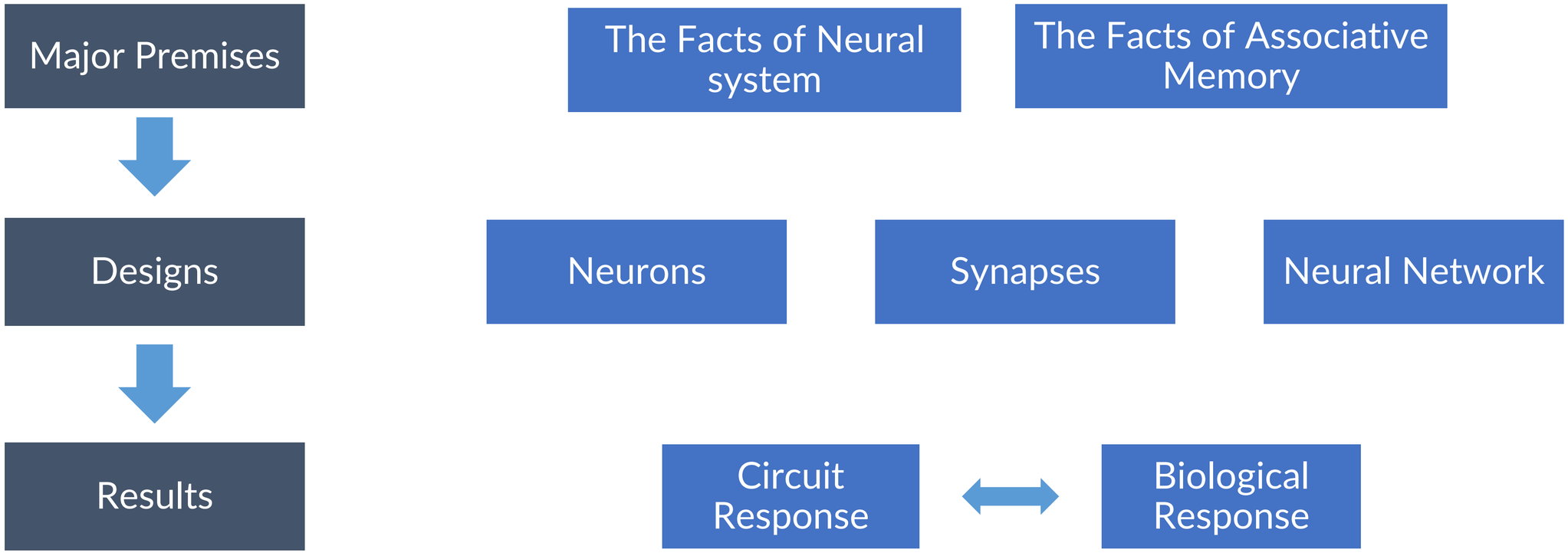
Mammals

Dogs

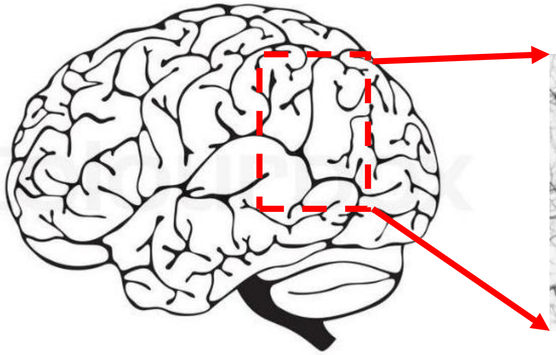
Humans

Apple

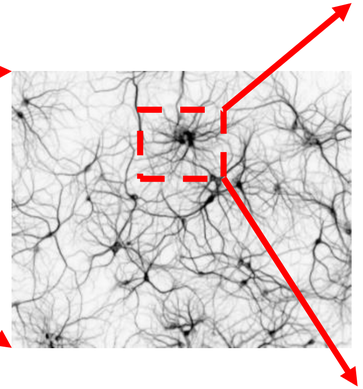
Design Methodology



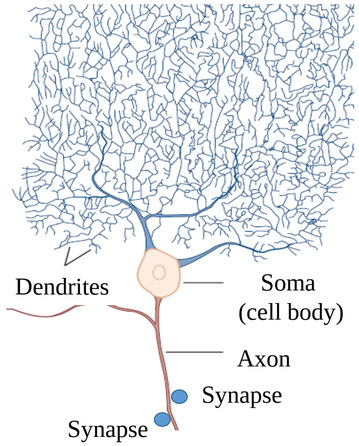
Neurons and Synapses



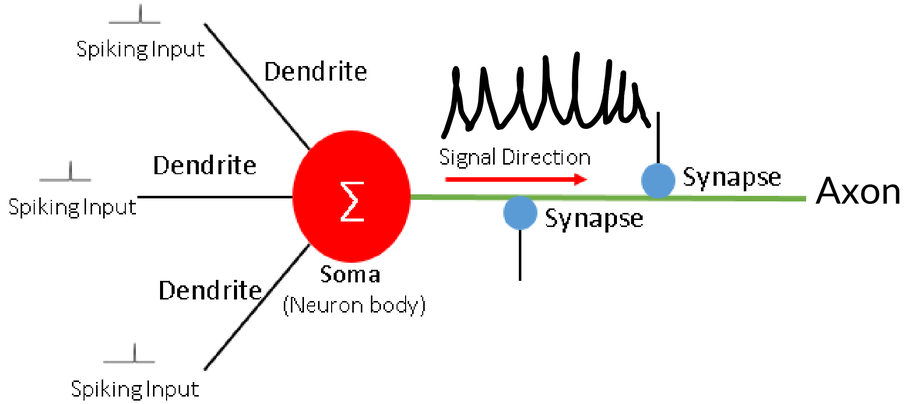
Brain



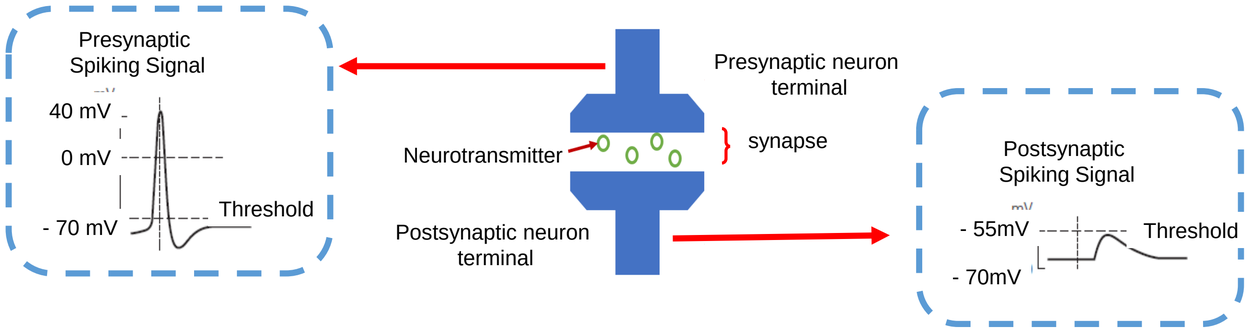
Neural network



Neuron structure



Neuron structure model



Synapse functions:

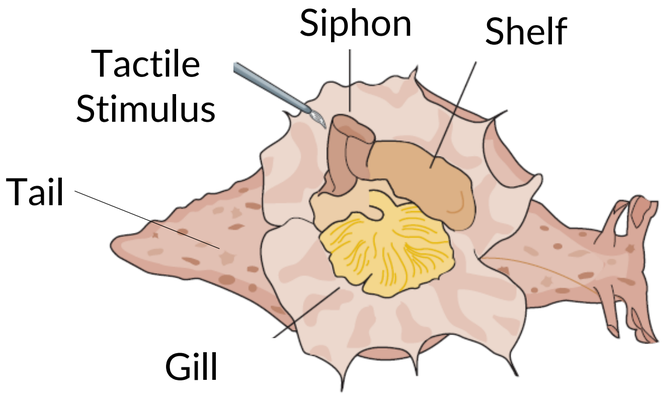
- Transfer signals between neurons
- Attenuate the spiking signals
- Synaptic strength of transmission can be modified

E. R. Kandel, *Principles of neural science vol. 4: McGraw-hill New York, 2000.*

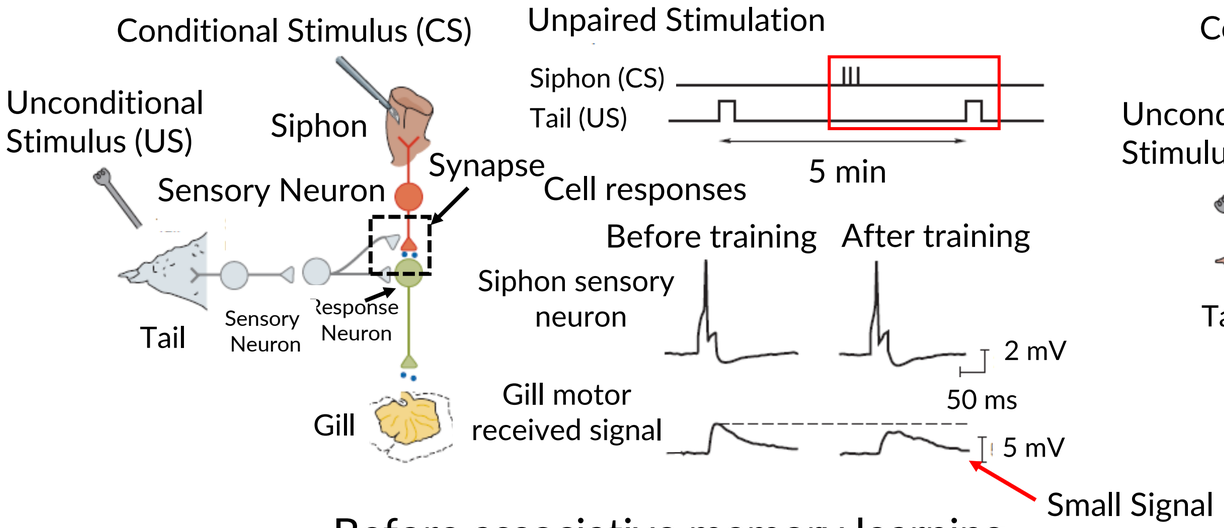
H. An.

Cellular Level Associative Memory in Sea Slugs

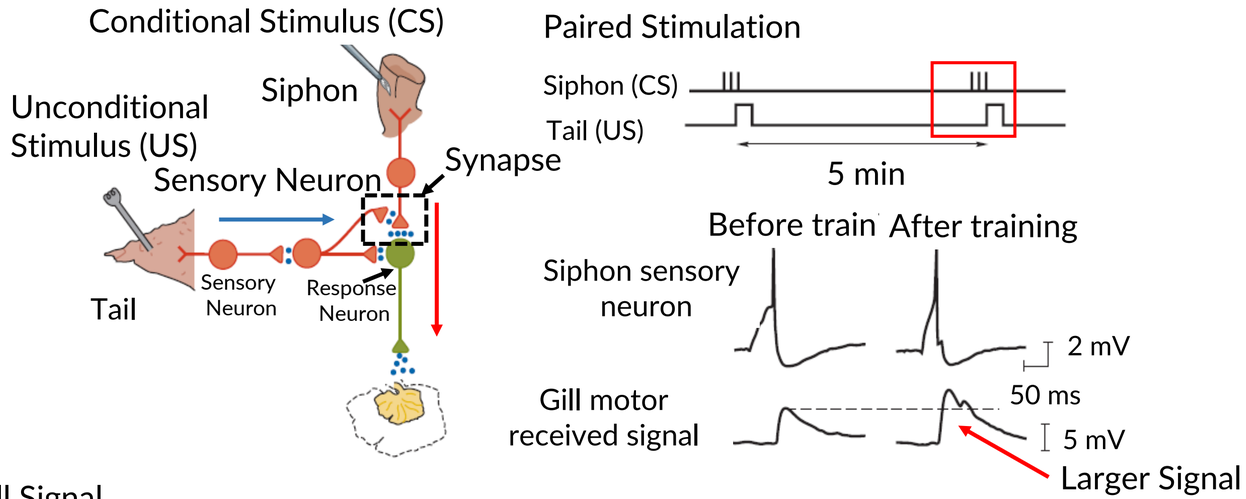
Sea Slugs



Experimental Setup



Before associative memory learning



After associative memory learning

E. R. Kandel, et al, *Principles of neural science vol. 4: McGraw-hill New York, 2000.* [2000 Nobel Prize]

Design Methodology

Major Premises

The Facts of Neural system

- Spiking Signals

The Facts of Associative Memory

- Signal Attenuation
- The synaptic strength becomes strong during the associative memory learning
- Large signal at postsynaptic neuron indicates a successful learning

Designs

Neurons

Synapses

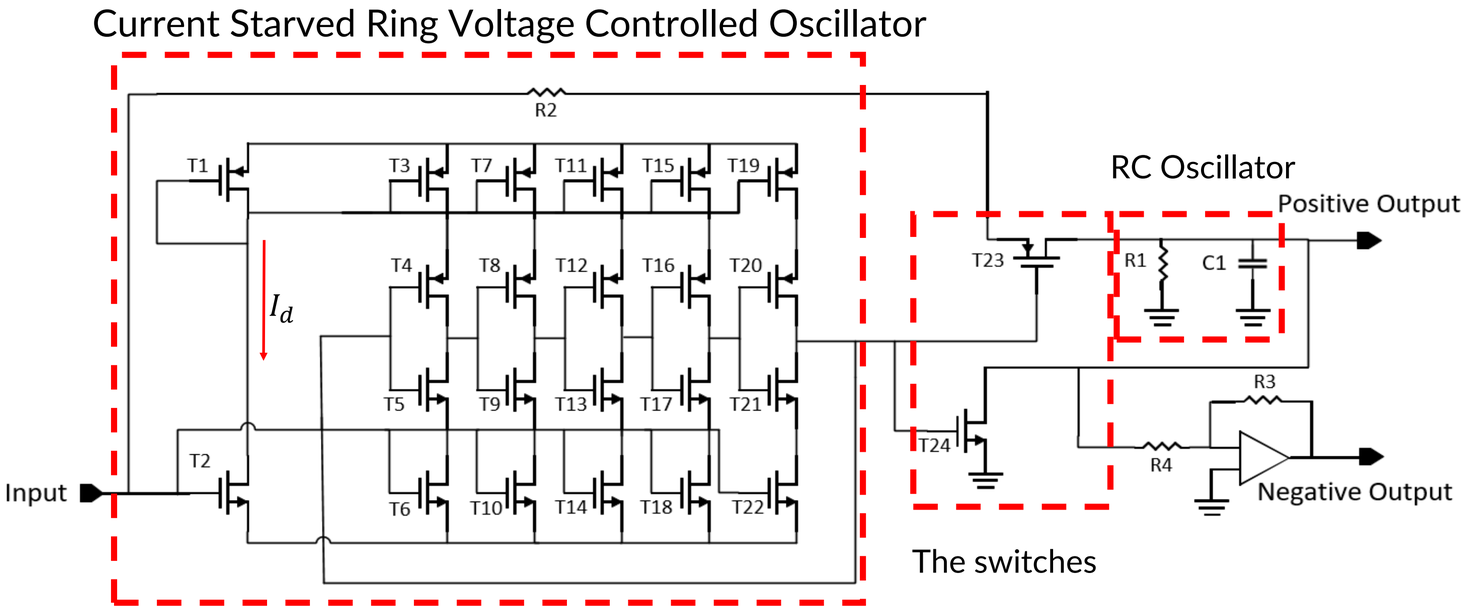
Neural Network

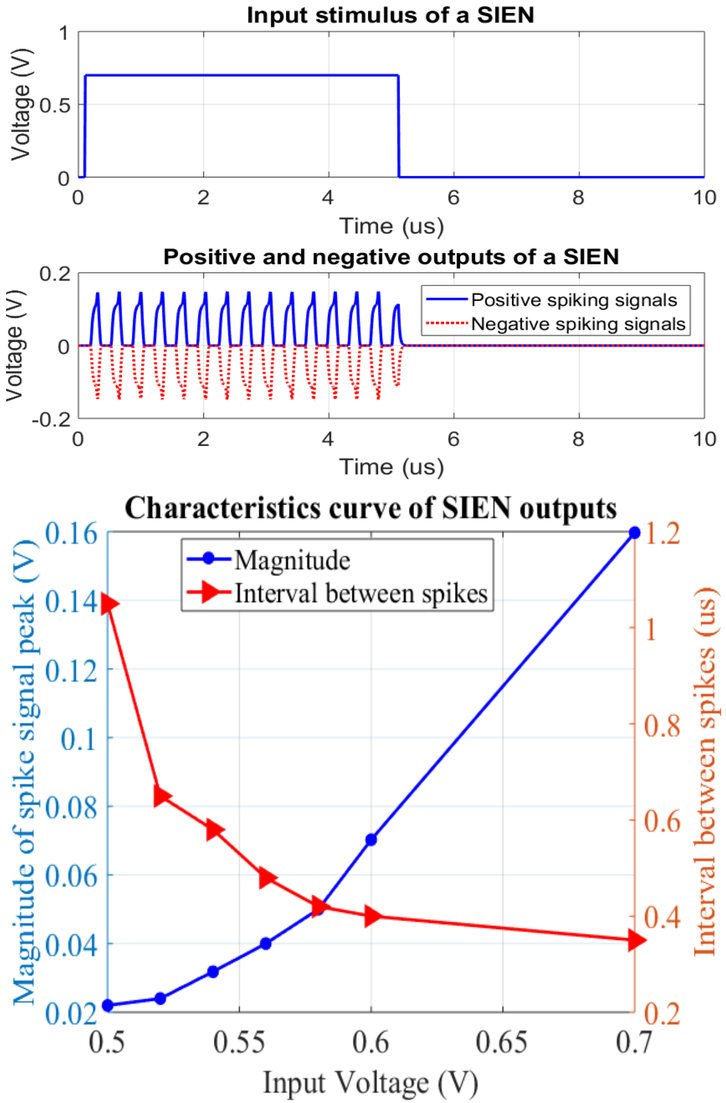
Results

Circuit Response ⟷ Biological Response

Mutual Corroboration

Signal Intensity Encoding Neuron

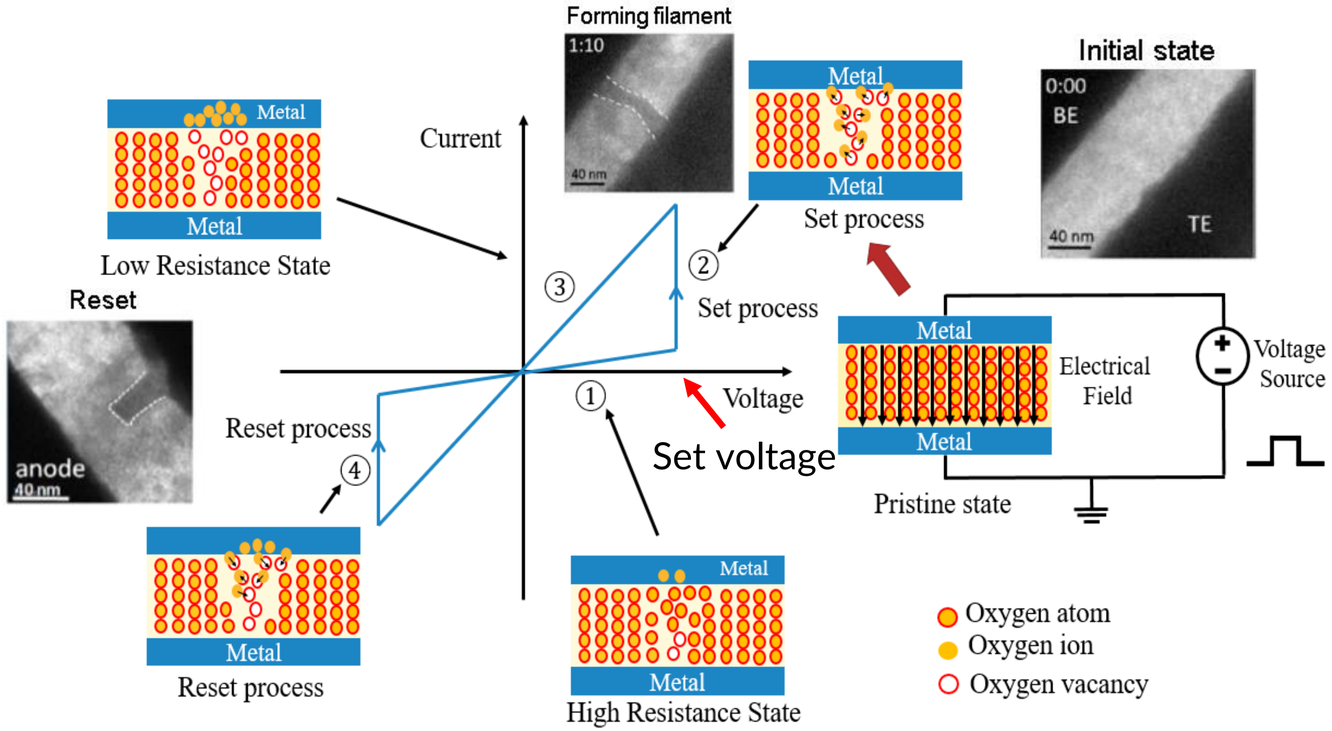




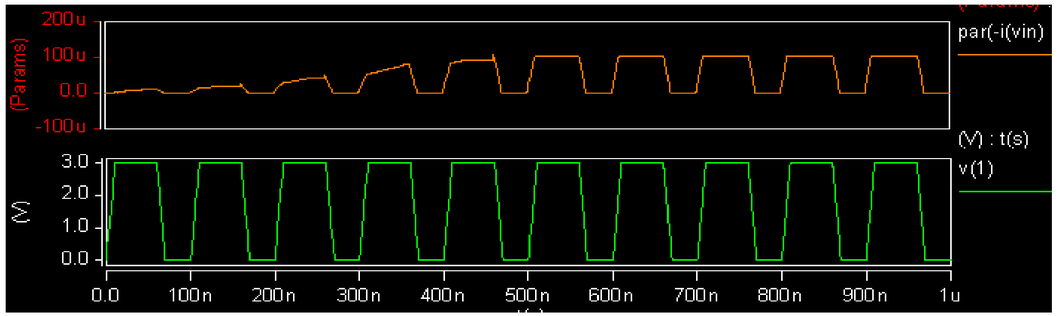
- Spiking signal generation;
- Positive and negative outputs;
- Magnitude and frequency corresponding to the input.

H. An, *et al.*, "Monolithic 3D neuromorphic computing system with hybrid CMOS and memristor-based synapses and neurons," *Integration, the VLSI Journal*, 2017.

Memristor as Synapse



1. The synapse should have the capability of attenuating signals;
2. The connecting strength of synapse is adjustable with a set voltage.



TEM image: J.-Y. Chen, *et al.*, "Dynamic evolution of conducting nanofilament in resistive switching memories," *Nano letters*, 2013.

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Designs

Neurons

- Signal Intensity Encoding Neuron

Synapses

- Memristive Synapse

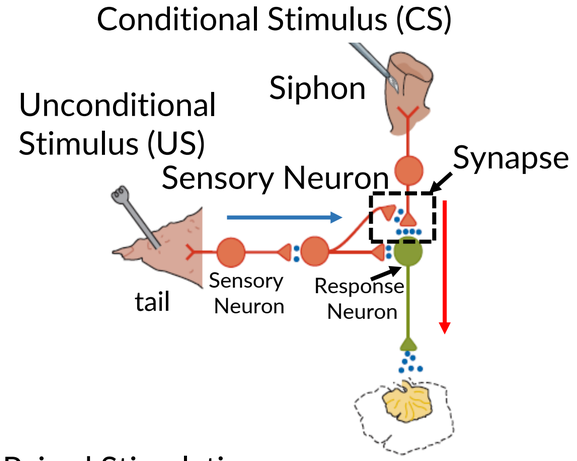
Neural Network

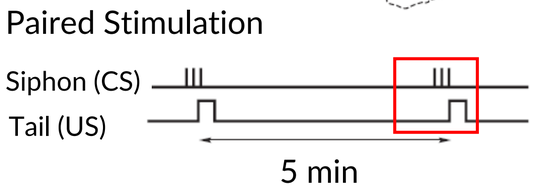
Results

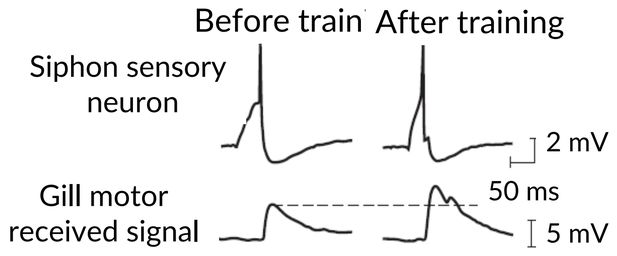
Circuit Response ⟷ Biological Response

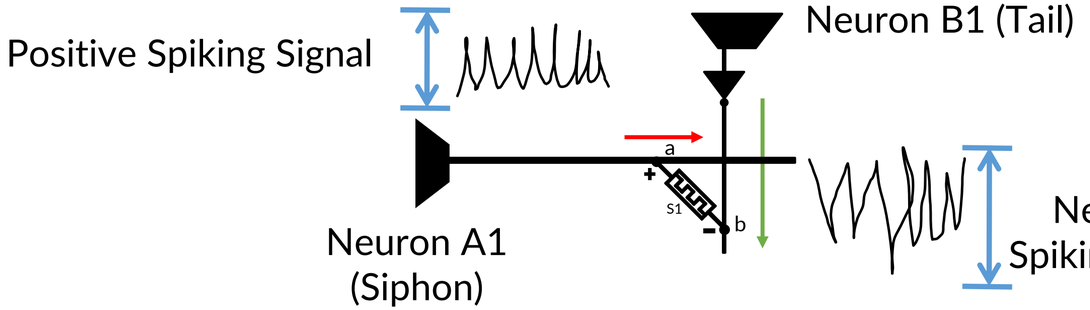
Mutual Corroboration

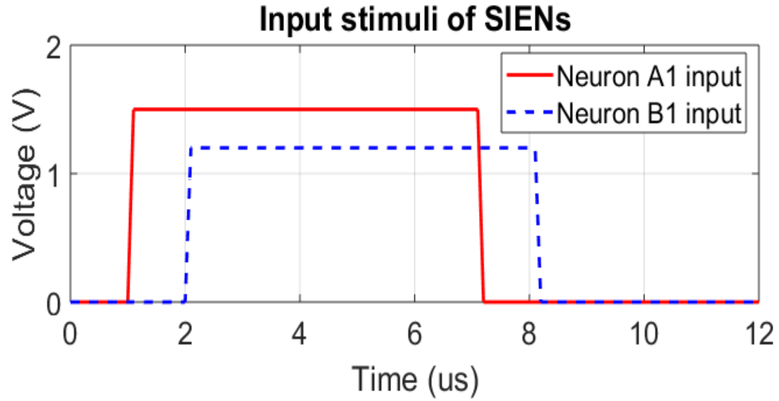
Reproducing Cellular Associative Memory Learning

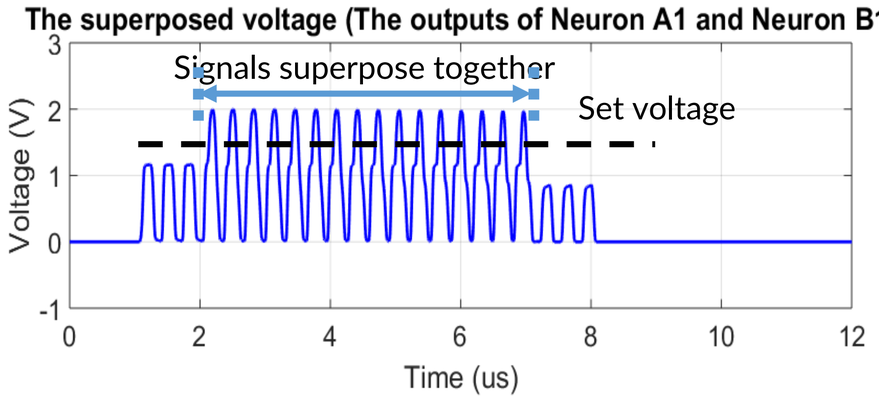


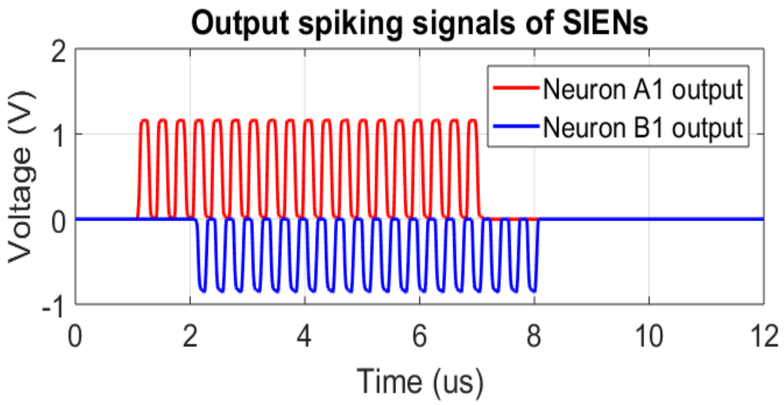


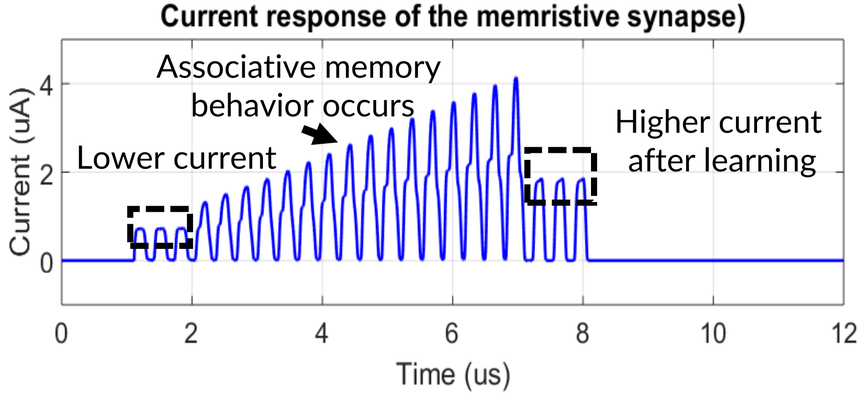






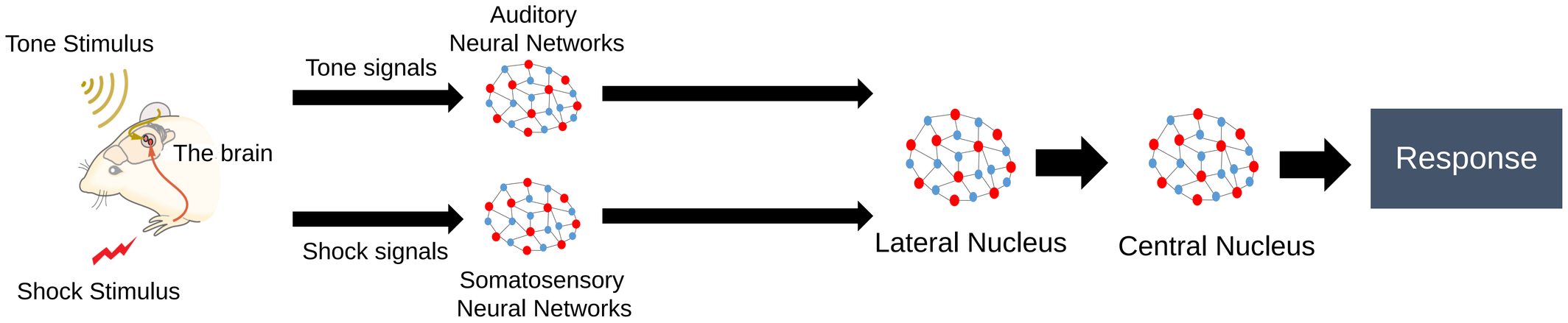






E. R. Kandel, *Principles of neural science vol. 4: McGraw-hill New York, 2000.*

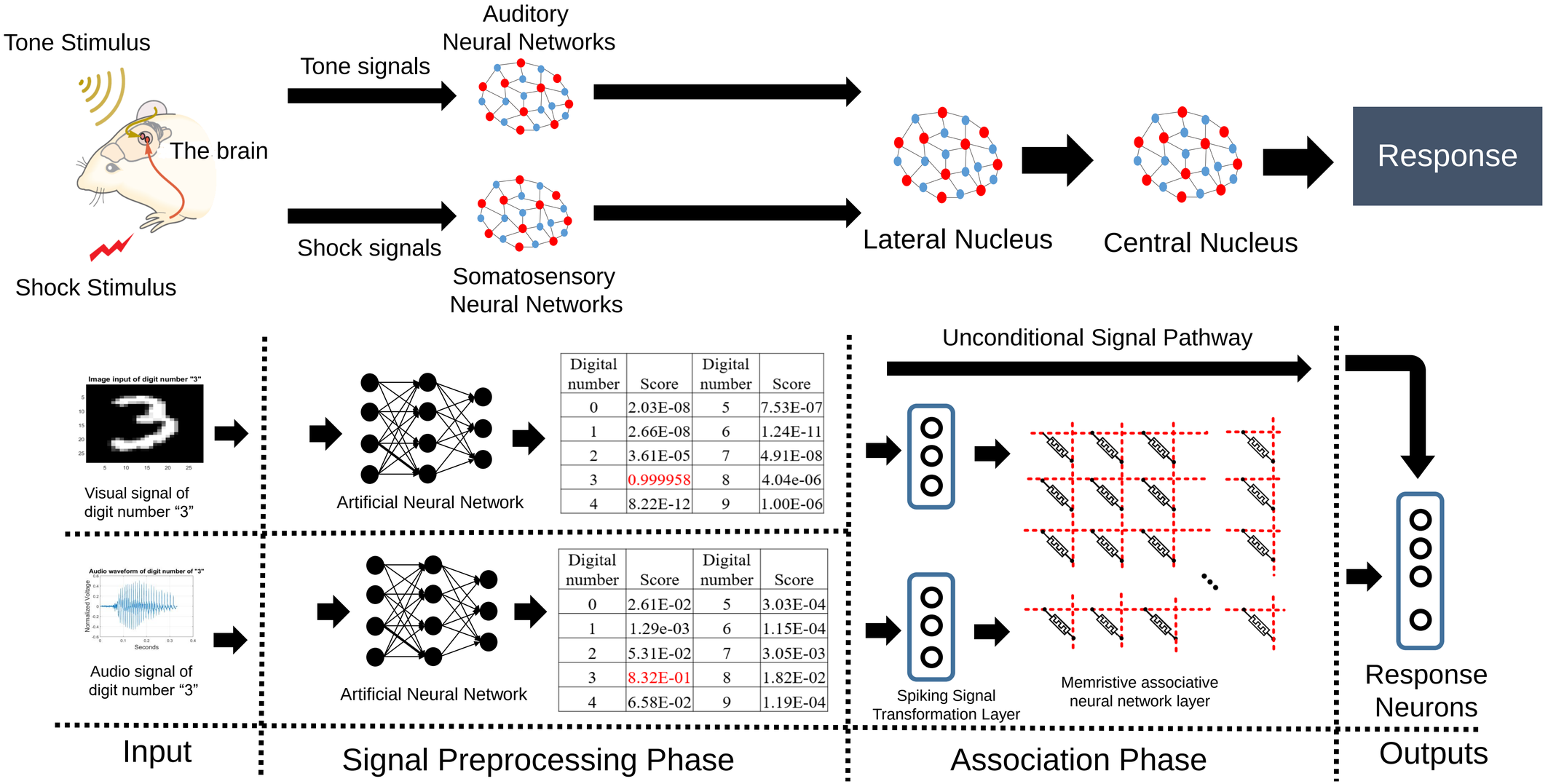
High Level Associative Memory Learning System



- Distinct types of signals are preprocessed at the different regions of brain
- The outputs signals after the preprocessing converged at Lateral nucleus

E. R. Kandel, *Principles of neural science vol. 4: McGraw-hill New York, 2000.*

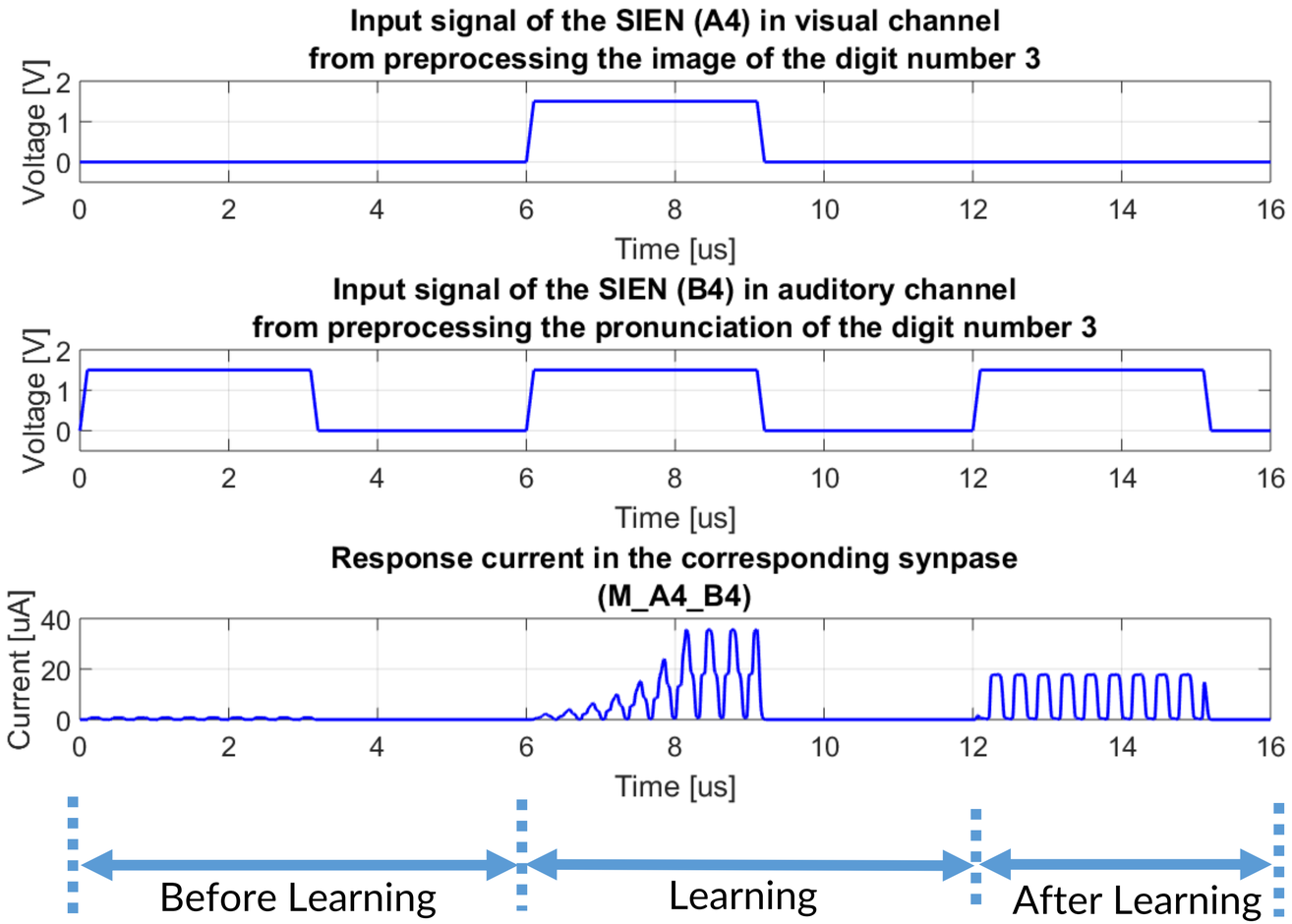
Associative Memory Learning System



Digital number	Score	Digital number	Score
0	2.03E-08	5	7.53E-07
1	2.66E-08	6	1.24E-11
2	3.61E-05	7	4.91E-08
3	0.999958	8	4.04e-06
4	8.22E-12	9	1.00E-06

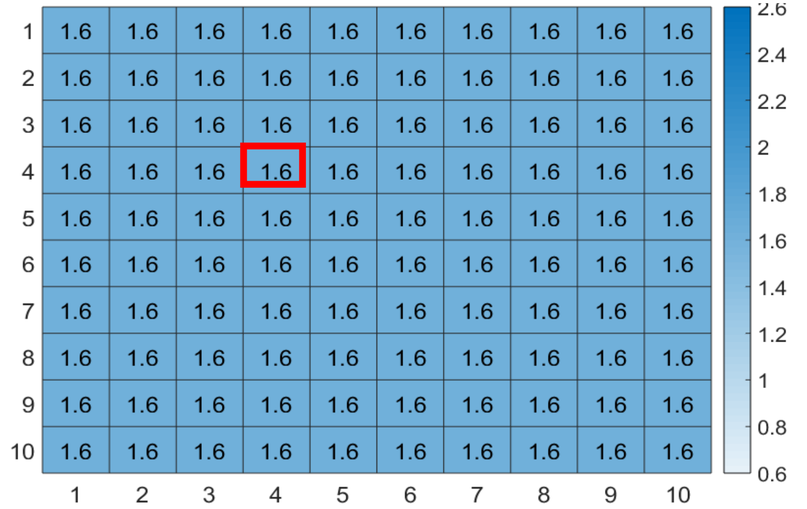
Digital number	Score	Digital number	Score
0	2.61E-02	5	3.03E-04
1	1.29e-03	6	1.15E-04
2	5.31E-02	7	3.05E-03
3	8.32E-01	8	1.82E-02
4	6.58E-02	9	1.19E-04

Synaptic Weight Updating in Associative Memory

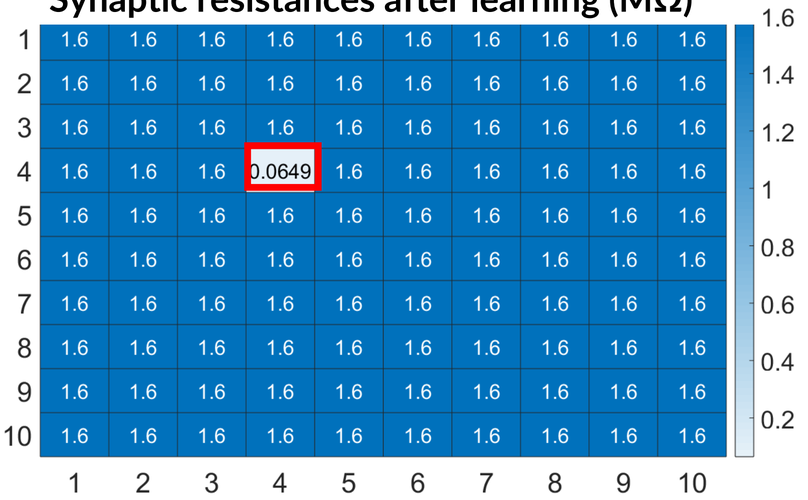


Input signals of SIENs and the response current
with the auditory and visual signals of digit number 3

Synaptic resistances with no learning (MΩ)

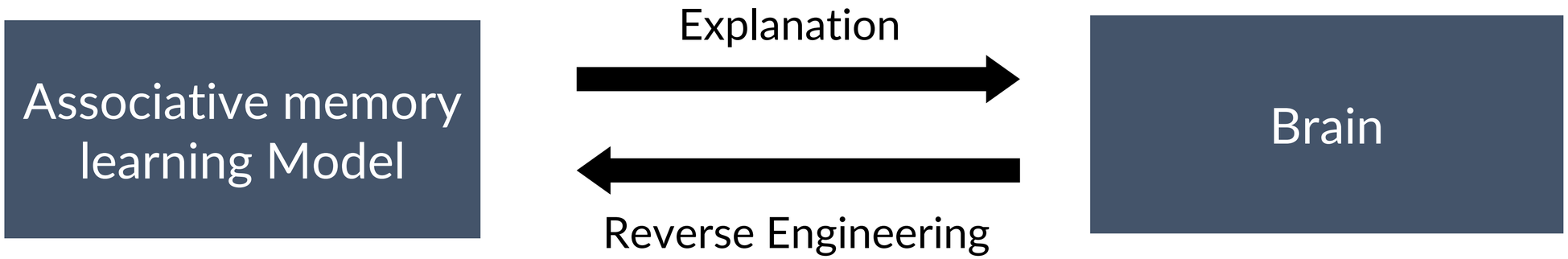


Synaptic resistances after learning (MΩ)



Conclusion and Significance

- Implement a brain-like associative memory learning that relates the pronunciation (auditory signal) and image (visual signal) of digits together by associating two artificial neural networks



Engineering Contributions:

- Human-Like self-learning capability
- High adaptivity with dynamic surrounding environment
- Novel Human-computer interaction system
- Spiking Signal based power efficient system

Scientific Contributions:

- Potential explanations regarding the human learning mechanism
- Potential interpretations of memory/forgetting mechanism
- Diseases: Alzheimer's disease and visual agnosia

Thank You

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