TINNE- Techniques for Innovative Nanoscale Neuromophic Electronics

nanoSTAR
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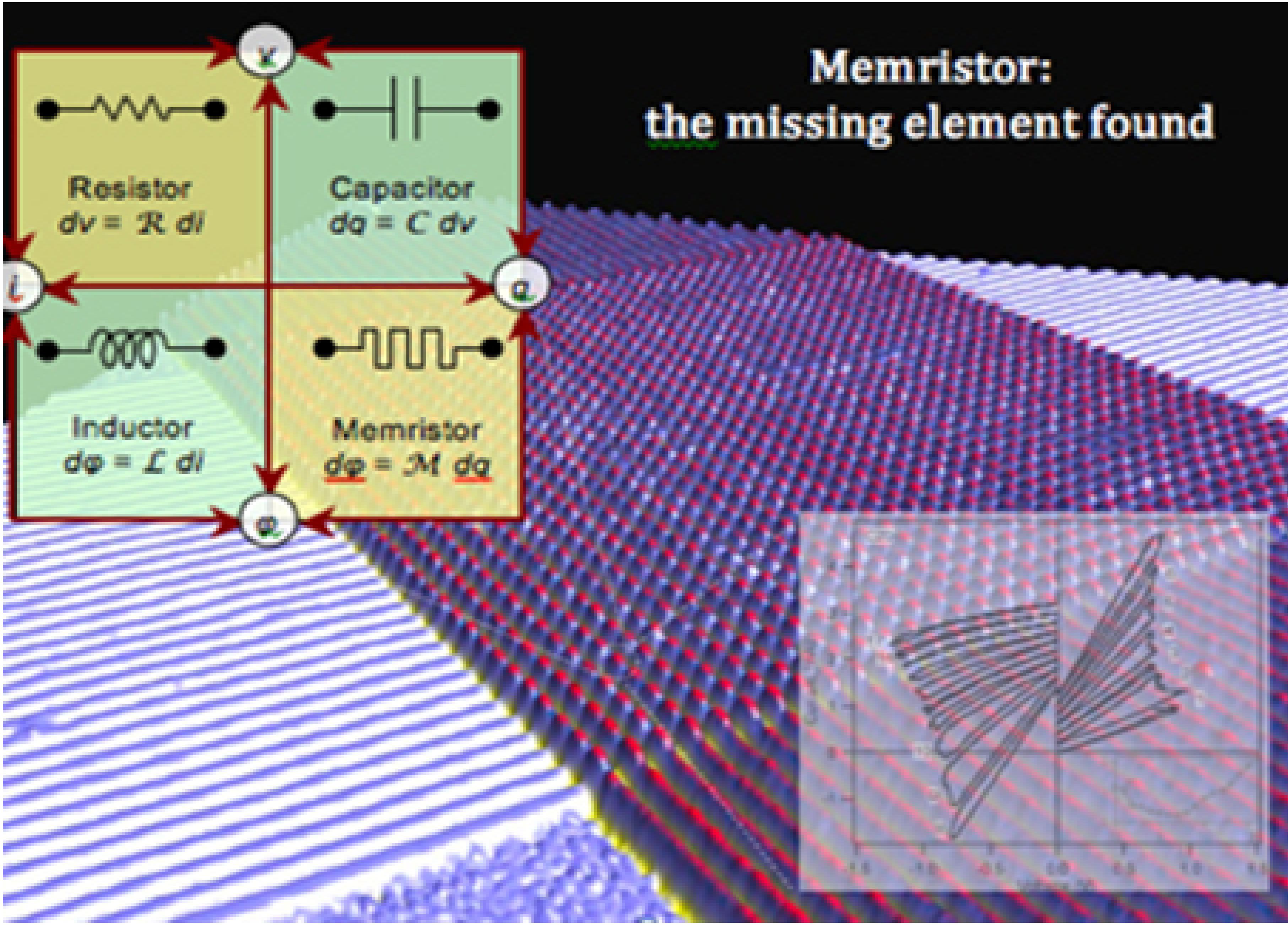
Project goals

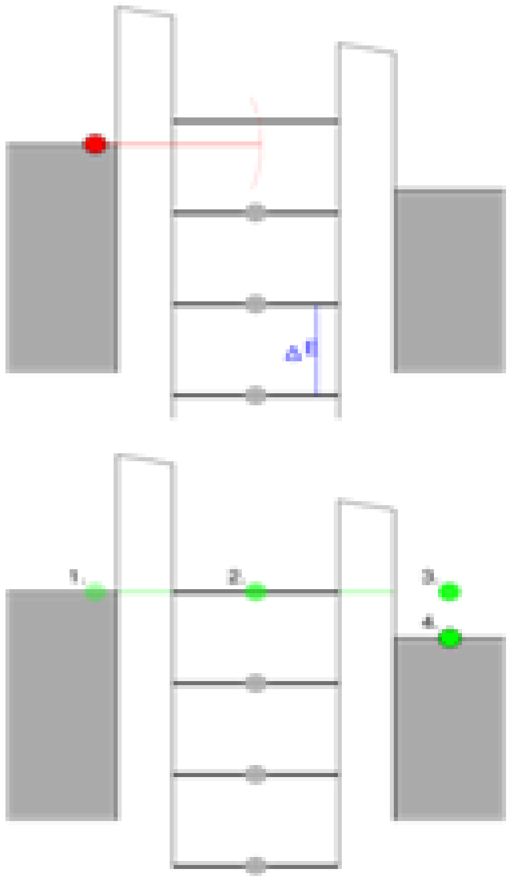
- establish collaboration model for Neuromorphic system research
- accomplish feasibility studies of adiabatic computation and interpulse interval coding for Neuromorphic systems
- lay the foundation for a design and simulation infrastructure that can be used for large and scalable Neuromorphic systems
- establish the needs of a larger faculty and student team for follow-up research
- explore collaboration with industry for Neuromorphic applications
- explore funding opportunities at DARPA, NSF, NRI, NIH

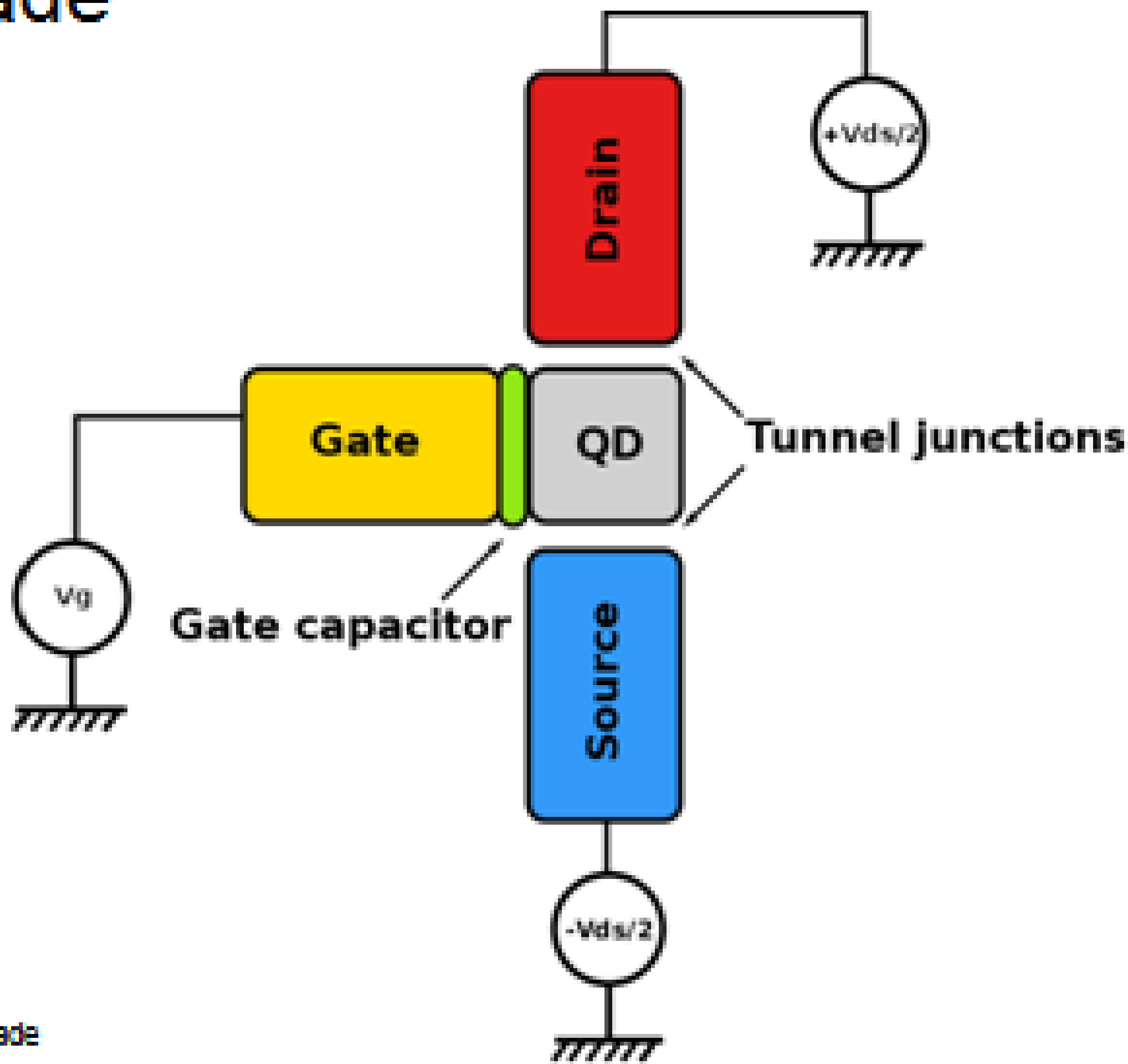


http://arstechnica.com/old/content/2008/05/maintaining-moores-law-with-new-memristor-circuits.ars

Single electron transistor - SET

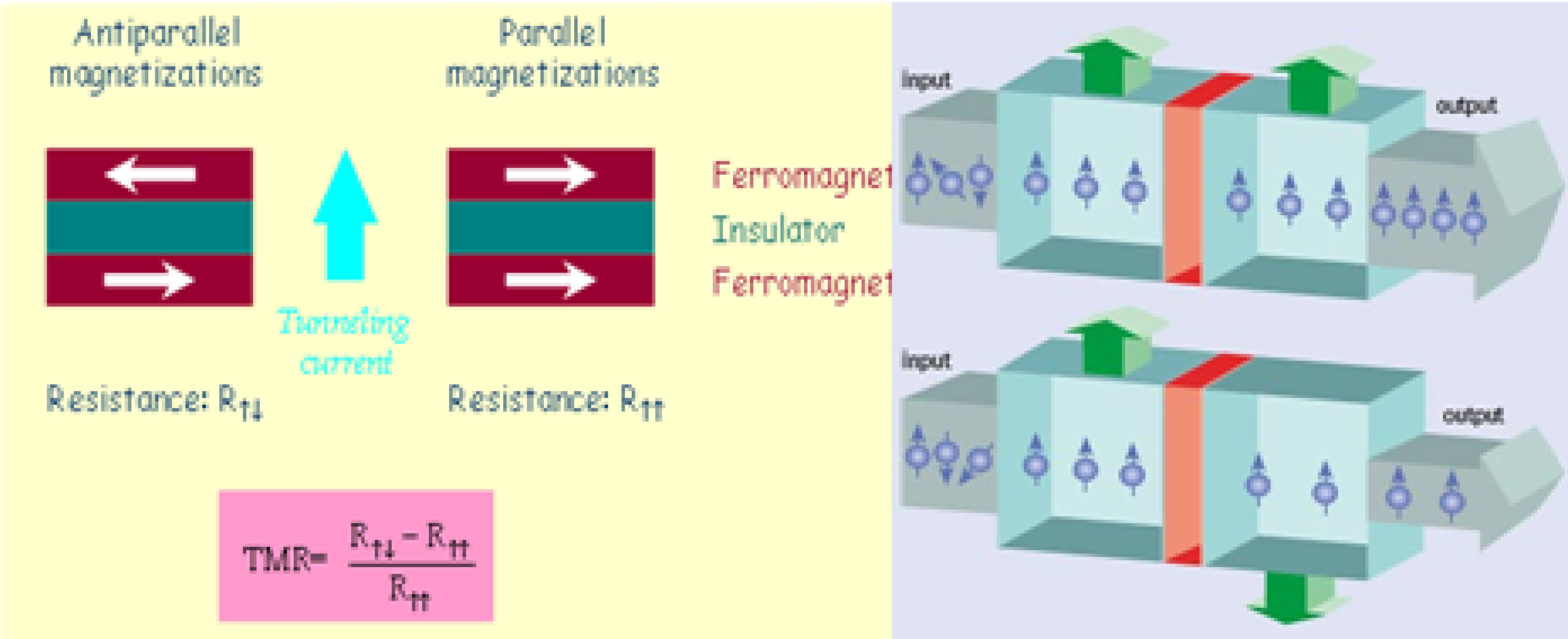
Coulomb blockade





http://en.wikipedia.org/wiki/Coulomb_blockade

Magnetic tunnel junction - MTJ



http://physicsworld.com/cws/article/print/32278/1/PWspi3_01-08

Sigma-Delta modulator neuron

- Inputs and outputs: current spikes
- Similar to neuron
- Can be implemented with both conventional and nanoelectronic technologies

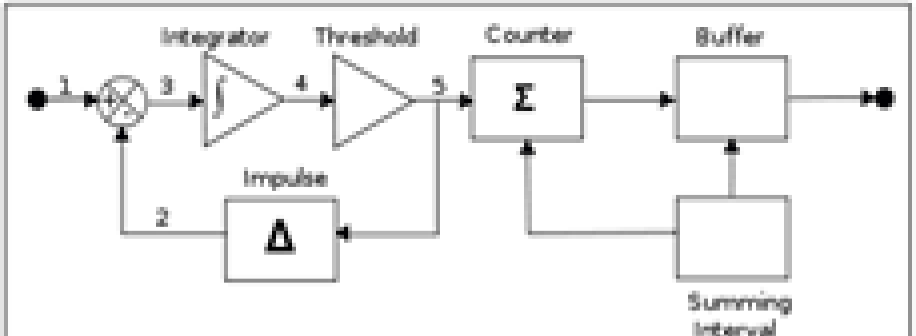
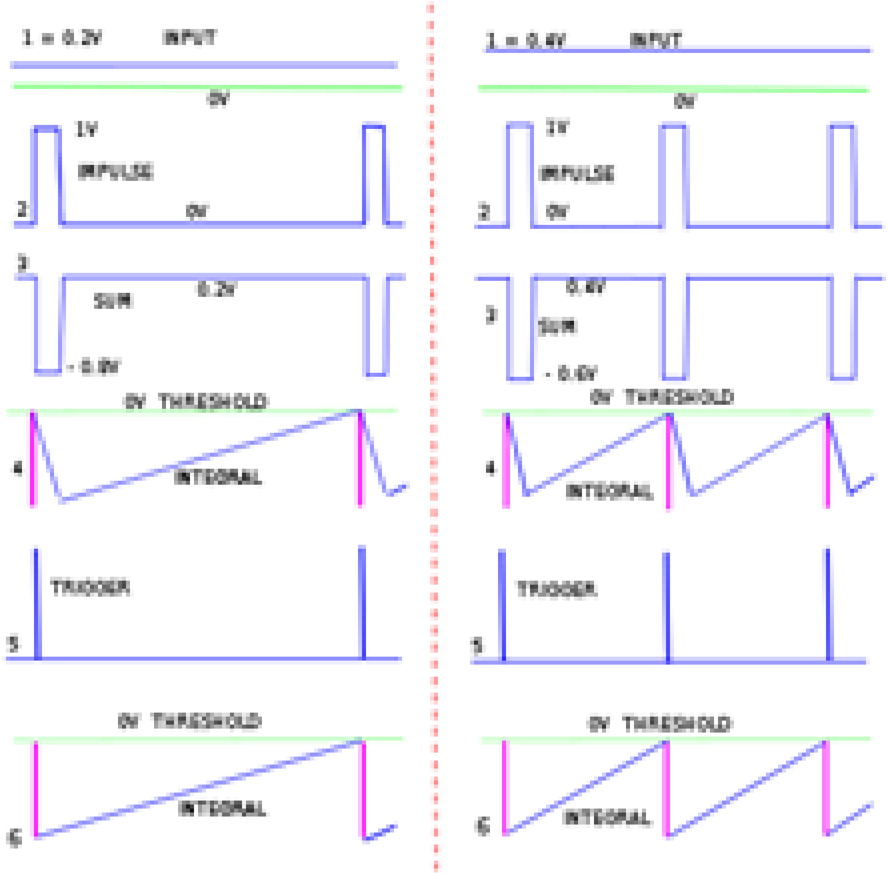


Fig. 1 - Block Diagram Delta Sigma ADC



Typical Waveforms

DARPA Synapse program

Hardware - Demonstrate an electronic synaptic component exhibiting Spike Timing Dependent Plasticity (STDP) with:

- Synaptic density scalable to > $10^{10}/cm^2$
- Operating speed >10 Hz
- Consumption < 10-12 Joules per synaptic operation at scale
- Dynamic range of synaptic conductance > 10
- Synaptic conductance increase >1%/pulse for presynaptic spike applied somewhere within 80-1 msec before a postsynaptic spike
- Synaptic conductance decrease >1%/pulse for presynaptic spike applied somewhere within 1-80 msec after postsynaptic spike.
- 0%-0.02% conductance decrease if presynaptic spike applied > 100 msec before or after postsynaptic spike
- Performance maintained over 3×10^8 synaptic operations
- Awarded to group led by IBM

http://p9.hostingprod.com/@modha.org/blog/2008/11/ibm_awarded_darpa_funding_via_1.html

NEURON MODEL: Izhikevich's Simple Spiking Neuron Model

Key Features:
No fixed threshold value, computationally fast
Only two equations and four variables to change the type of neuron
> 20 neuron types can be represented by the model
Biologically plausible

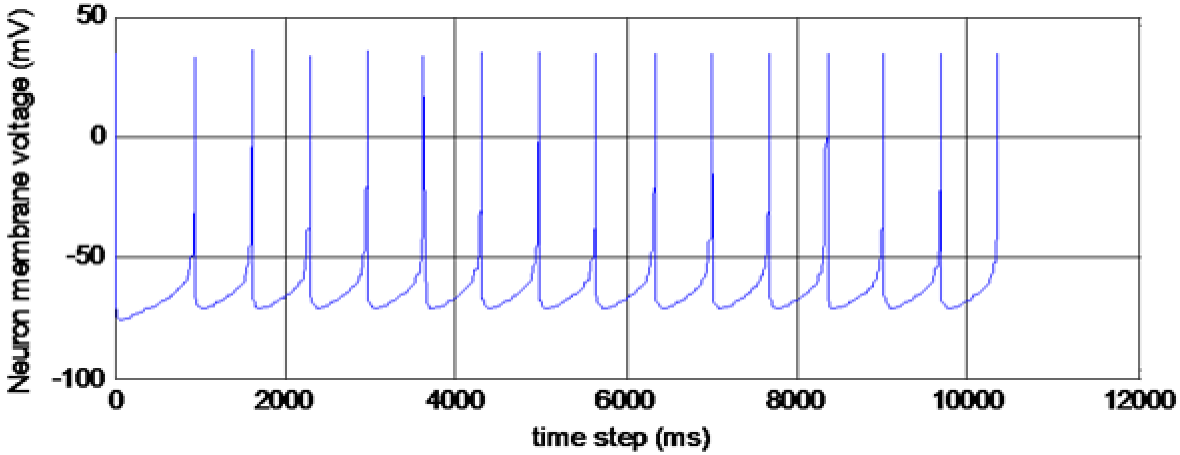
$$v' = 0.04v(t)^2 + ev(t) + f - u(t) + I(t)$$

$$u' = a(bv(t) - u(t))$$

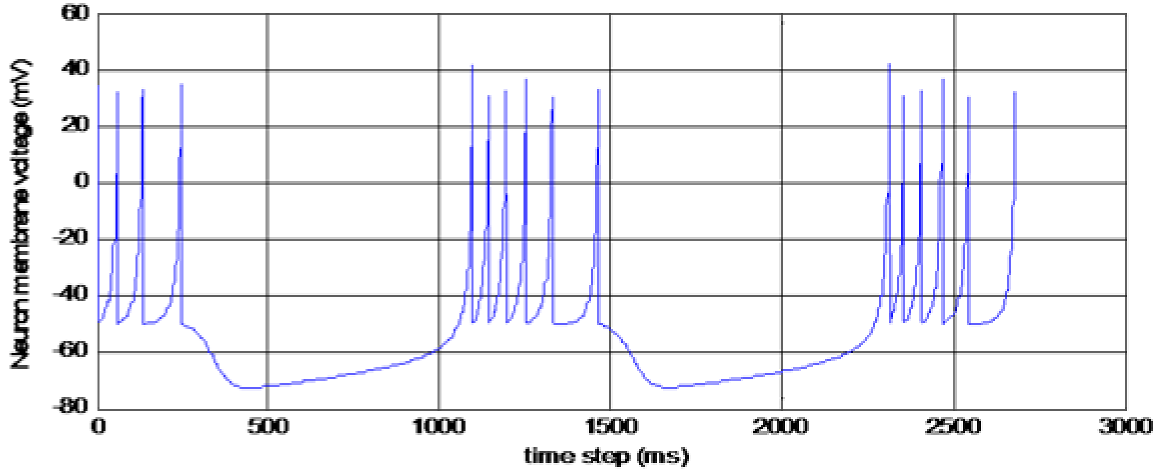
v: membrane potential of the neuron
u: membrane recovery variable
a: time scale of the recovery variable
b: sensitivity of the recovery variable
c: after spike reset value of 'v'
d: after spike reset value of 'u'
I: synaptic input currents

E. M. Izhikevich, *Simple Model of Spiking Neurons,* IEEE Trans. Neural Networks 14 (2003) 1569-1572

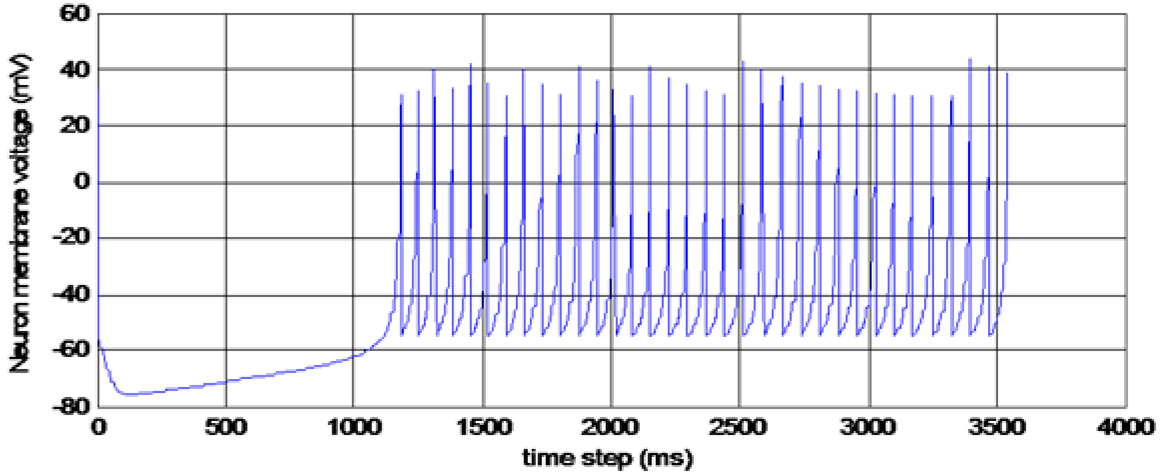
Examples



Neuron membrane voltage (mV)
50
0
-50
-100
0
2000
4000
6000
8000
10000
12000
time step (ms)



Neuron membrane voltage (mV)
60
40
20
0
-20
-40
-60
-80
0
500
1000
1500
2000
2500
3000
time step (ms)

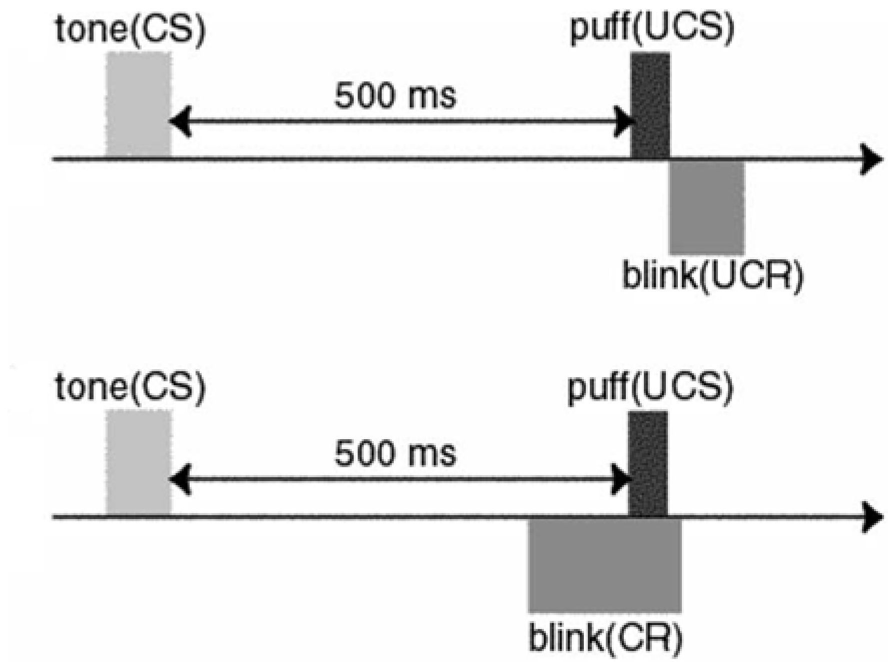


Neuron membrane voltage (mV)
60
40
20
0
-20
-40
-60
-80
0
500
1000
1500
2000
2500
3000
3500
4000
time step (ms)

NETWORK MODEL: Levy's Minimal Hippocampal Model

Hippocampus: Long term memory and spatial navigation

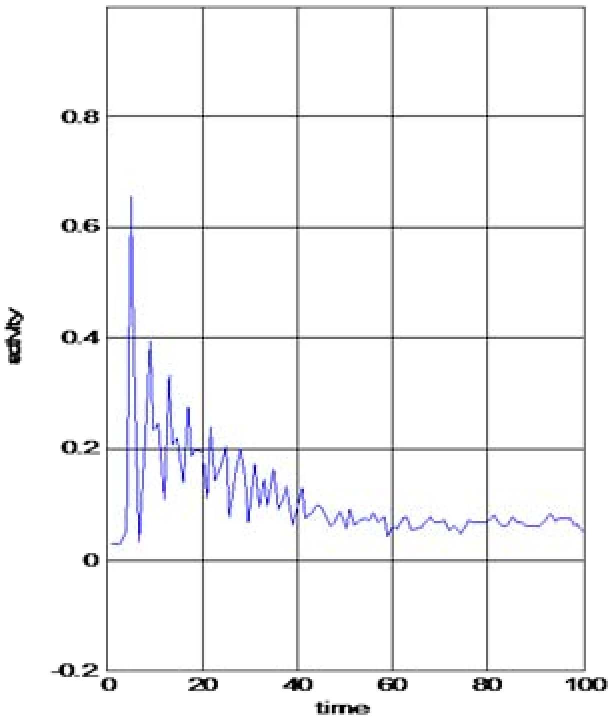
Trace conditioning

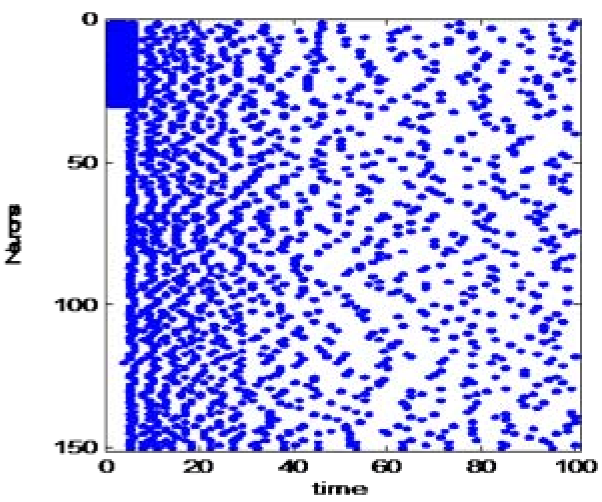


W. B. Levy, A. B. Hocking, X. Wu, *Interpreting Hippocampal Function As Recoding and Forecasting,* Neural Networks 18 (2005) 242-1264

INTEGRATED MODEL

Number of Neurons: 1000
Desired network activity: 0.1 (%10)
Network connectivity: 0.3 (%30)

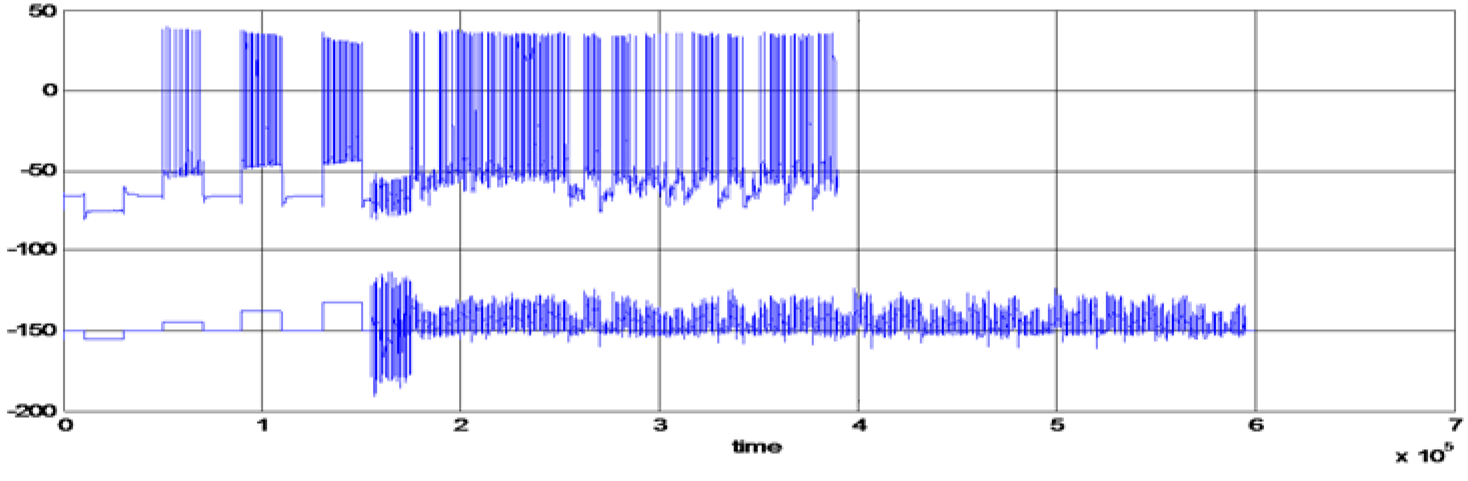




VALIDATION of MODEL

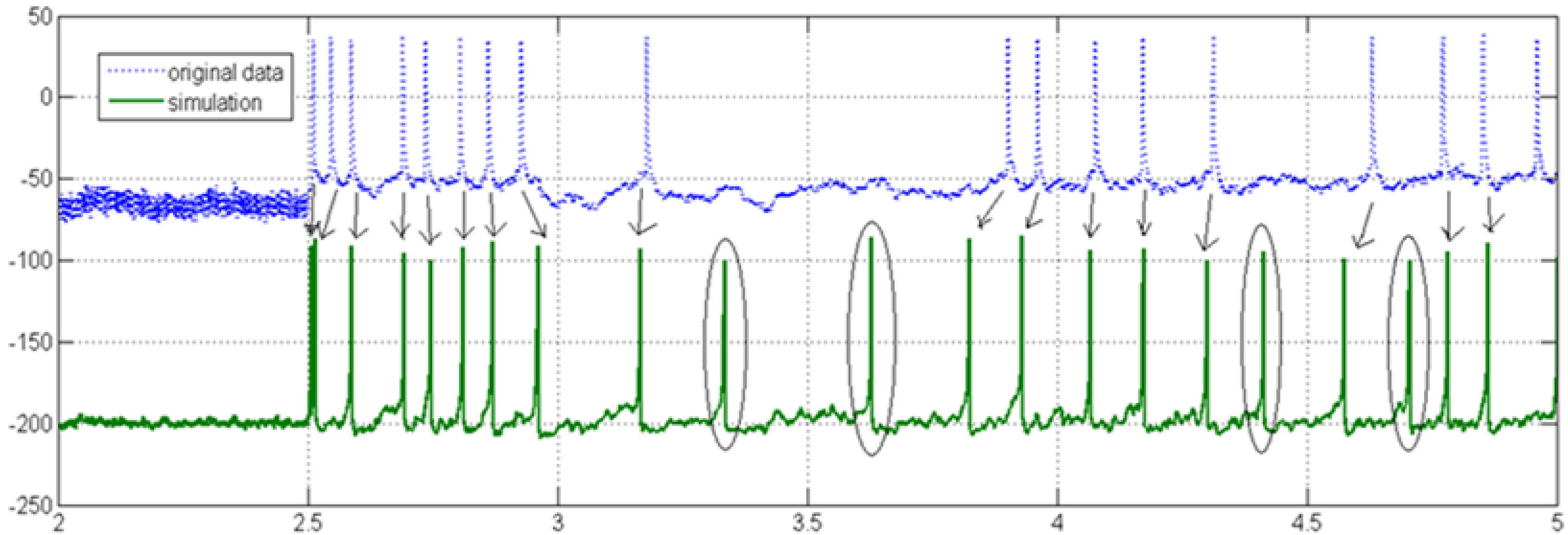
Quantitative Single-Neuron Modeling Competition

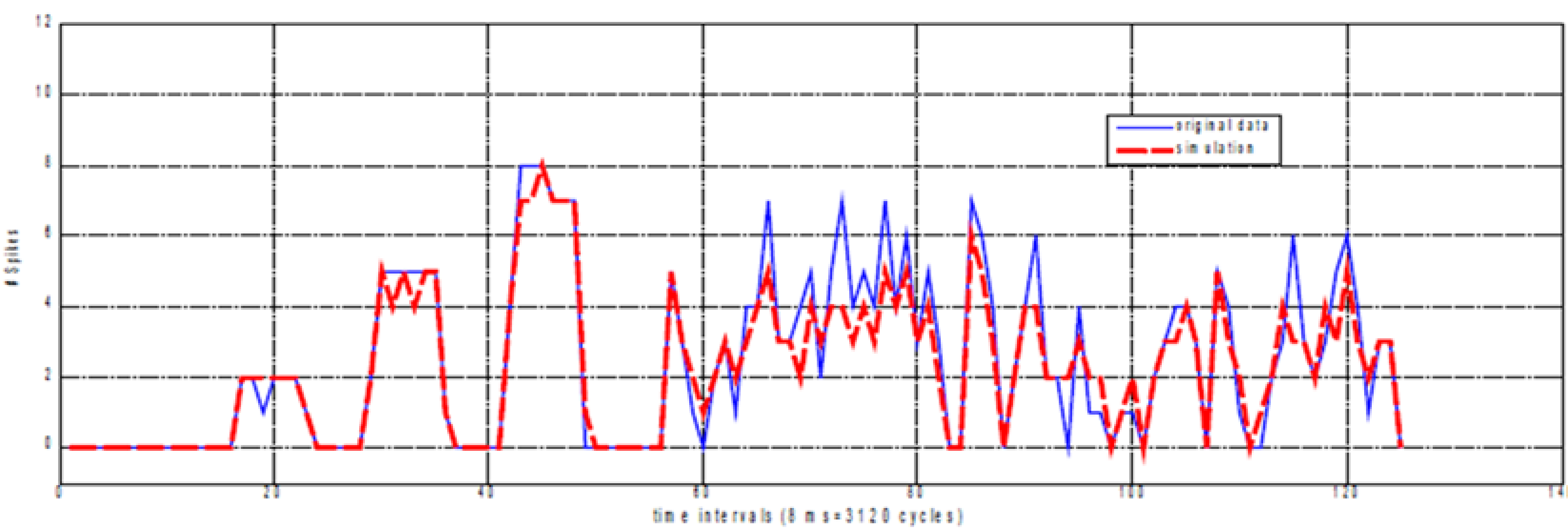
- **Goal:** Bridge the gap between experimentalists and modelers
- Predict the spike timing of a regular spiking L5 pyramidal cell responding to in-vivo-like current injection
- **Input Current:** First part is 17.5 seconds of 3 step current with a duration of 2 seconds and an inter-step rest time of 2 seconds followed by an injection of white noise of 2 seconds



http://www.incf.org/Events/competitions/spike-time-prediction/2009/

Preliminary results





Conclusions and future work

- Opportunities: biologically inspired, low energy, potential to exploit novel technologies, electronic “brain”
- Challenges: heavily interdisciplinary, many possible points of failure
- Next: funding, refining of neuron model, realize a full neural network, physical implementation