Biomimetic Spiking Neural Network and Neurohybrid systems for AI and biomedical

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Content

- Context
- Digital system
- Artificial Intelligence
- Biomedical
- Conclusion

Neumorphic engineering

Maths

- Neuronal models
- Optimization
- Wavelet filters
- Dosimetric modelling

Physics

- Exposure systems
- Neuromorphism
- Neural probes
- Custom IC
- Analog processing
- Nanotechnology

Biology

- In vitro
- Diabetes
- Ex vivo
- Neurodegenerative disease
- In vivo
- Spinal cord lesion

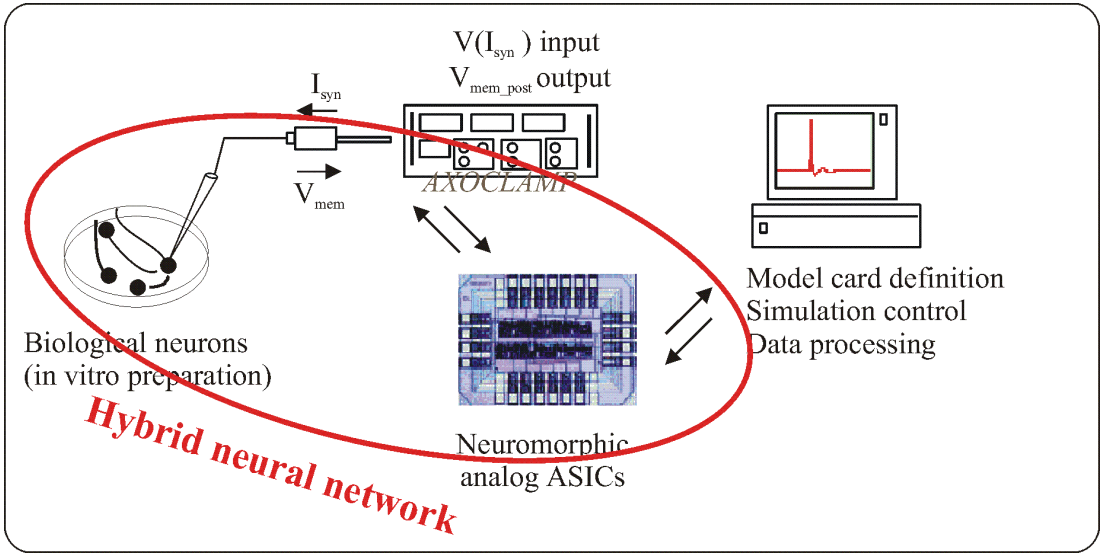
Real-time closed-loop systems at the biology-physics interface for diagnosis and therapy

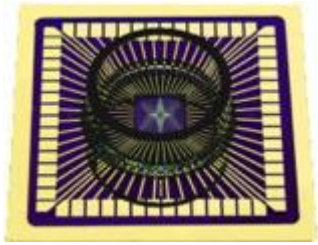
Objective of our research

1 population of biological neurons

↔

1 population of artificial neurons

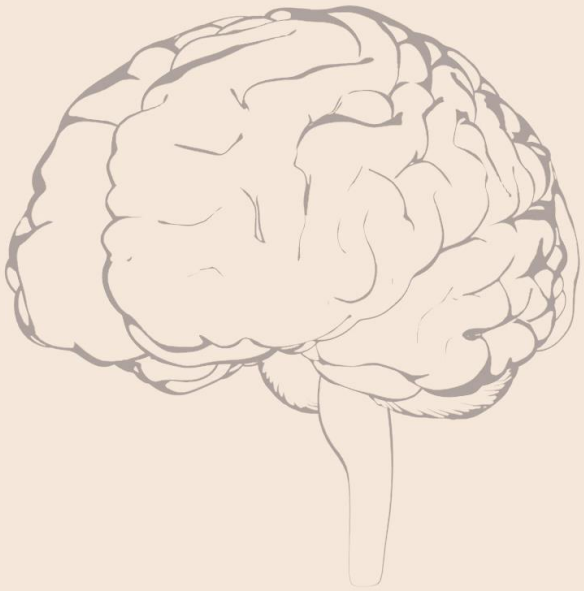




Spiking Neural Network

Le Masson, G., Renaud, S., Debay, D., and Bal, T. (2002). Feedback inhibition controls spike transfer in hybrid thalamic circuits. *Nature*. 417, 854-858.

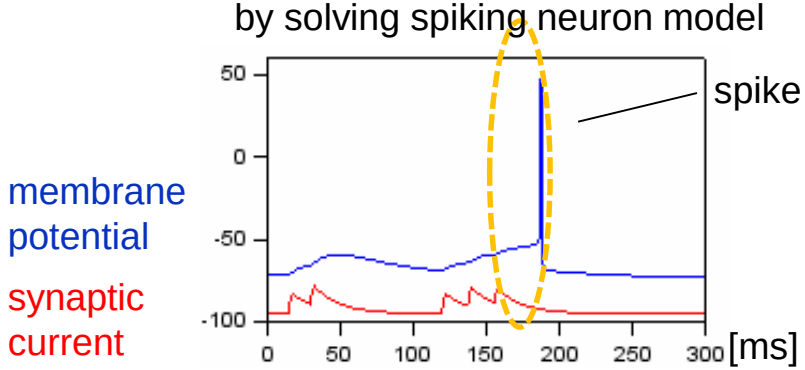
Reconstruction of neural network



Spiking Neural Network (SNN)

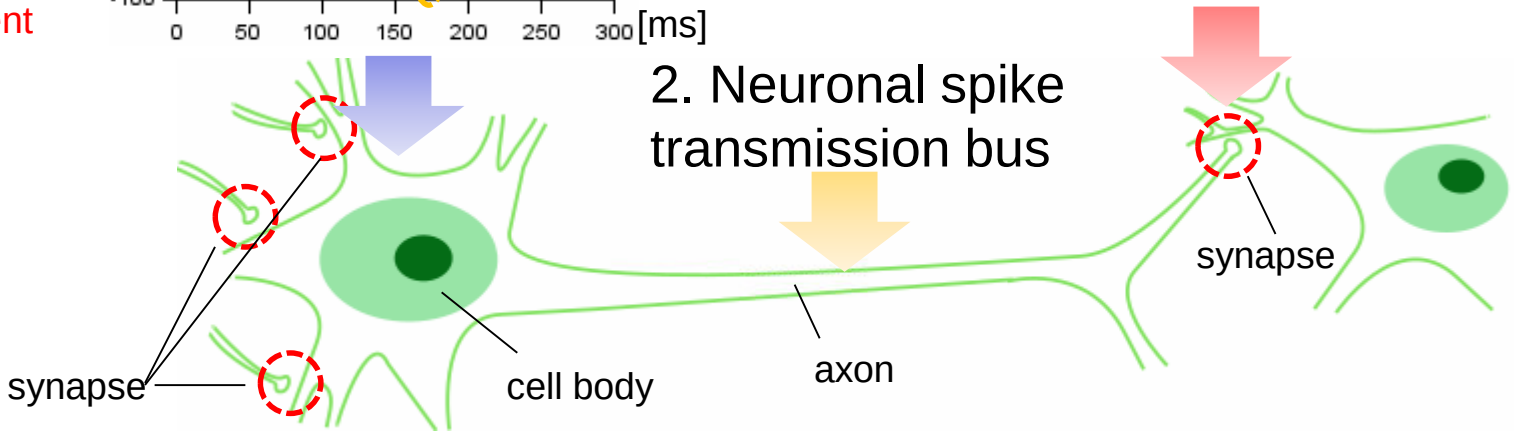
- Electronic: reproduces information processing in the nervous system.

1. Silicon neuron
- calculate membrane potential by solving spiking neuron model



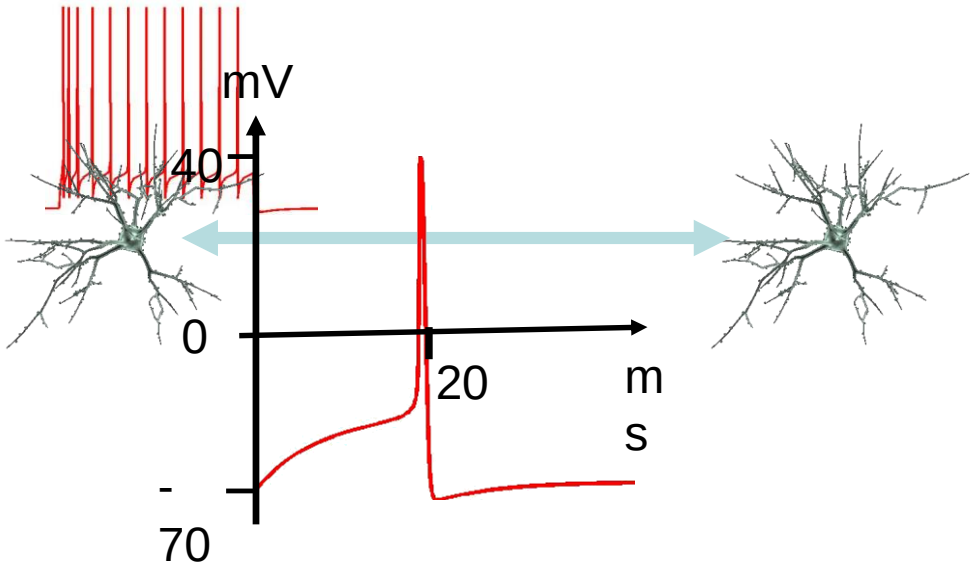
3. Silicon synapse
- synaptic current
- synaptic efficiency
- learning rules

2. Neuronal spike transmission bus



Requirements for neural model

- Action Potential
  - Frequency
  - Shape
- Closest to biology
- Different Neuron class
- Biophysically detailed



- Biological time scale
- Unsupervised real-time system

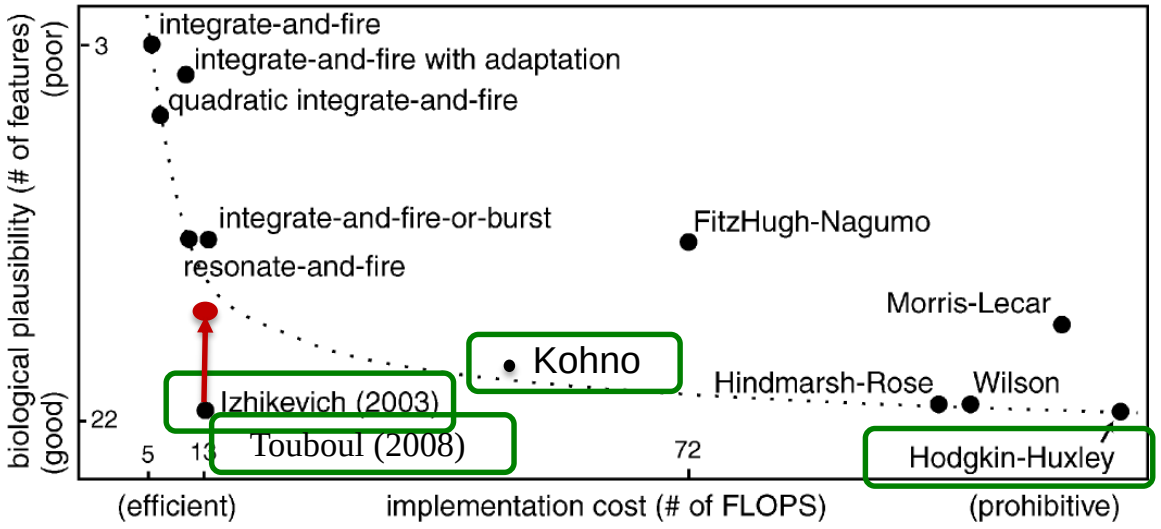
Neuron model

Which model to use for cortical spiking neural networks hardware simulations?

Integrate & Fire

Izhikevich

Hodgkin-Huxley



Source: www.izhikevich.com

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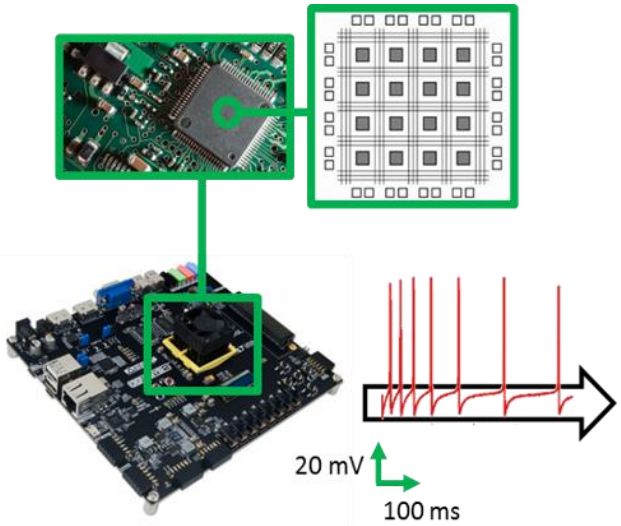
Digital implementation of SNN

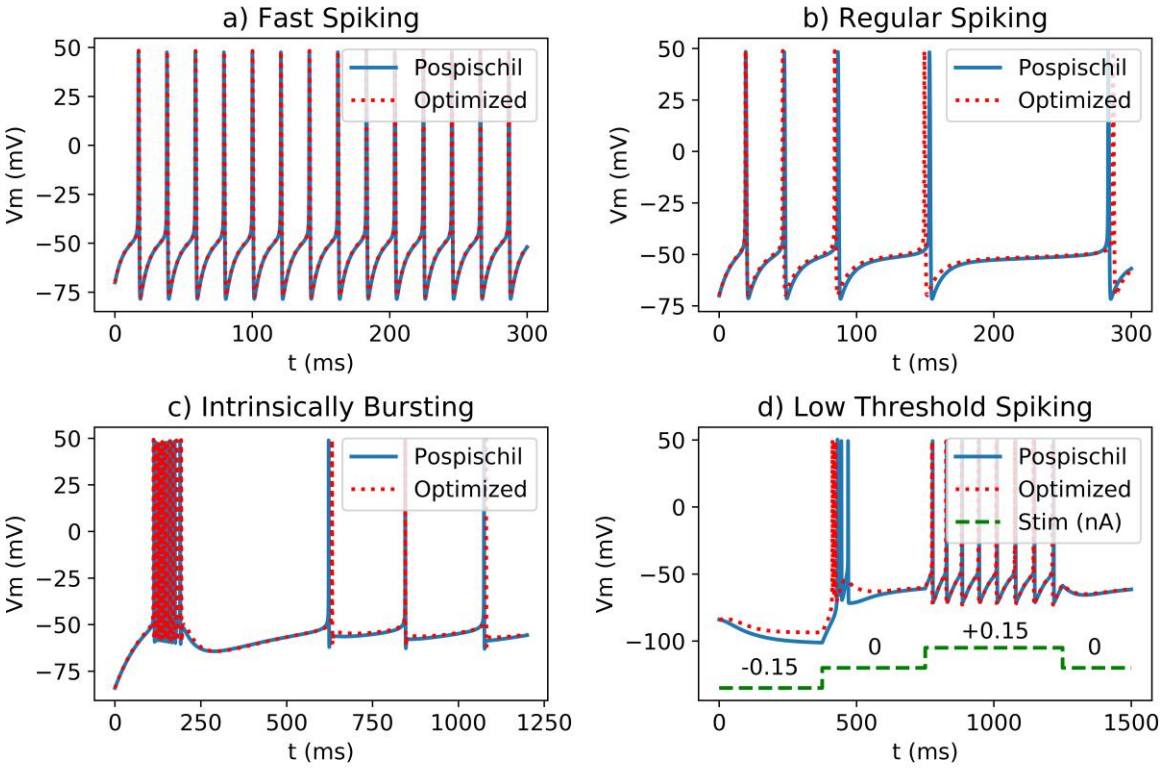
- FPGA board
- HH, Izh, LIF, DSSN model
- Real-time
- Unsupervised
- Biological scale

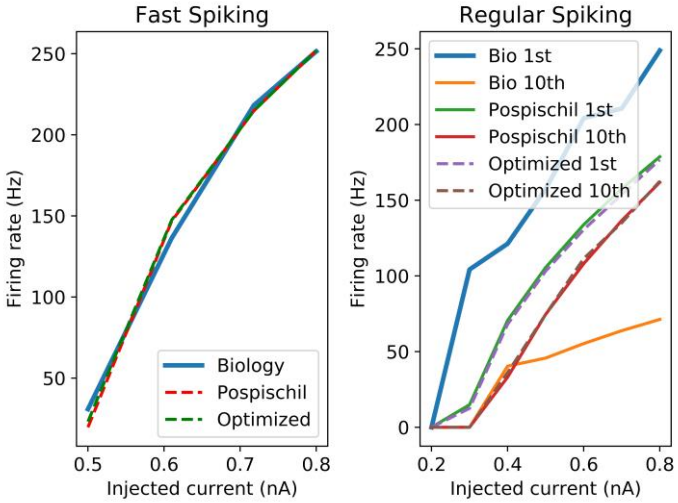
- Pipeline implementation

- Few resources



Validation of the HH model



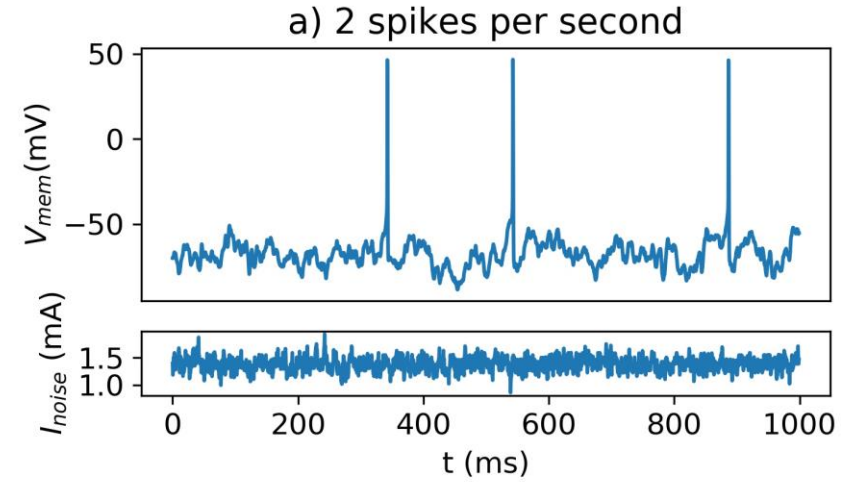


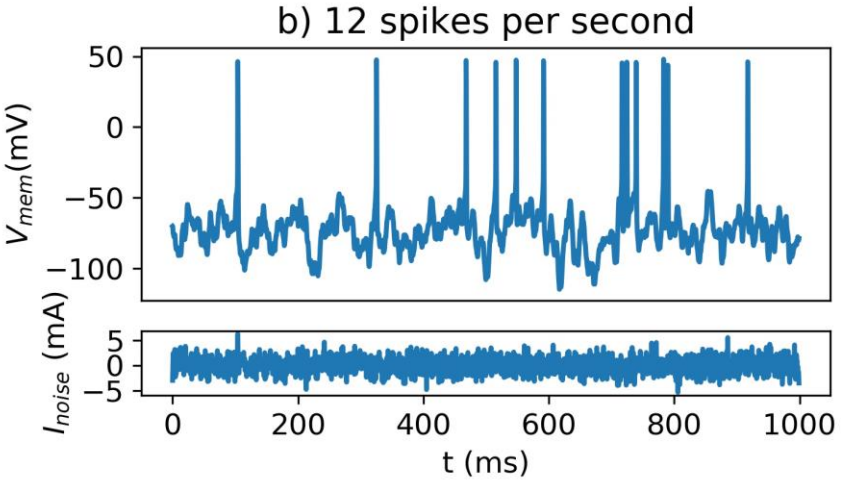
FPGA implementation of HH model

	Original equations	One core (only FS)	One core (FS, RS, IB, LTS) + N^2 Synapses + synaptic noise	30 cores (FS, RS, IB, LTS) + N^2 Synapses + synaptic noise	Bonabi et al., 2014	4 cores (only FS) Akbarzadeh Sherbaf et a 2018
N	150	1034	500	15,000	150	2048
F (MHz)	100	100	100	100	63.386	58.8
LUT	169,003	4735	5551	167,346	86,032	46,045
FF	65,059	1552	2360	71,608	30,528	4,606
DSP	332	16	28	840	1,112	280

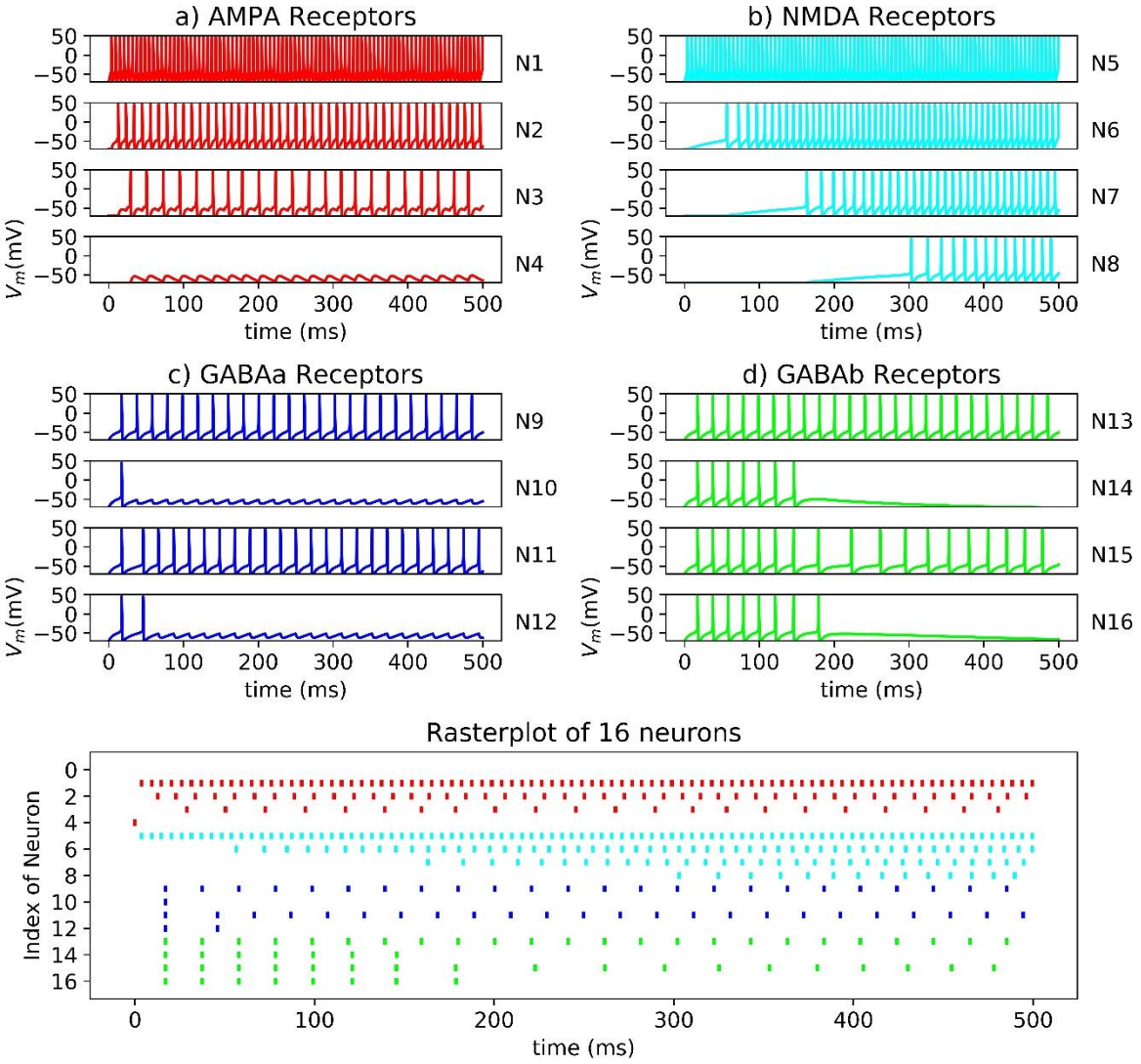
Synaptic noise

- Biomimetic synaptic noise
- Orstein Ulhenbeck process
- Tune spontaneous activity



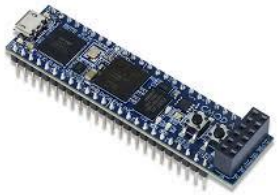


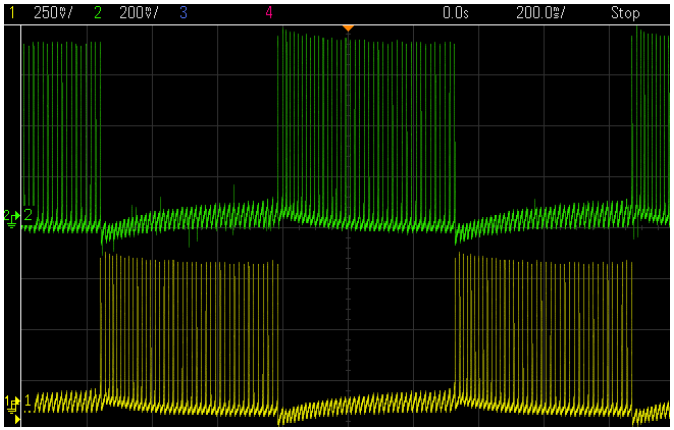
Synapses

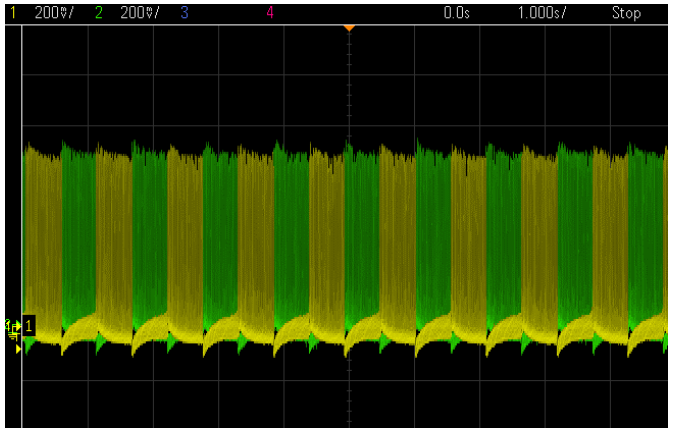

a) AMPA Receptors
b) NMDA Receptors
c) GABAa Receptors
d) GABAb Receptors
N1
N2
N3
N4
N5
N6
N7
N8
N9
N10
N11
N12
N13
N14
N15
N16
V_m(mV)
time (ms)
Rasterplot of 16 neurons
Index of Neuron

CPG with HH model

- Reproduction of Hill system
- HH neuron with synaptic plasticity
- Tunable period of frequency and duty cycle





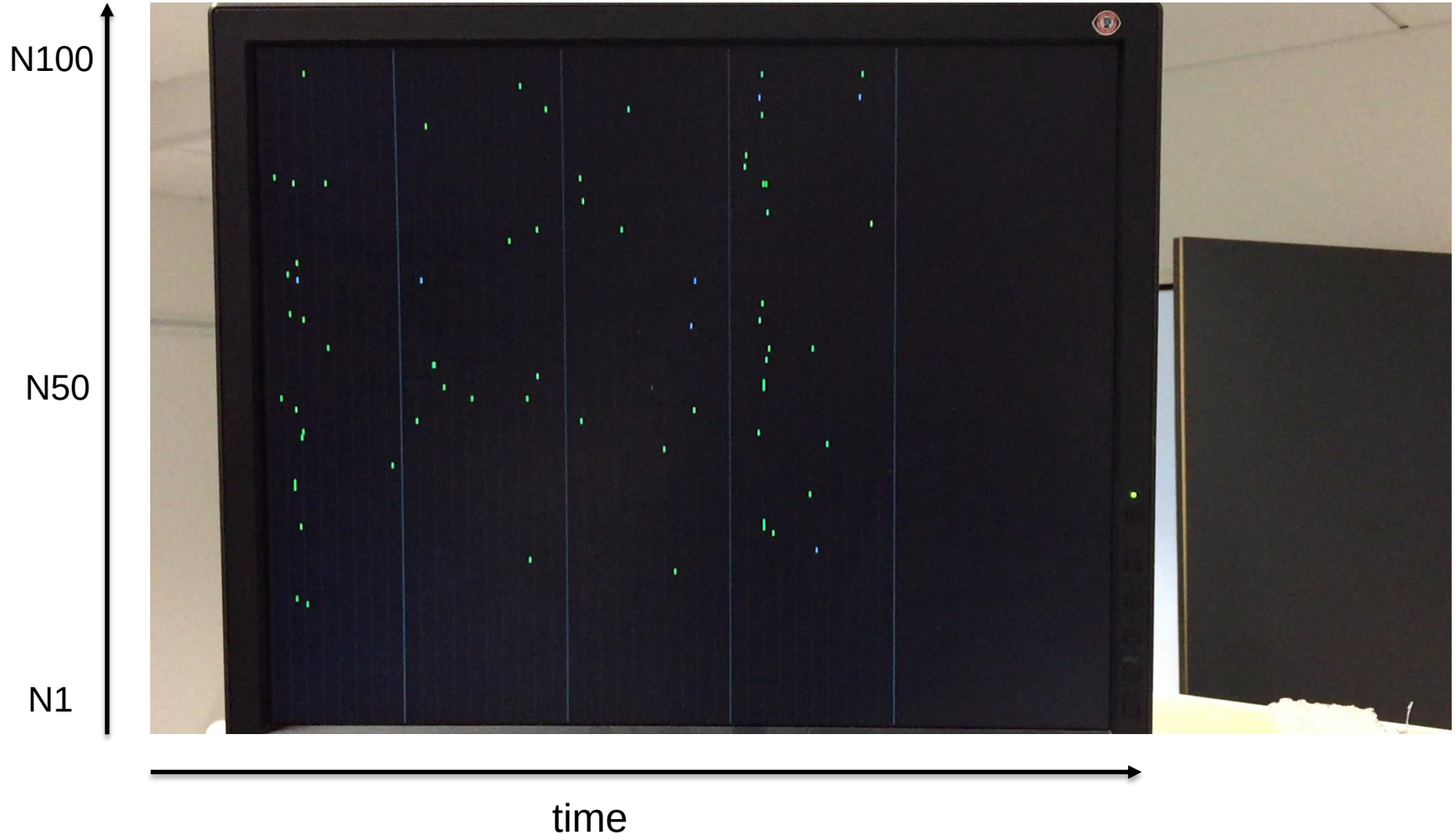


Choice of topology file

- Depending on the application
  - Choice of options
- Configuration file via hyperterminal
- Library of SNN for hybrid experiments:

ANN Name	Burst/min	Mean weights		Connectivity
		Excitatory	Inhibitory	
ANN_1	**1,95**	0,99	-2,01	26%
ANN_5	**5,65**	1	-1	25%
ANN_10	**9,3**	1,02	-1,02	25%
ANN_15	**13,25**	1,06	-1,2	25%
ANN_20	**23,45**	1	-1	28%

First week neuronal culture



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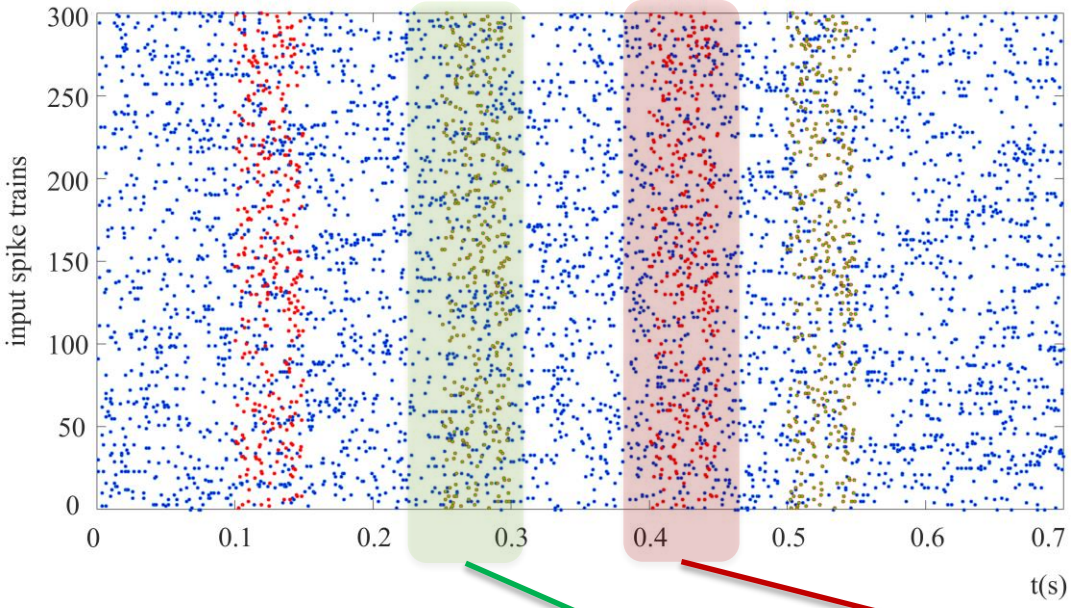
Neuromorphic system for AI

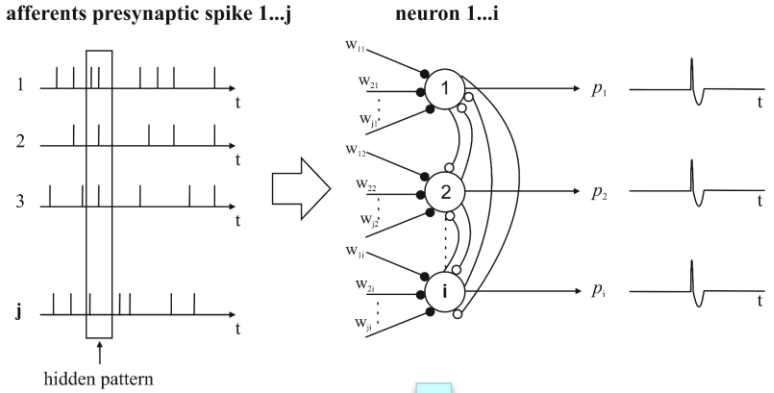
Brain	Computer
Operates at low speeds (< 10 Hz)	Operates at very high speeds (> GHz)
Spike Encoding	Digital Encoding
Power and energy efficient	Power and energy hungry
Asynchronous (no global clock) – *clock free*	Synchronous (global clock) – *clock aligned*
Analog computing and communication	Digital computing and communication
Memory and computation are fully integrated	Memory and computation are separated
Small world network organization with *multi-scale interactions*	Access to a single pre-determined scale with local interactions only

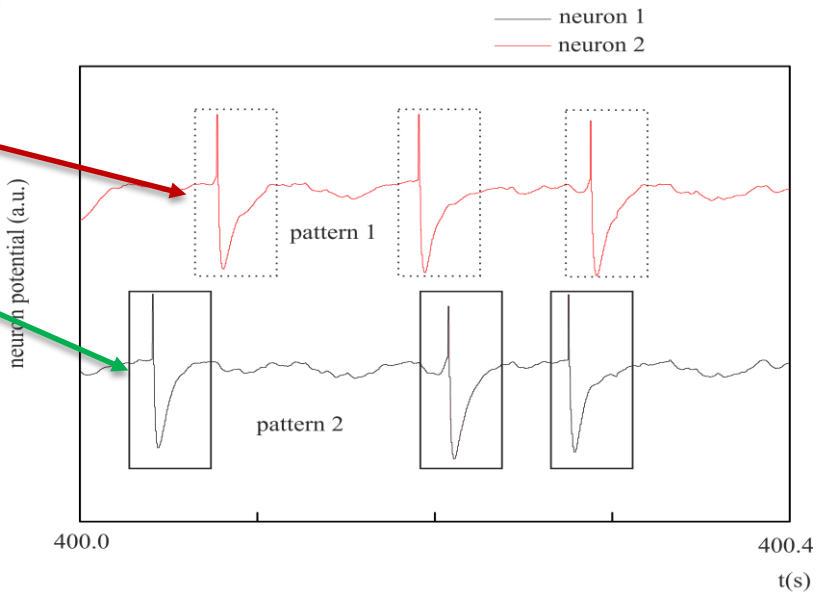
Pattern recognition

- Use of SNN with plasticity
  - Reduce simulation time and power consumption
- Intelligent sensor, unsupervised learning
- Detect pattern hidden in noise
  - Remove of amplifier, filters, detection modules

Spatiotemporal spike patterns



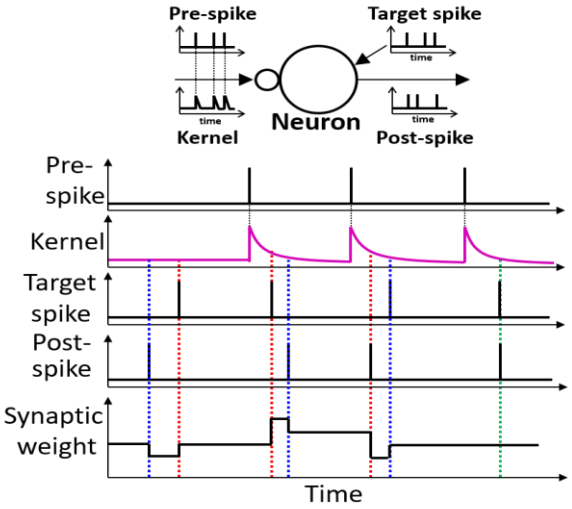




- 500 inputs spike trains
- Two hidden patterns
- Excitatory synapses governed by STDP.
- Lateral inhibitory connections

Reservoir computing

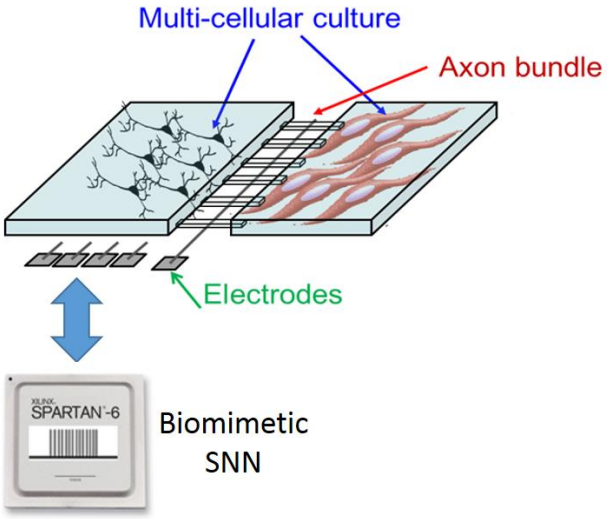
- Real-time
- Pre-learning with STDP
- Learning with ReSuMe algorithm
- Detect pattern

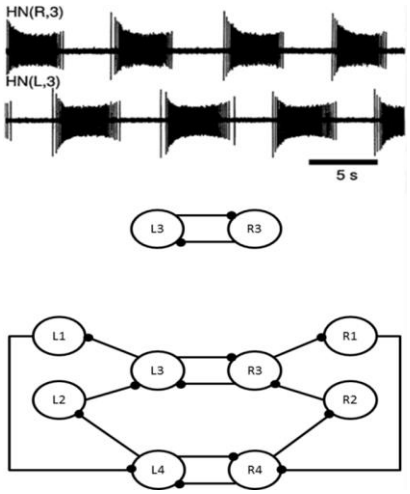


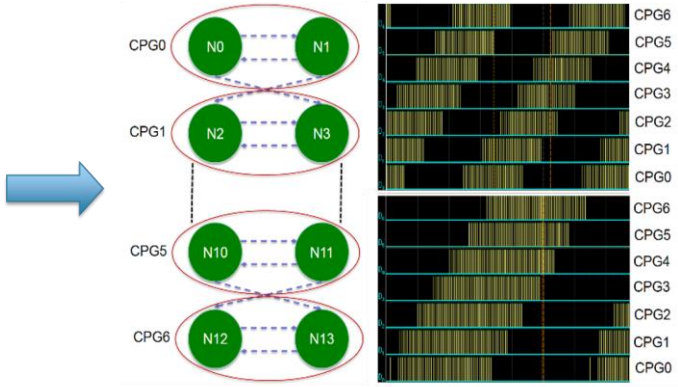
- Test of neuron model (LIF, DSSN, HH)
- Test of plasticity rules (STDP, ReSuMe, others)
- Other layers

Biohybrid robotic

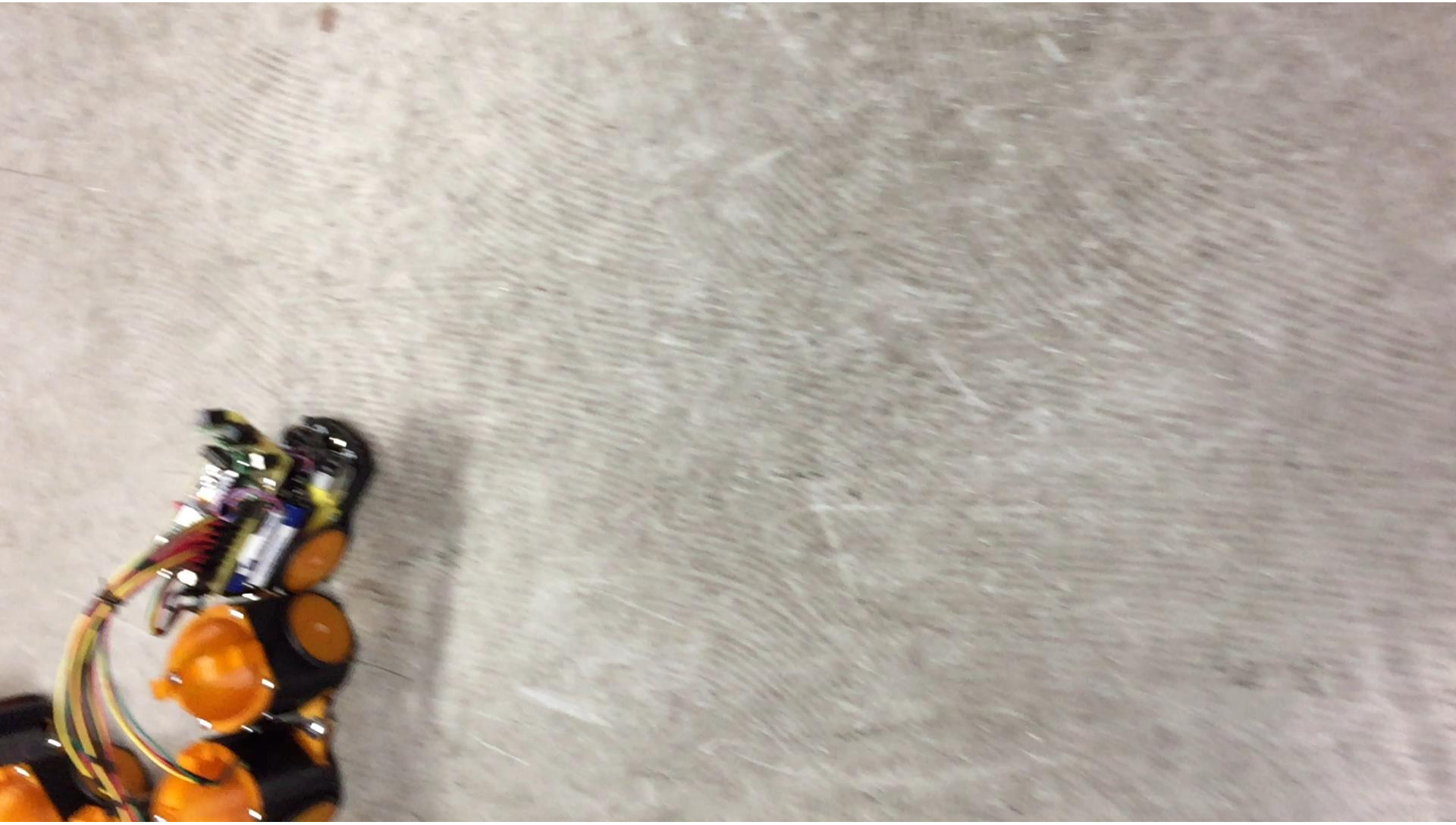
- SNN controlled the dynamic of BNN
- Biohybrid robot system controlled by SNN







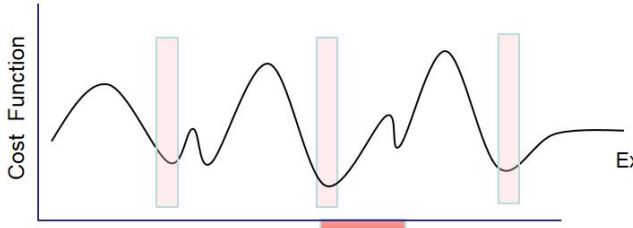
- Biomimetic Microfluidic systems
  - Controlled by electrical, chemical and optical techniques
  - ‘in vitro’ human-like system
  - Future for computer (microfluidic brain)



Translation to BioIntelligence

Software

NP Complex

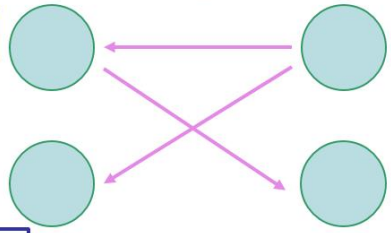


Ex: Travelling salesman problem

- High CPU time
- Power Consumption Issue

FPGA

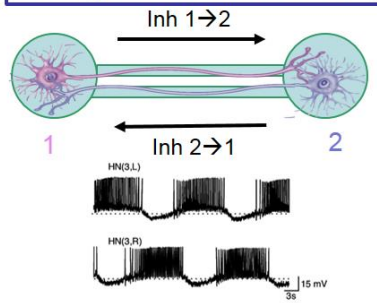
Spiking Neural Network (SNN)

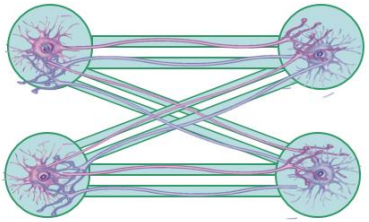


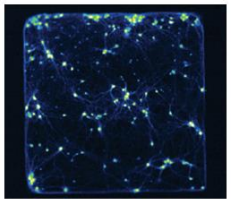
Biomimetic SNN

Bio-hybrid

Biological Neural Network (BNN)







Pattern neuron culture BNN

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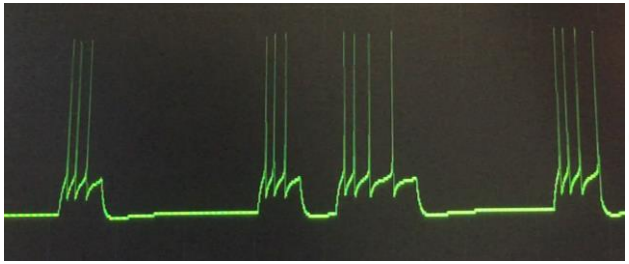
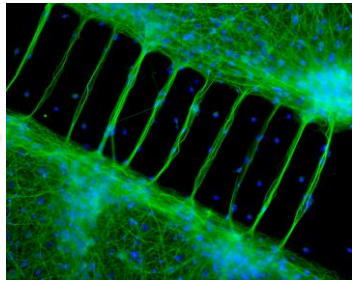
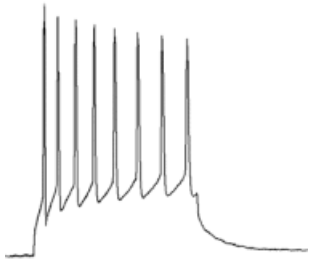
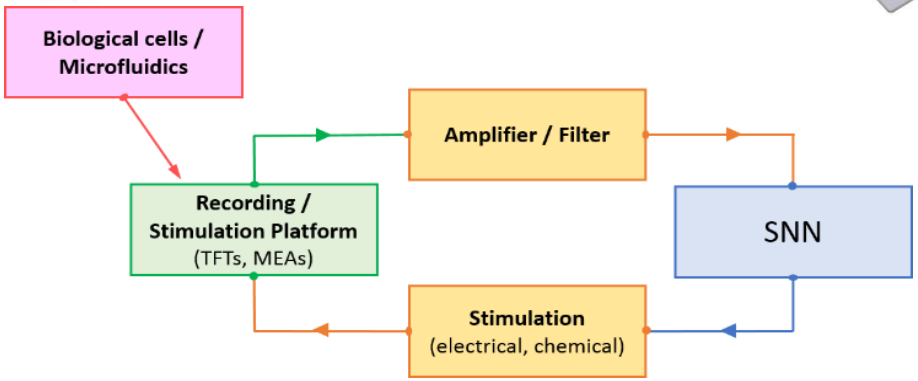
Bio-hybrid experiments

- Bi-directional communication between artificial and living neurons









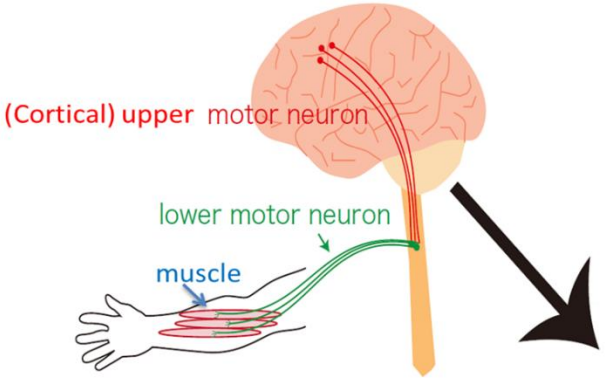
Neuron model in FPGA

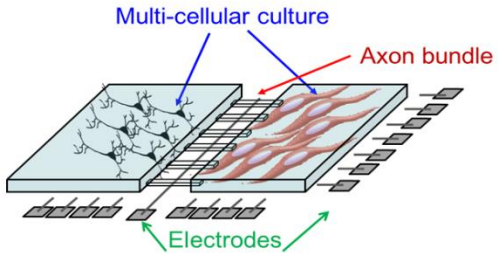
- Single cell study to small network

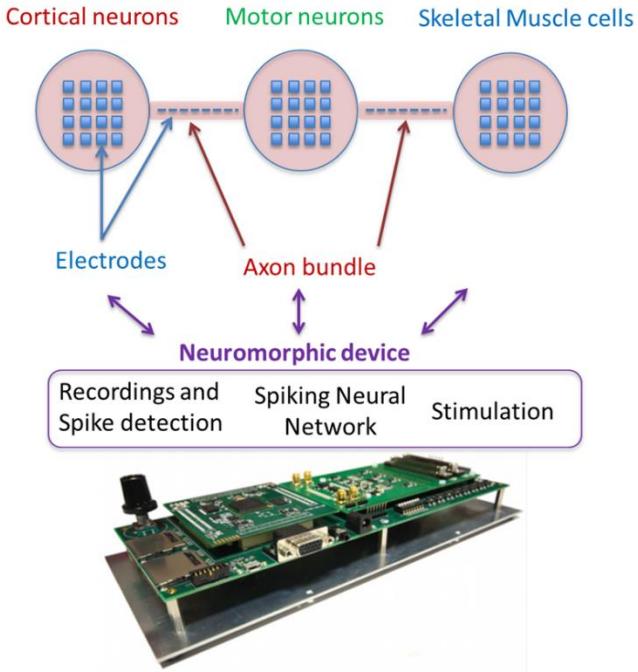
- Shape of action potential
- Multicompartmental approach
- Model for neurological disease

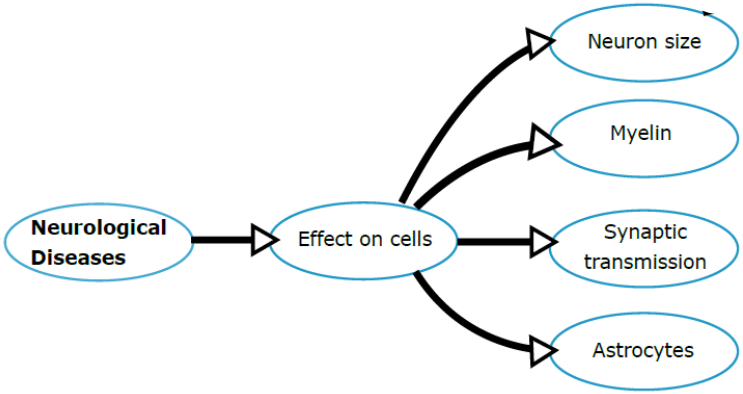
- Easier for neuroscientist
- More biomimetic dynamics

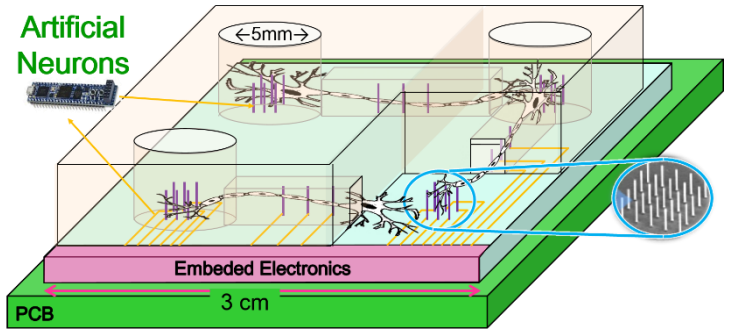
Neurological disease study



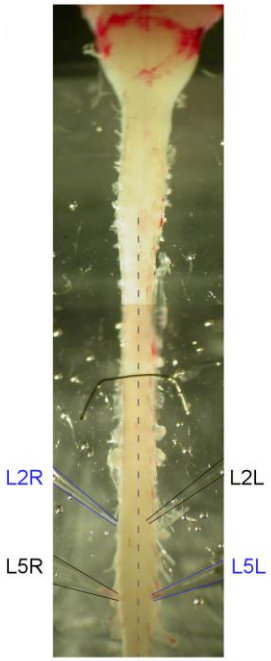


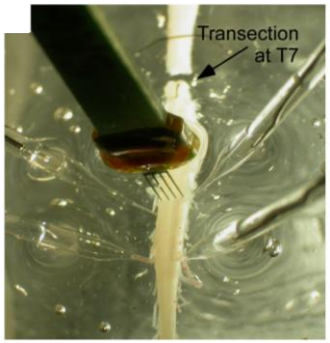


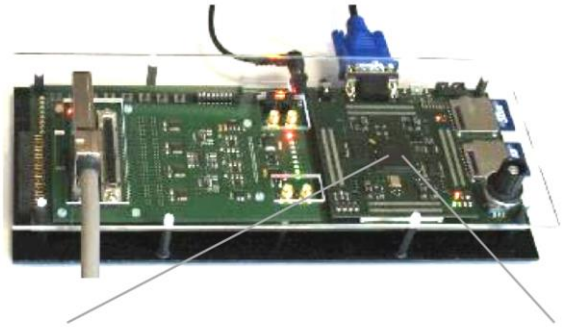


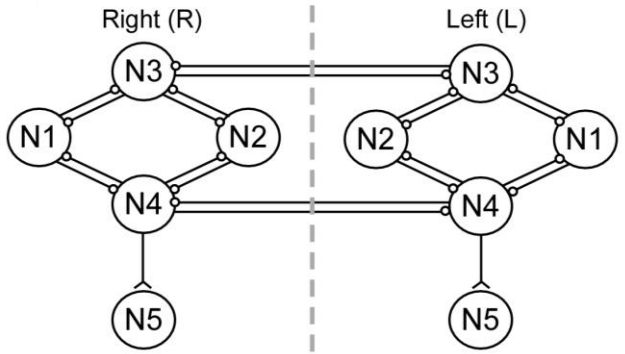


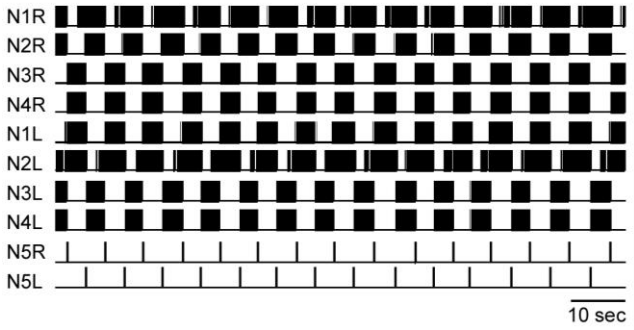
Hybrid experiment with spinal cord

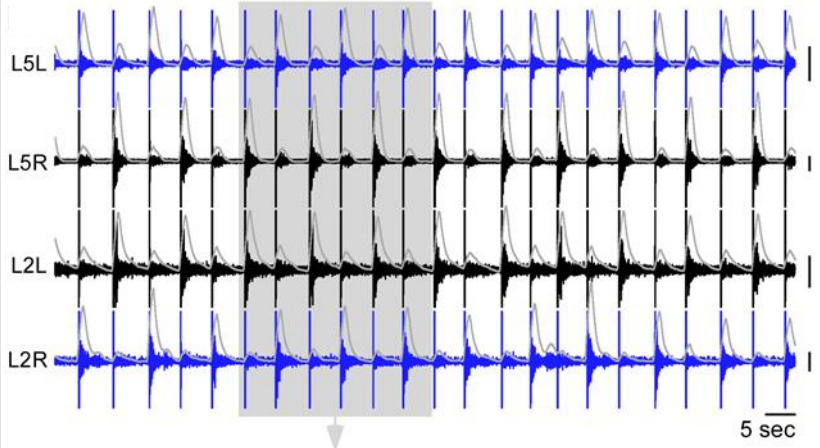


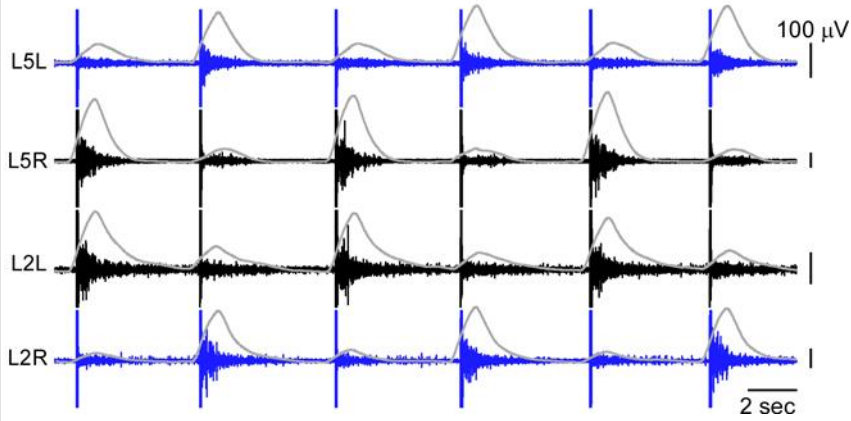






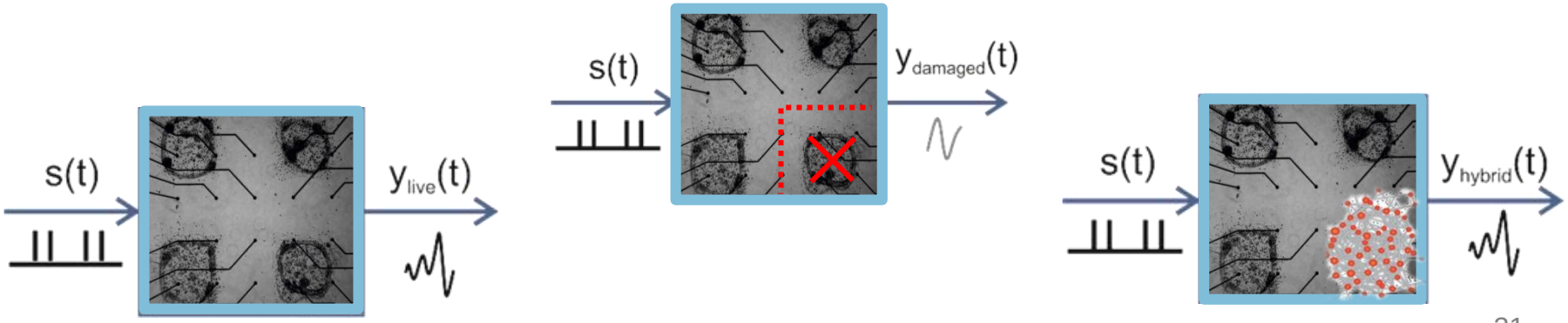


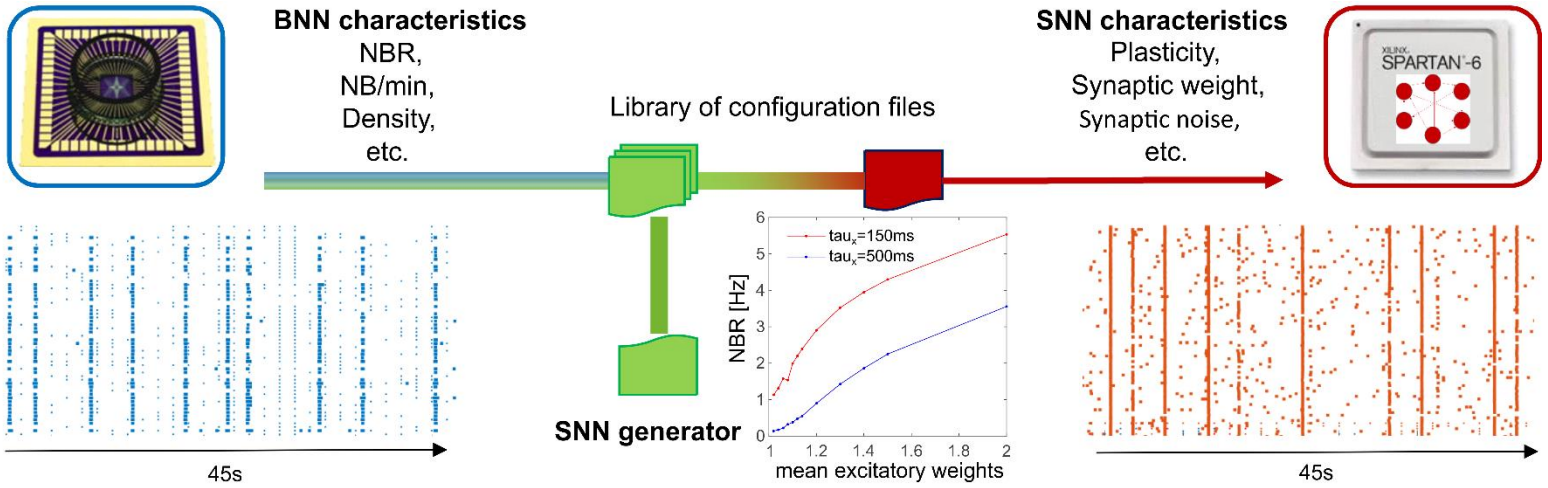




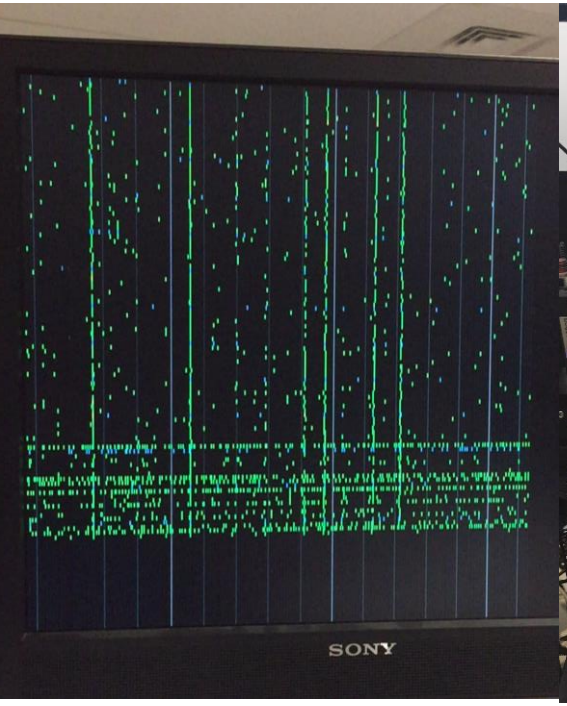
Replacement experiments

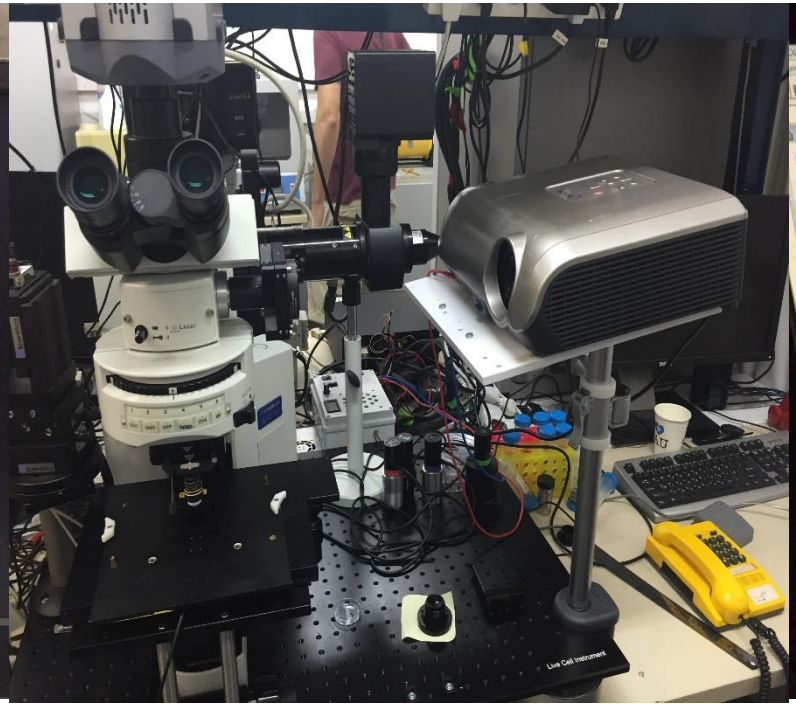
- Design of next-generation neuroprosthesis
- Restoring injuries at the level of the brain (‘brain-prosthesis’)

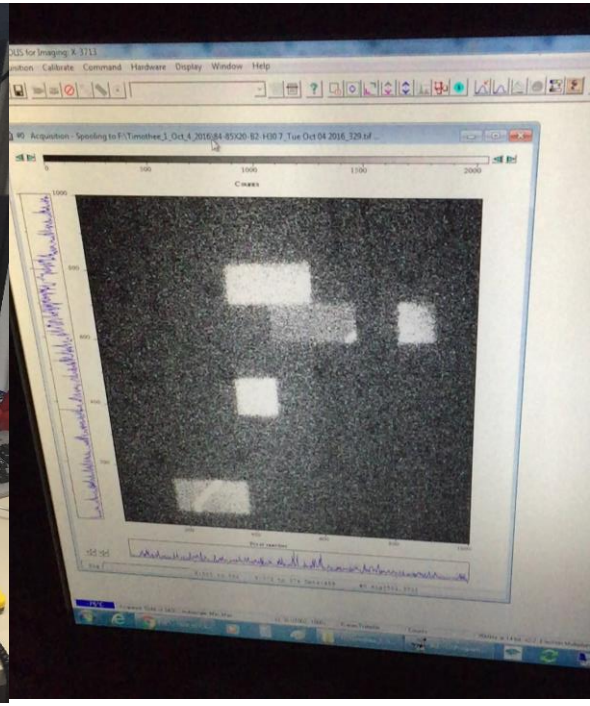




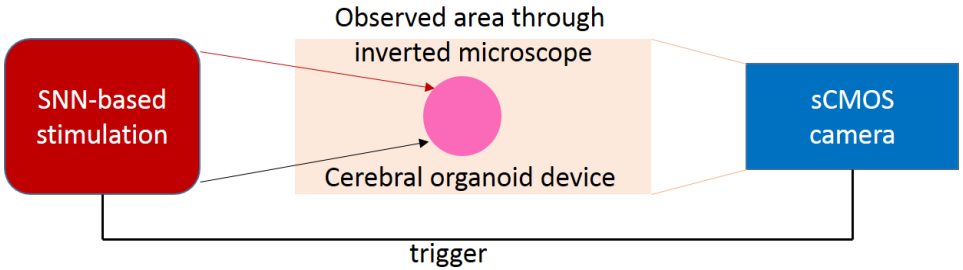
Optogenetic stimulation control by SNN

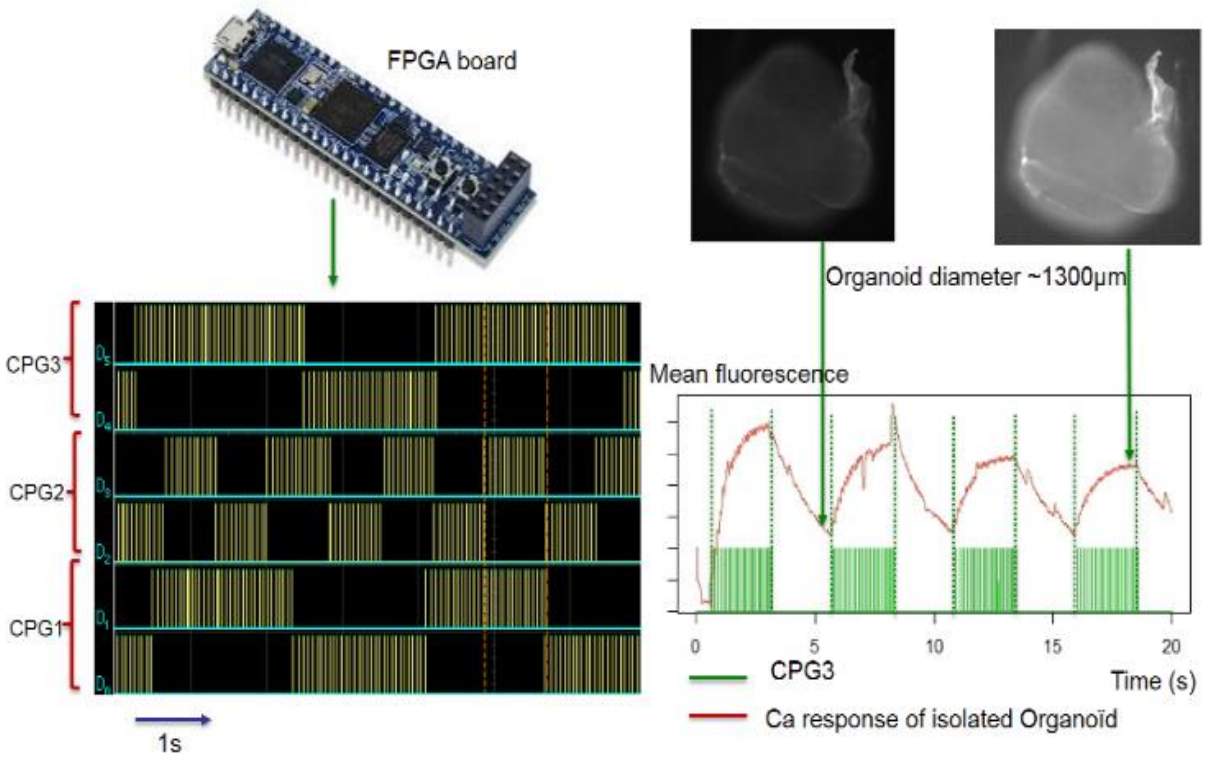


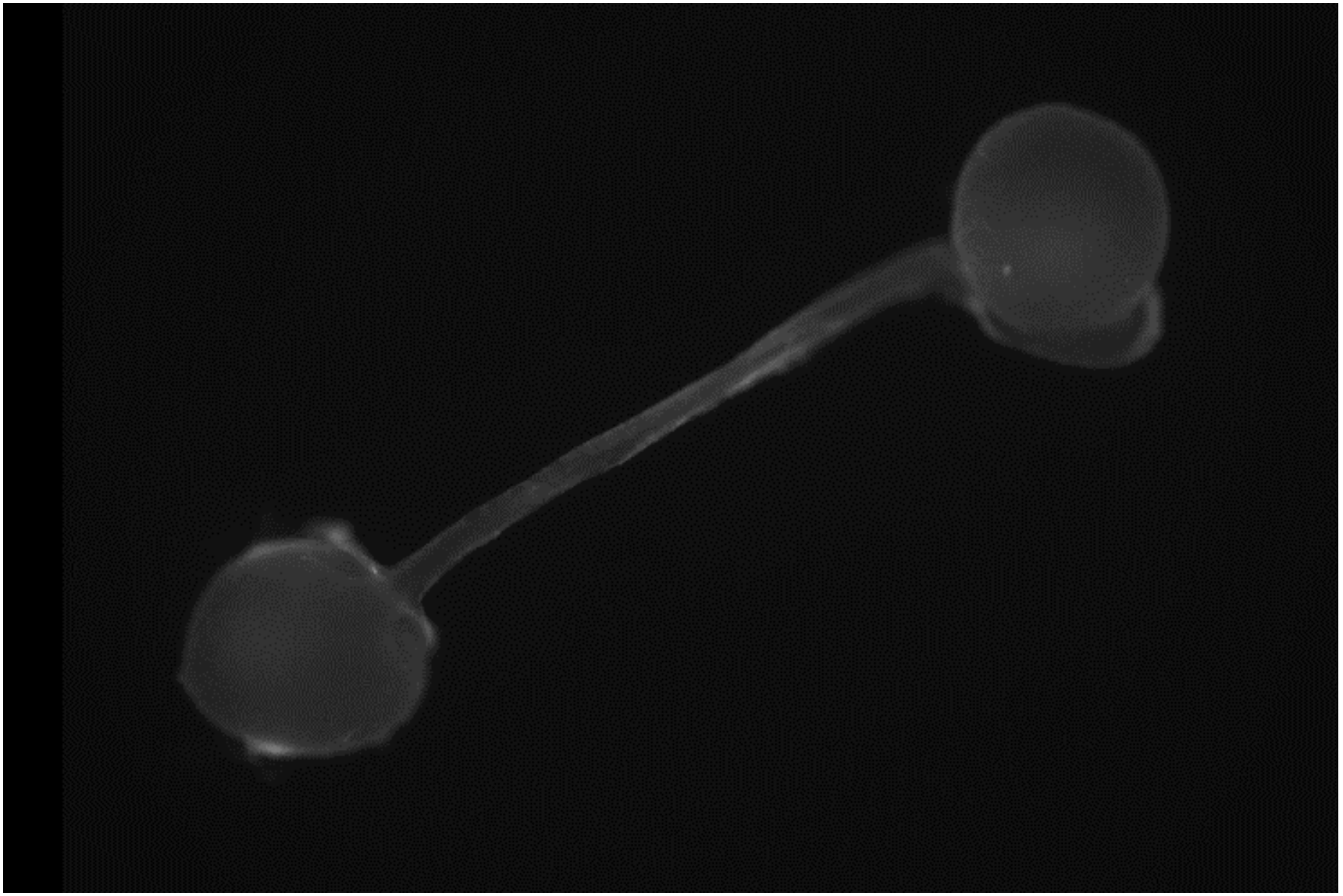




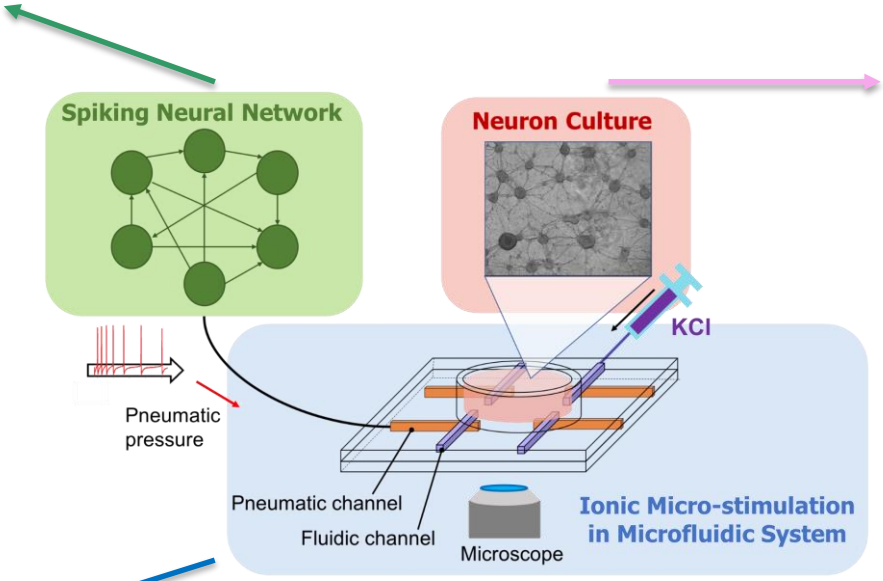
Using CPG for hybrid experiments

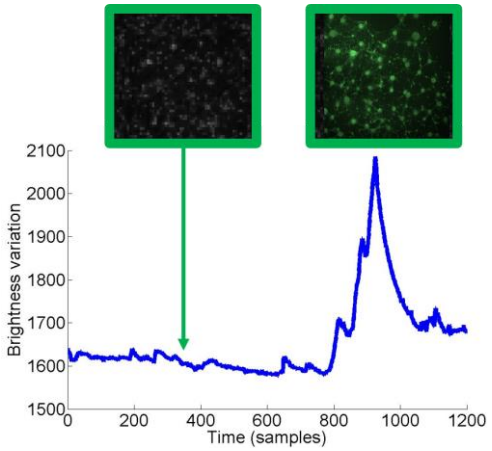


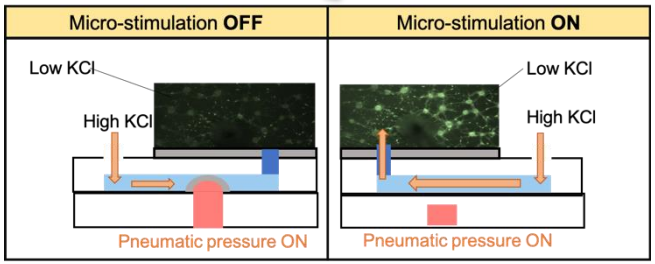




SNN for biomimetic stimulation







Content

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- Artificial Intelligence
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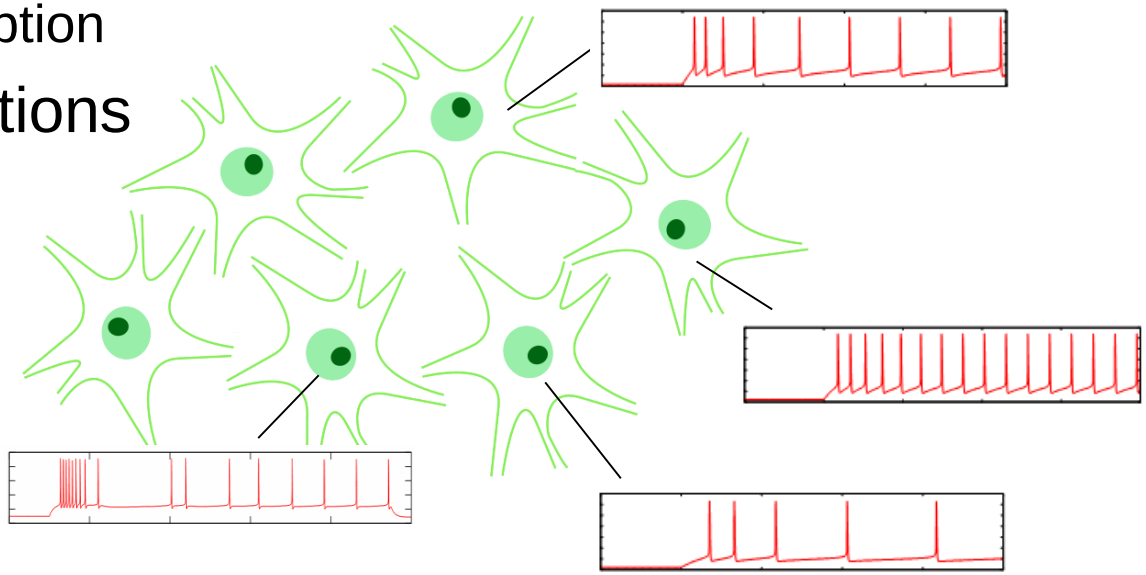
- Conclusion

Conclusion and perspectives

- Different neuron model
- Digital Spiking Neural Network
- Applications on AI
  - Pattern recognition
  - Low power consumption
- Biomedical applications
  - Bio-hybrid exp
  - Neuroprostheses



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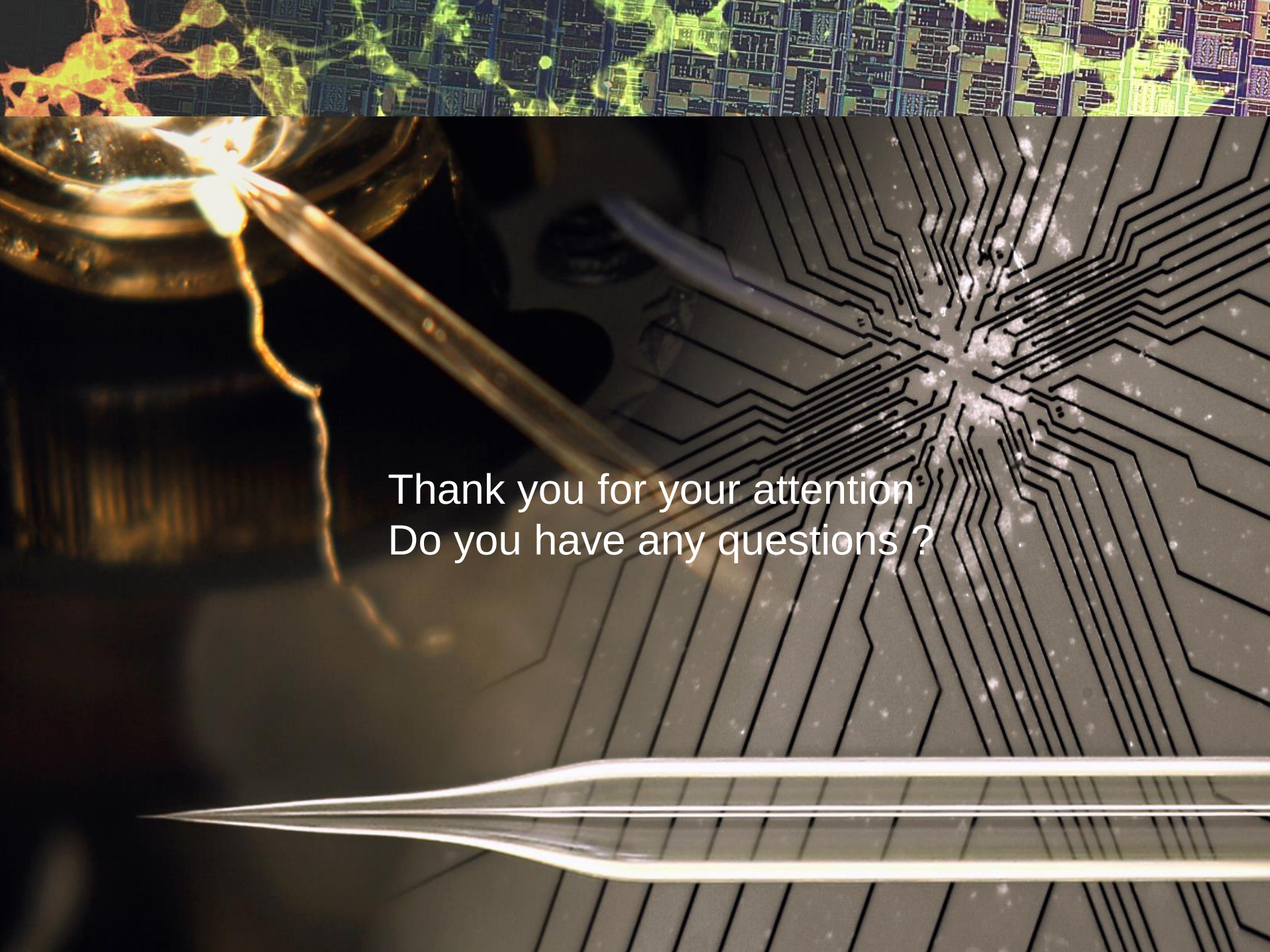
Thank you for your attention
Do you have any questions ?