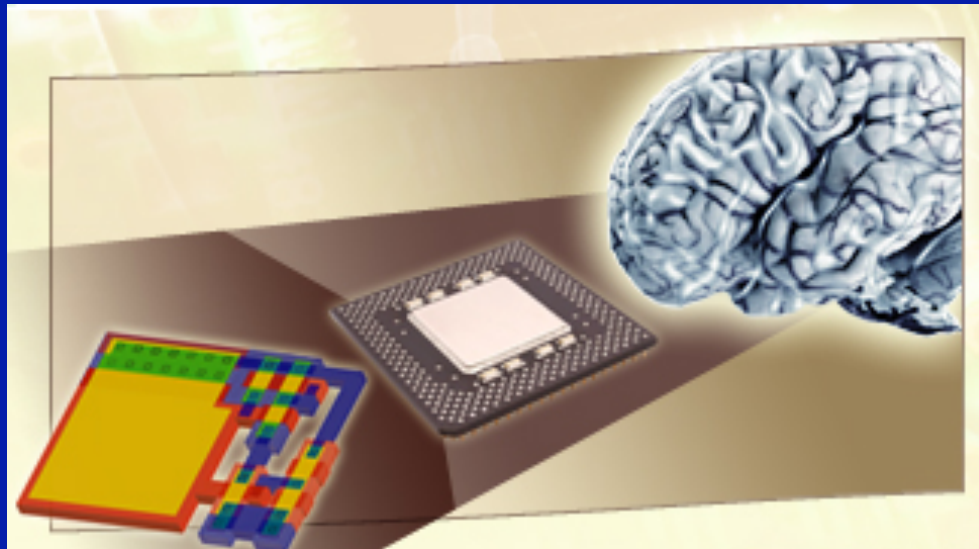
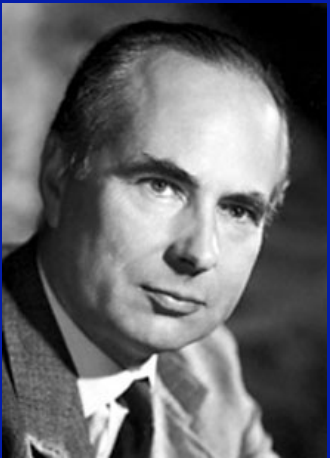
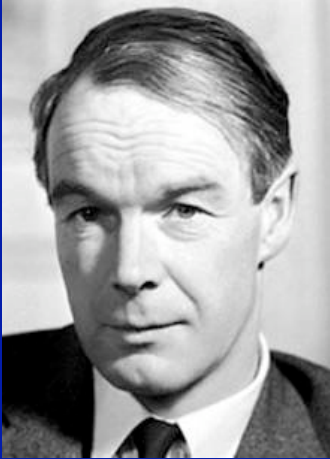


Neurogrid: Emulating a million neurons in the cortex



Kwabena Boahen
Stanford Bioengineering
boahen@stanford.edu



J. Physiol. (1952) 117, 500-544

A QUANTITATIVE DESCRIPTION OF MEMBRANE CURRENT AND ITS APPLICATION TO CONDUCTION AND EXCITATION IN NERVE

By A. L. HODGKIN AND A. F. HUXLEY

From the Physiological Laboratory, University of Cambridge

(Received 10 March 1952)

This article concludes a series of papers concerned with the flow of electric current

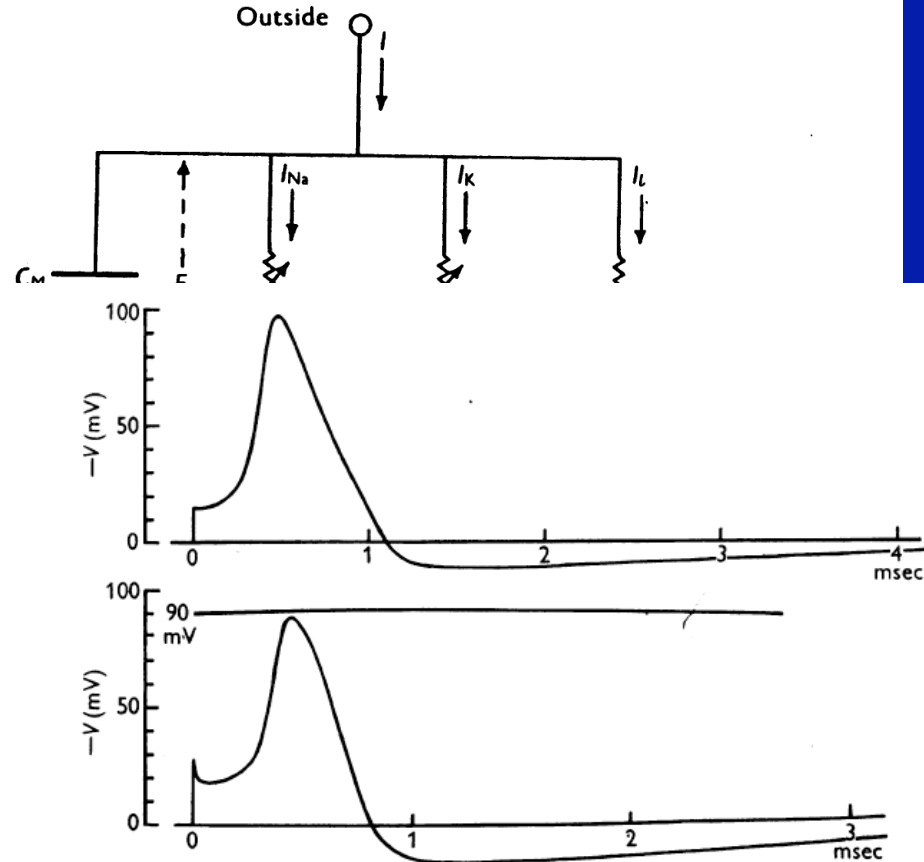


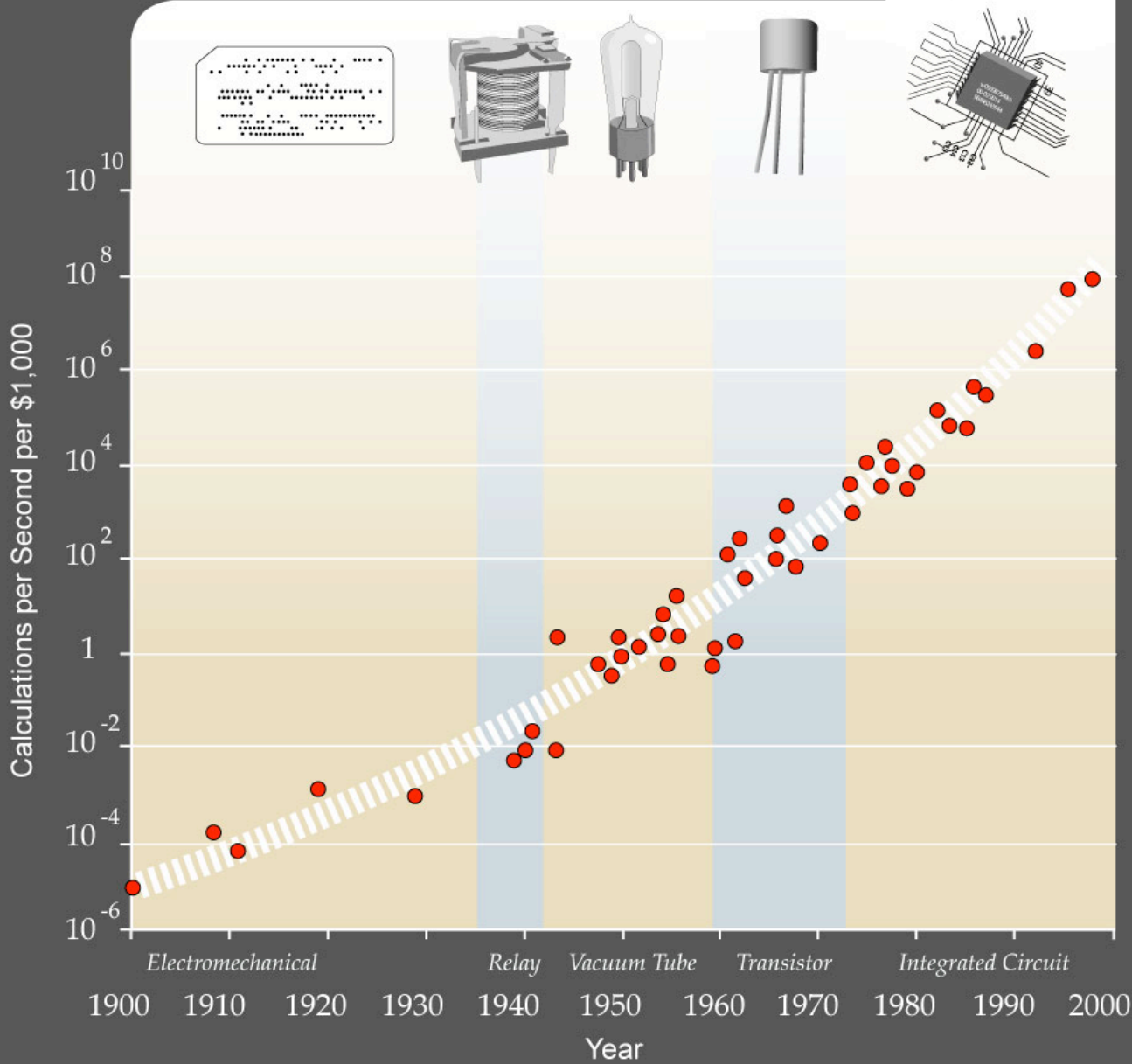
Fig. 1. E
 R_K

Fig. 14. Upper curve: solution of eqn. (26) for initial depolarization of 15 mV, calculated for 18.5° C. Lower curve: tracing of membrane action potential recorded at 20.5° C (axon 11). Vertical scales are similar. Horizontal scales differ by a factor appropriate to the temperature difference.

Moore's Law

The Fifth Paradigm

Logarithmic Plot



3GHz Dell Precision

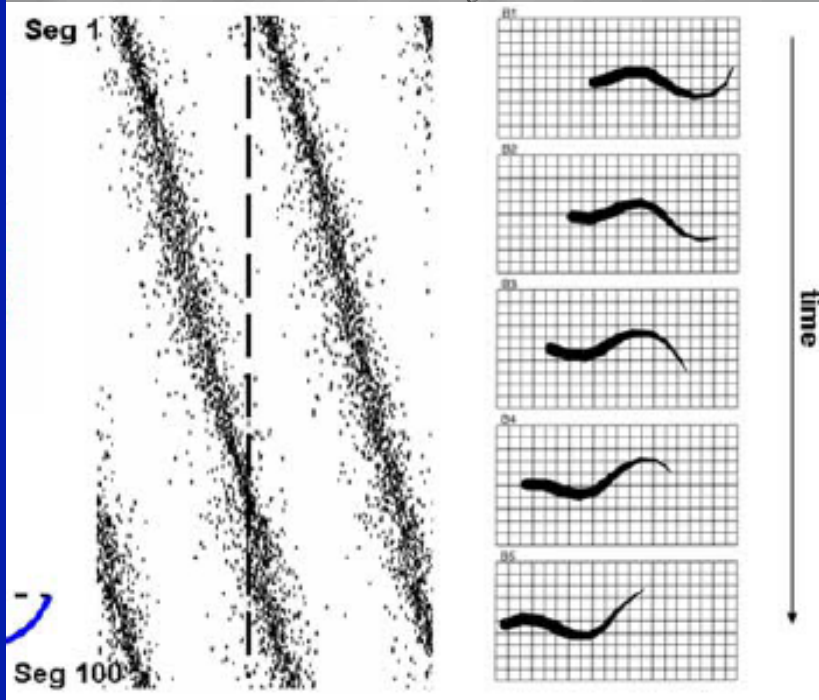
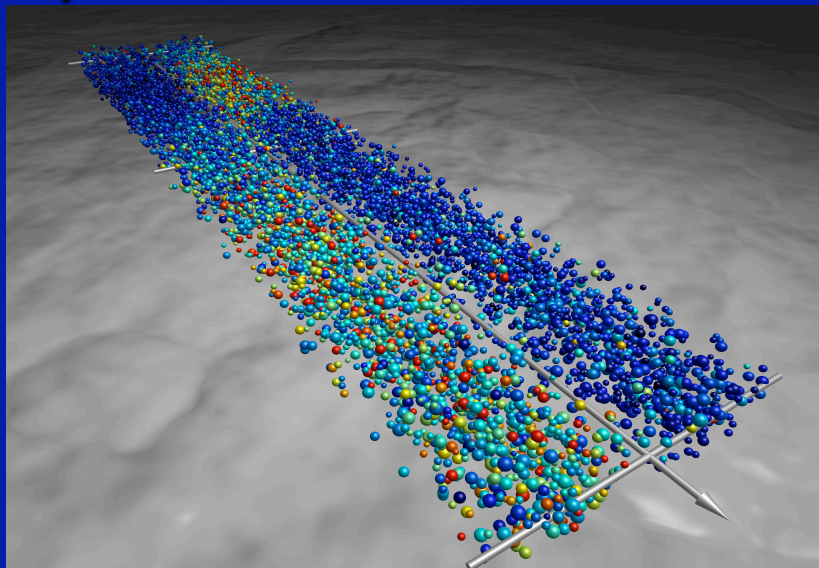


100Mhz Compaq Presario



Brunsviga Model 20

Spinal cord

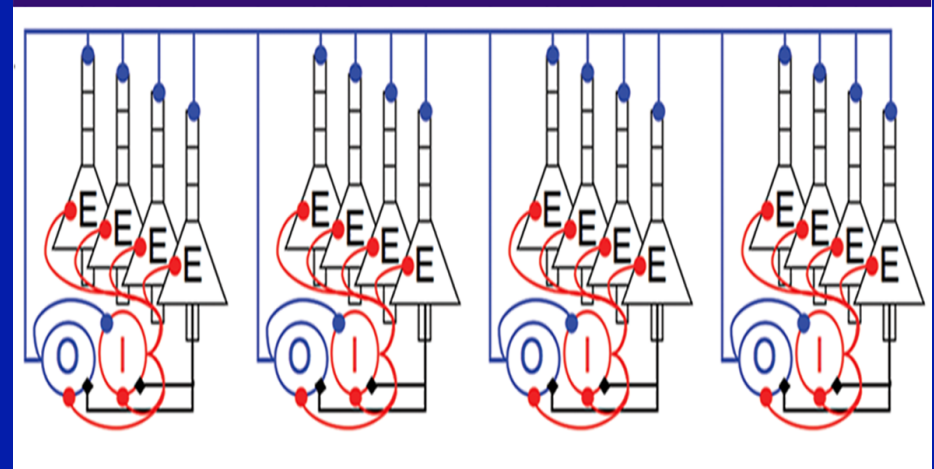
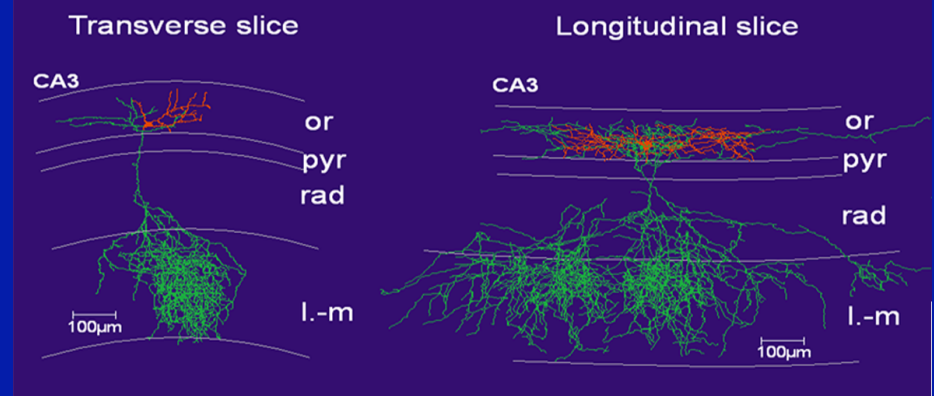


© Kwabena Boahen

Grillner et al 07

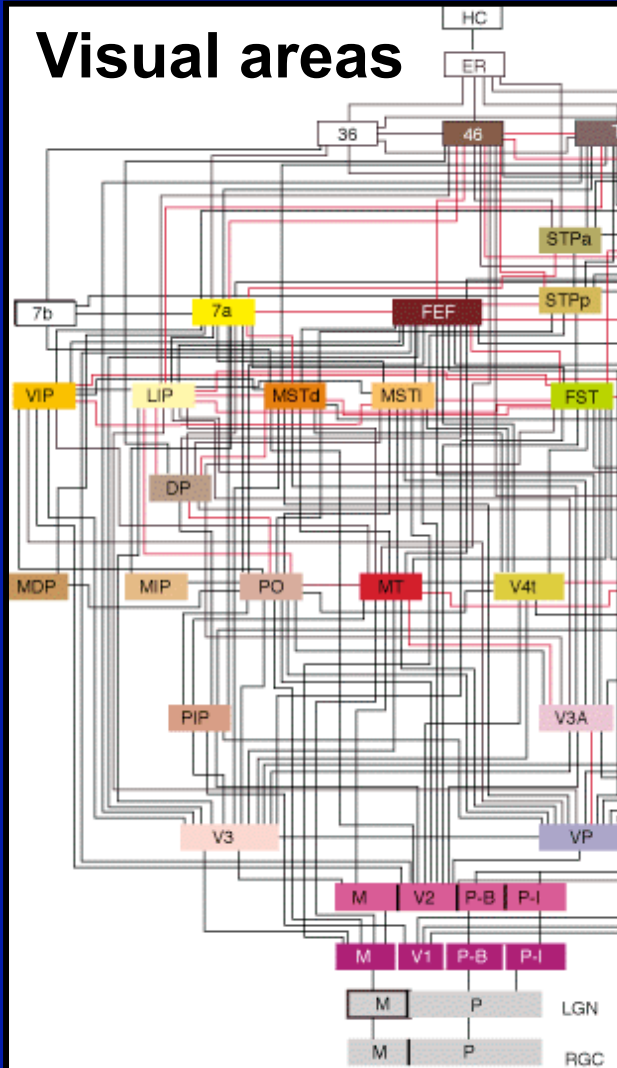
Hippocampus

O-LM cell

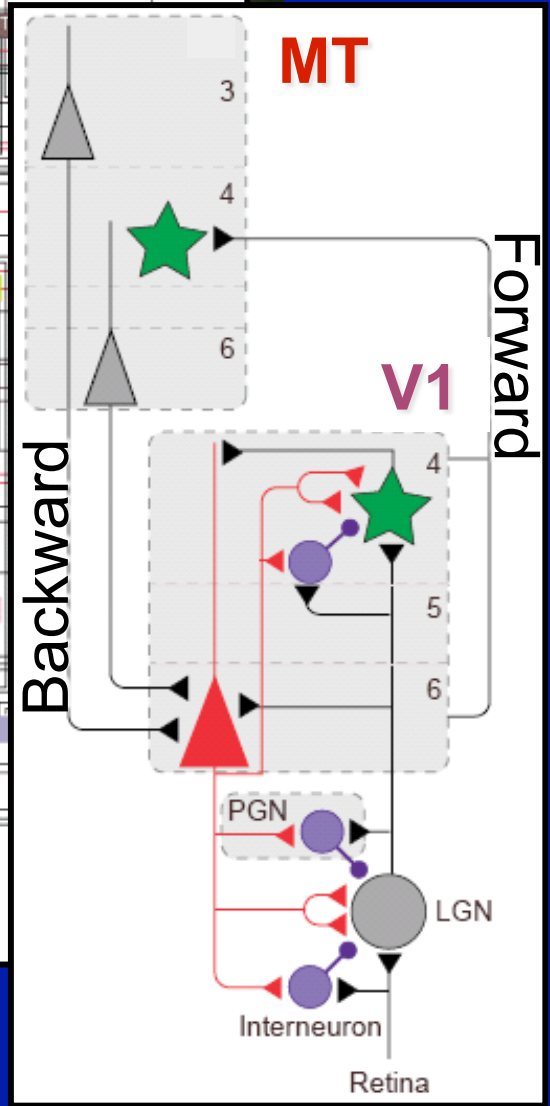


Kopell et al 07

Visual areas

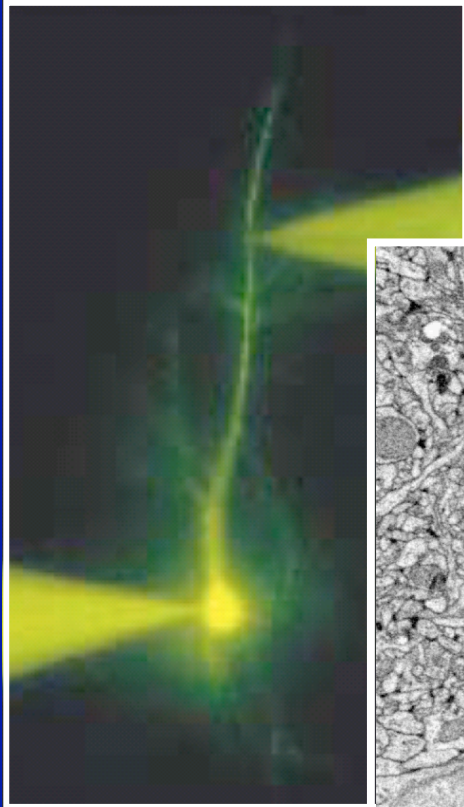


Van Essen & Felleman 1991



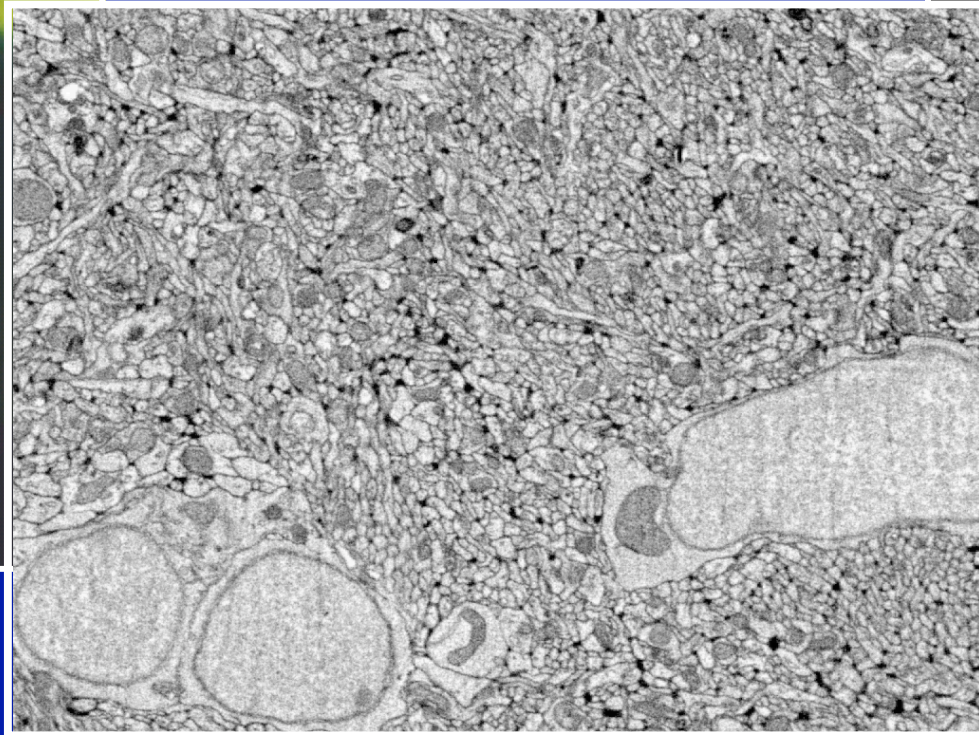
Sillito 2006

Dendritic recording



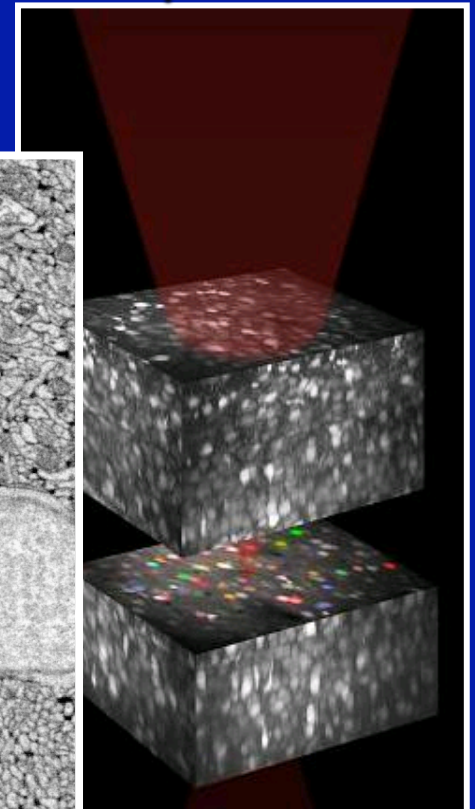
Hausser et al 1997

Serial Scanning EM



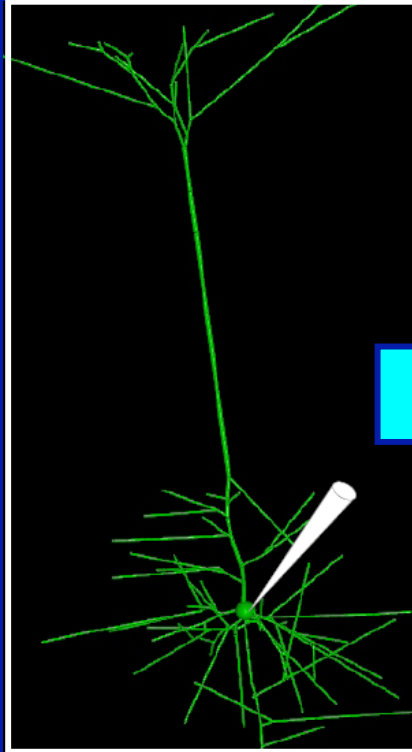
Denk et al 2005

Two-photon LM

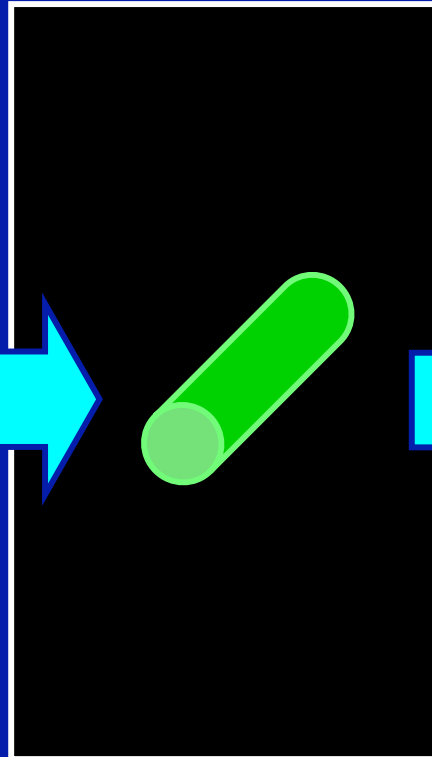


Reid et al 2005

Cell



Compartment



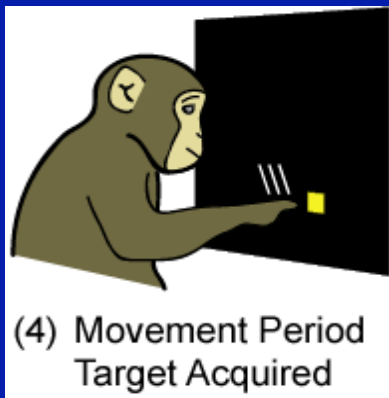
Ion-channel

$$1 - u \xrightleftharpoons[\beta(V)]{\alpha(V)} u$$

$$\frac{du}{dt} = \frac{u_{\infty}(V) - u}{\tau(V)}$$

$$\tau(V) = \frac{1}{\alpha(V) + \beta(V)}$$

$$u_{\infty}(V) = \frac{\alpha(V)}{\alpha(V) + \beta(V)}$$



(4) Movement Period Target Acquired

Shenoy et al. 2006



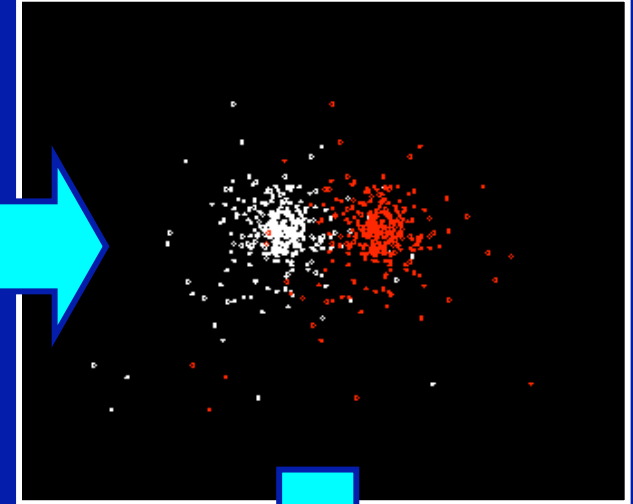
Blue Gene Supercomputer

Two spiral galaxies



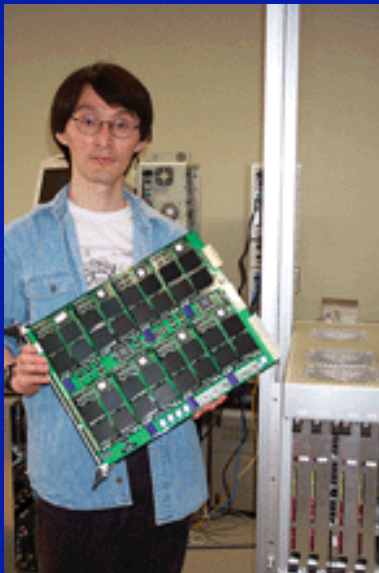
Hubble Telescope 1999

Point mass approx.

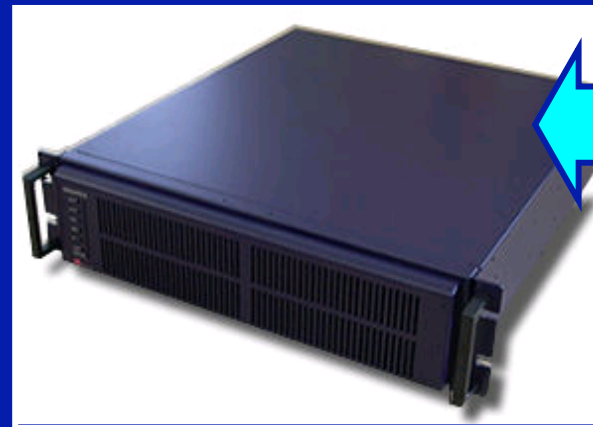


$$F_j = Gm_j \sum_i \frac{m_i}{r_{ij}^2}$$

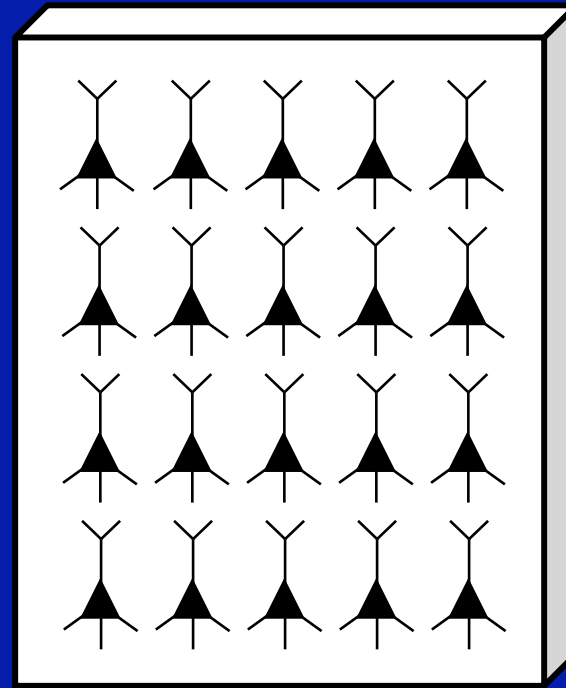
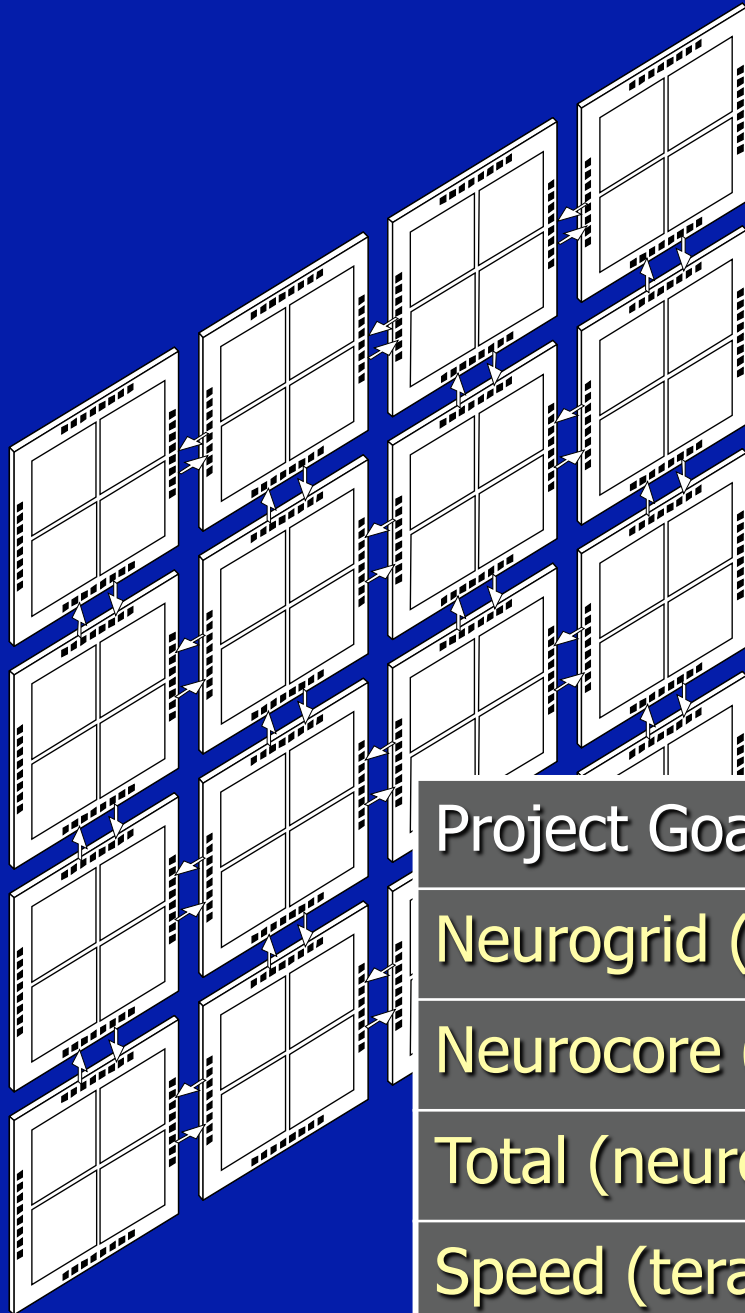
Law of gravity



Jun Makino



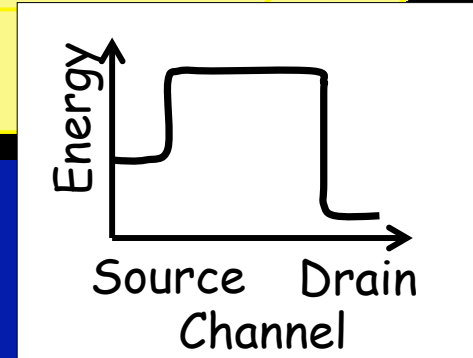
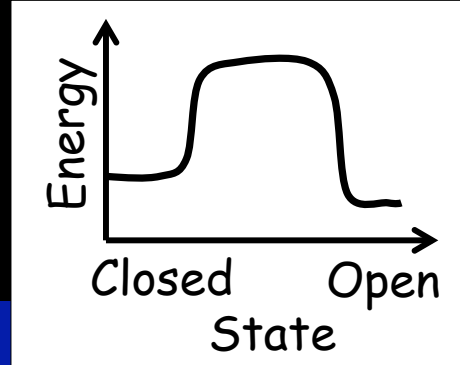
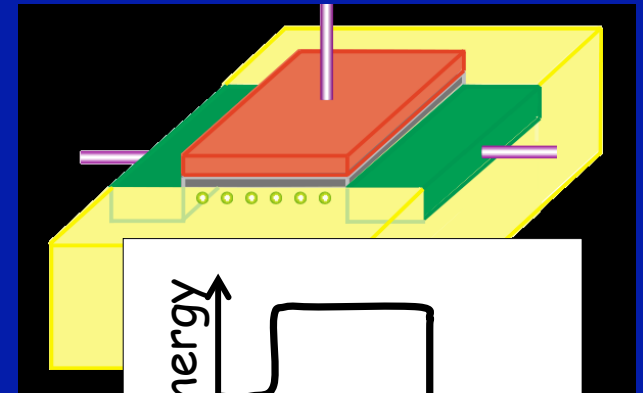
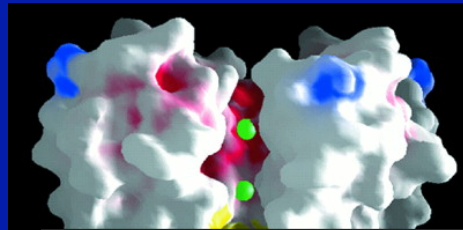
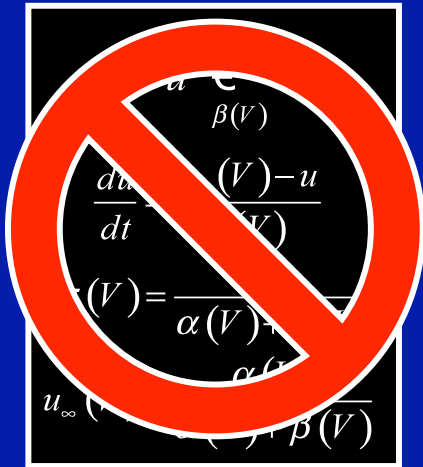
GRAPE6 Supercomputer



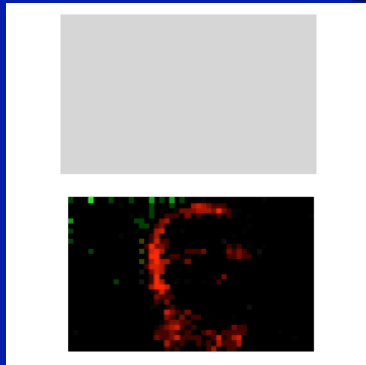
Project Goals [2006]	2008	2011
Neurogrid (chips)	4x4	8x8
Neurocore (neurons)	256x256	1Kx1K
Total (neurons)	1M	64M
Speed (teraflops)	280	18,200

Ion channel

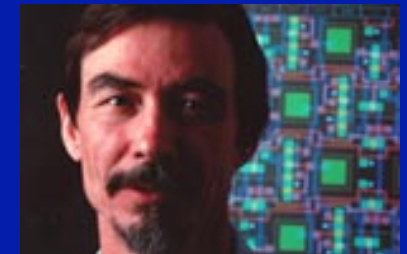
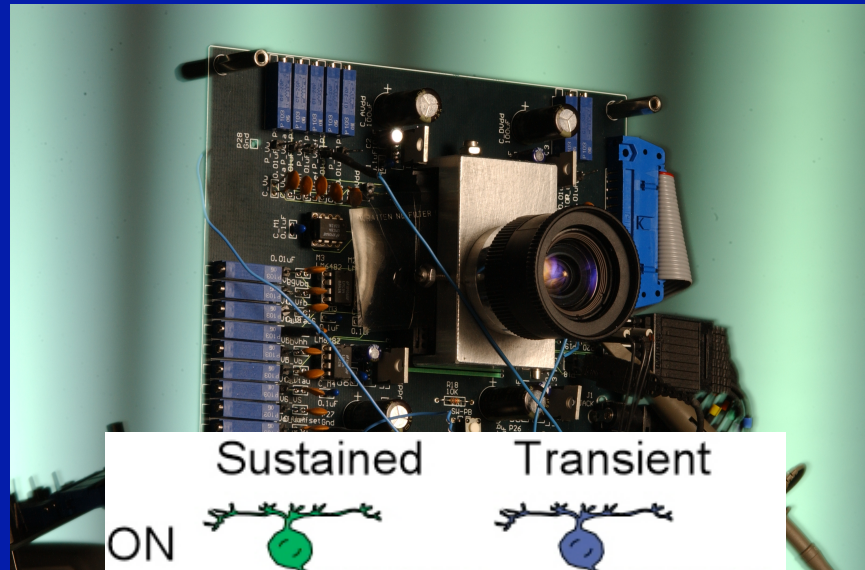
Transistor



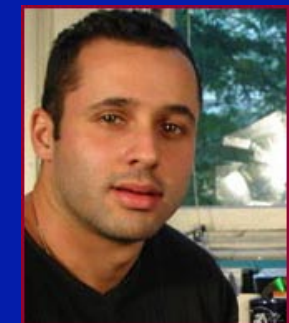
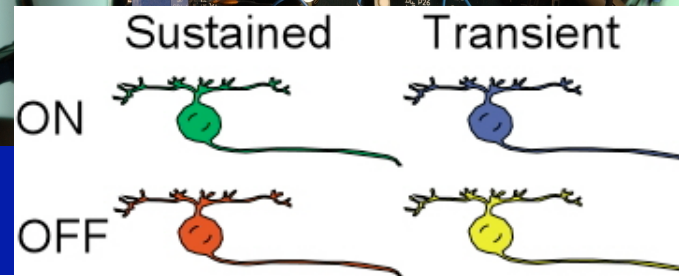
Decoded Image



Spike Output

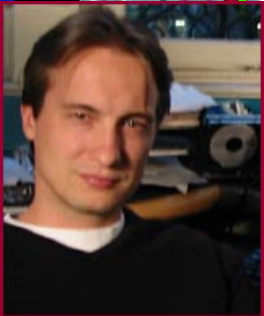
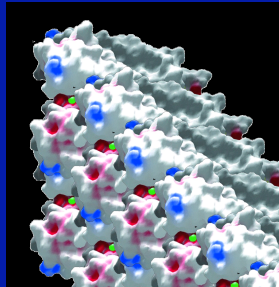


Carver Mead

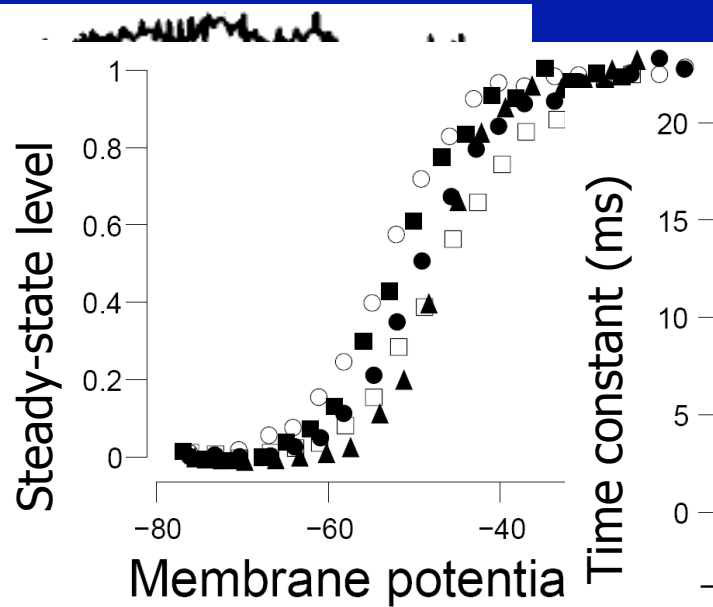
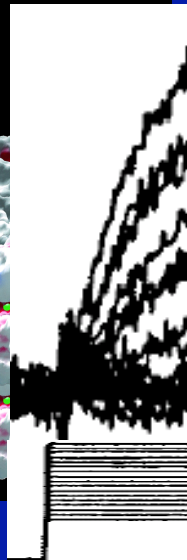


Kareem Zaghloul

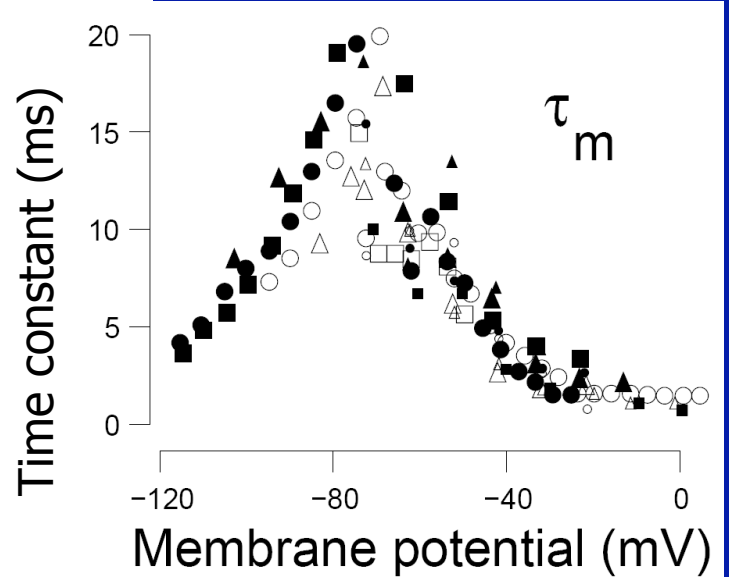
Ion-channel population



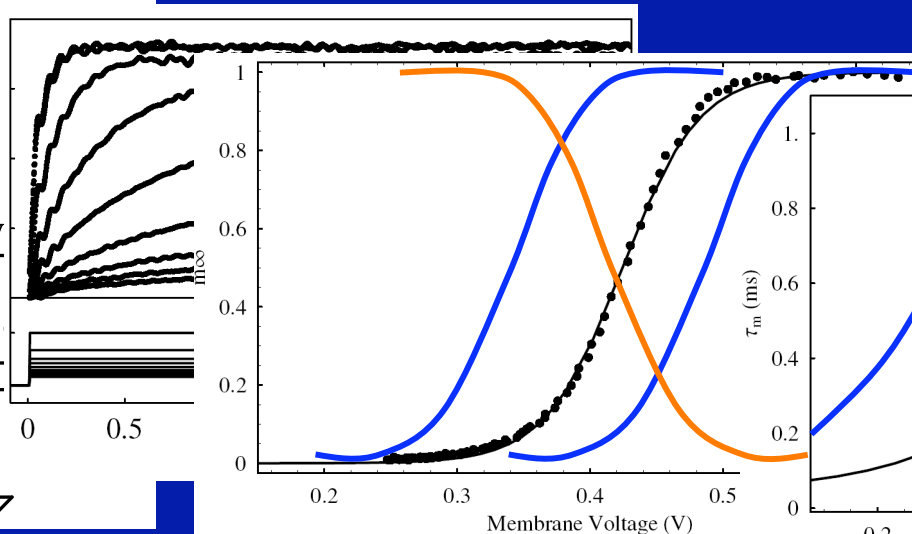
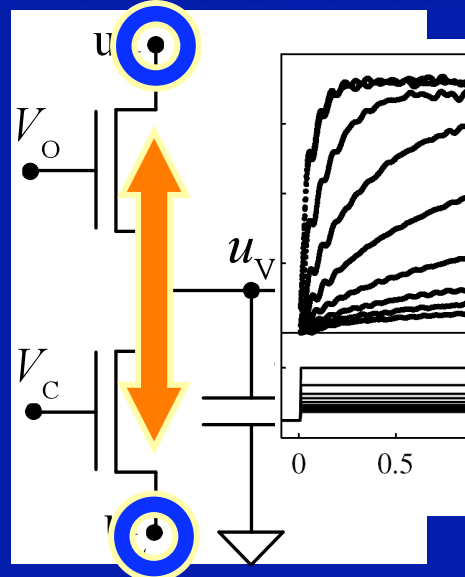
Kai Hynna



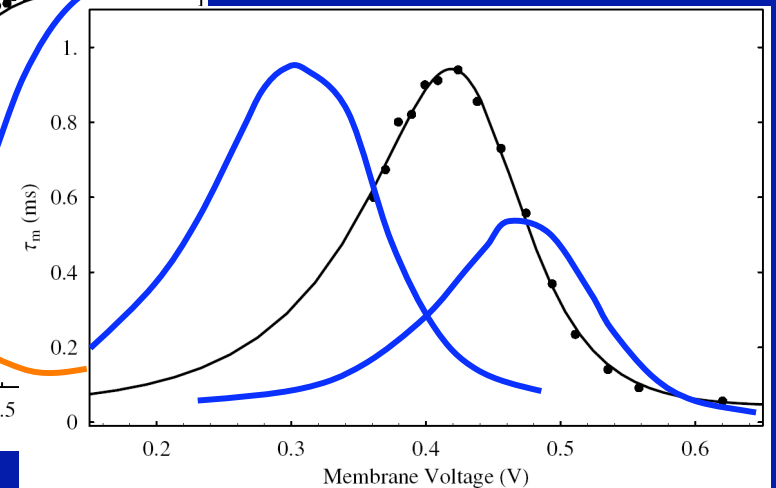
Huguenard & McCormick 1992



Transistor circuit



A first in silicon!



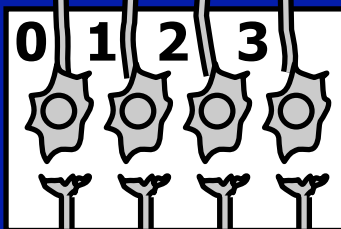
Soft wires

Chip 2

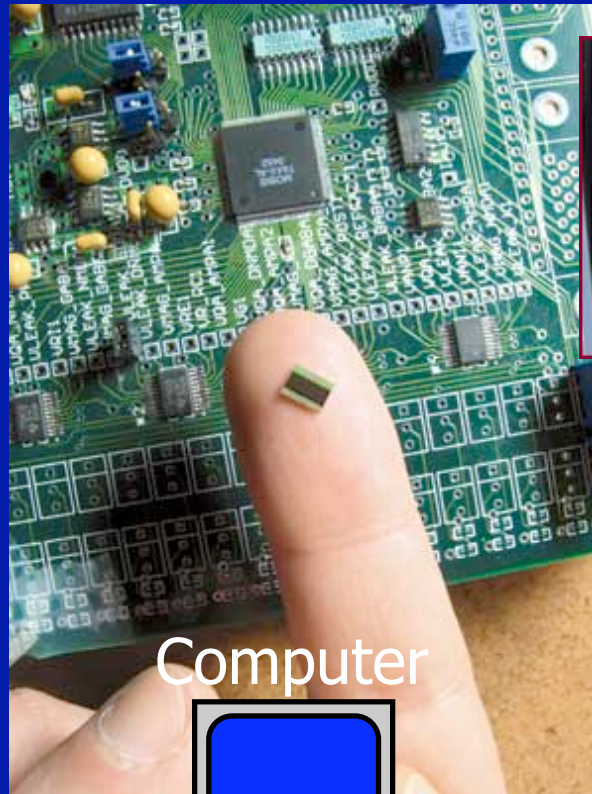


RAM

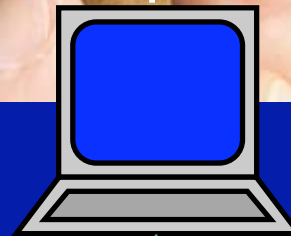
post	1	3	2	0
pre	0	1	2	3



Chip 1

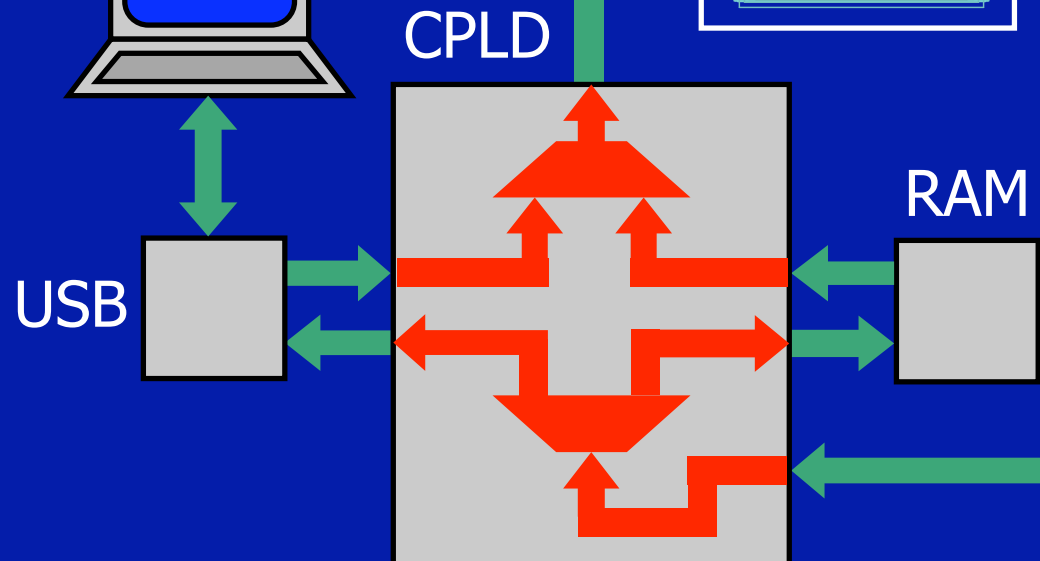
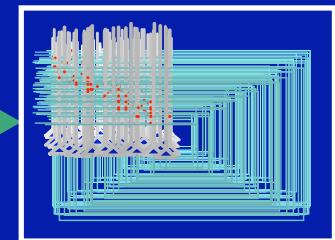


Computer

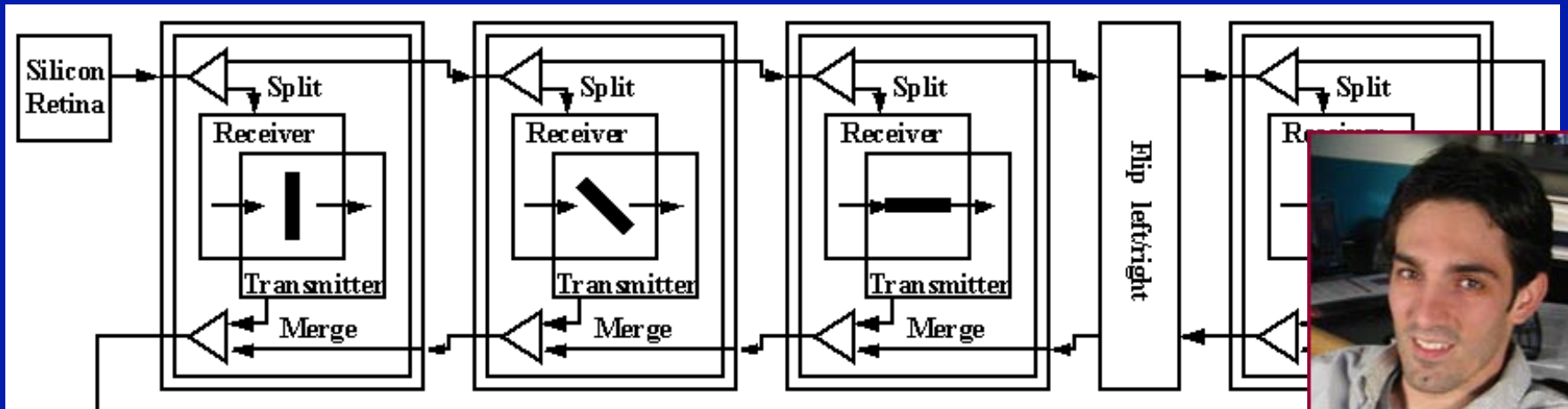


John Arthur

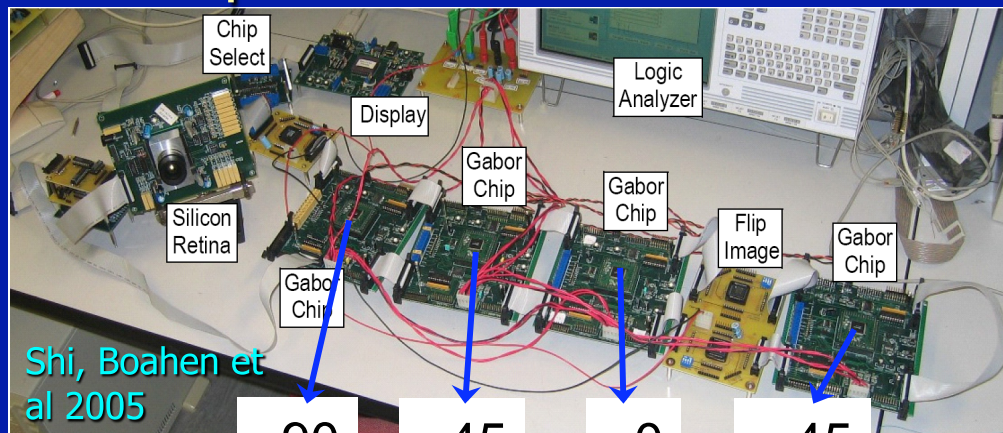
Neuron Chip



1-D grid: 32,768 neurons on 4 chips

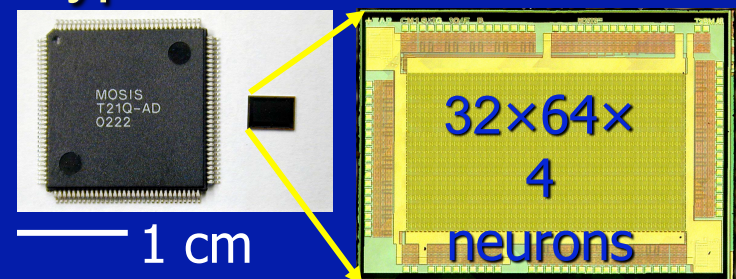
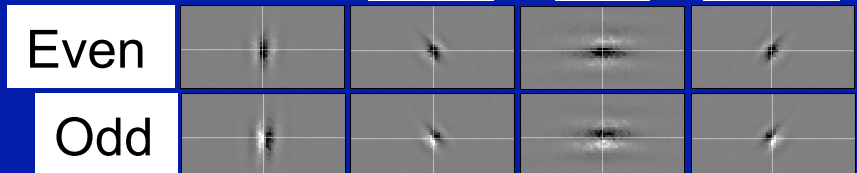


Multichip model of cortical orientation hypercolumns



Shi, Boahen et al 2005

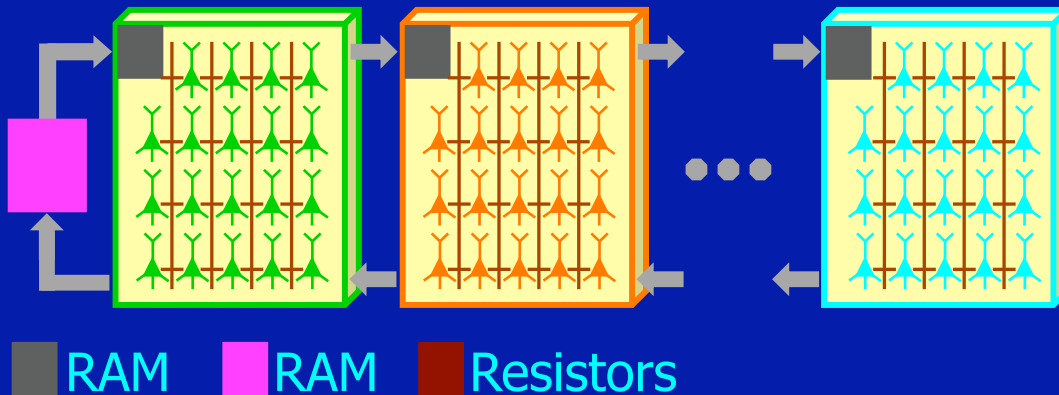
90 45 0 -45



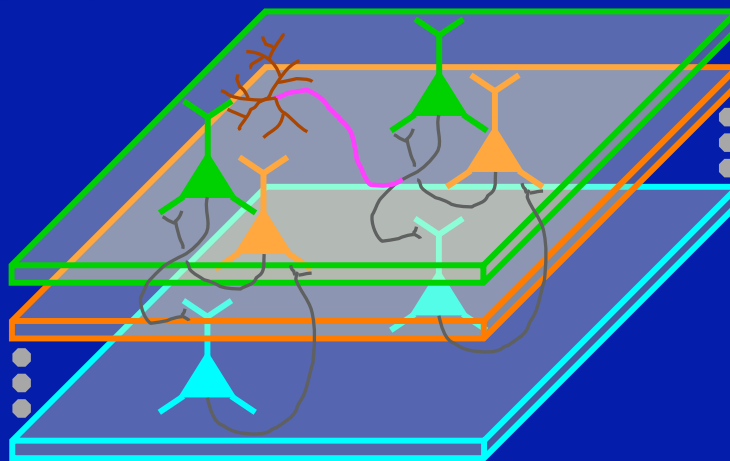
8,192 neurons
TSMC 0.25 μm
9.8 mm^2 ; 3 mW

Steerable orientation
Even/odd, on/off

Neurogrid



Cortex



Connecting 6000
synapses

❖ Off-chip RAM:

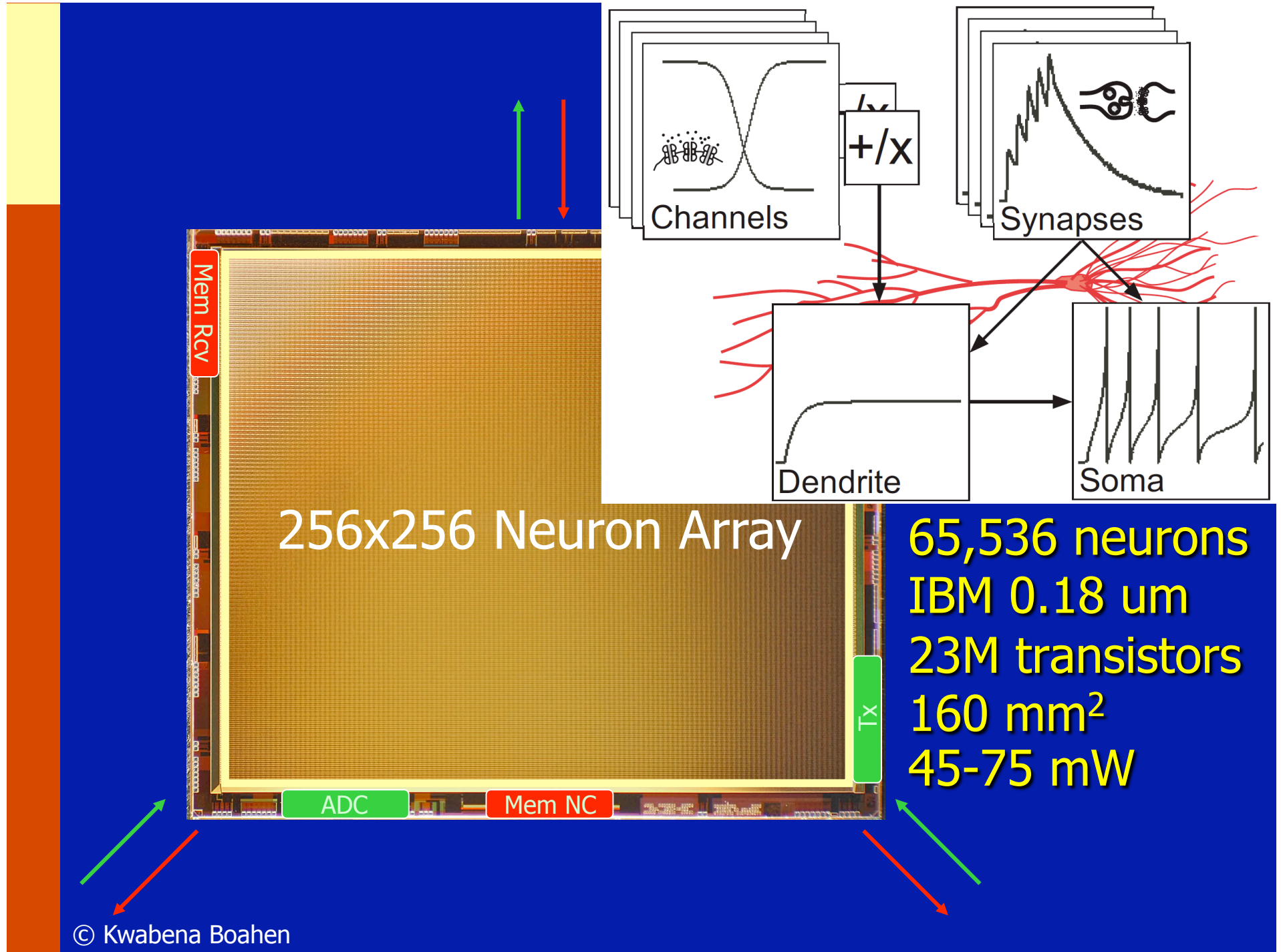
Horizontal
projections
($f = 10$)

❖ On-chip RAM:

Vertical
projections
($f = 6$)

❖ Resistive mesh:

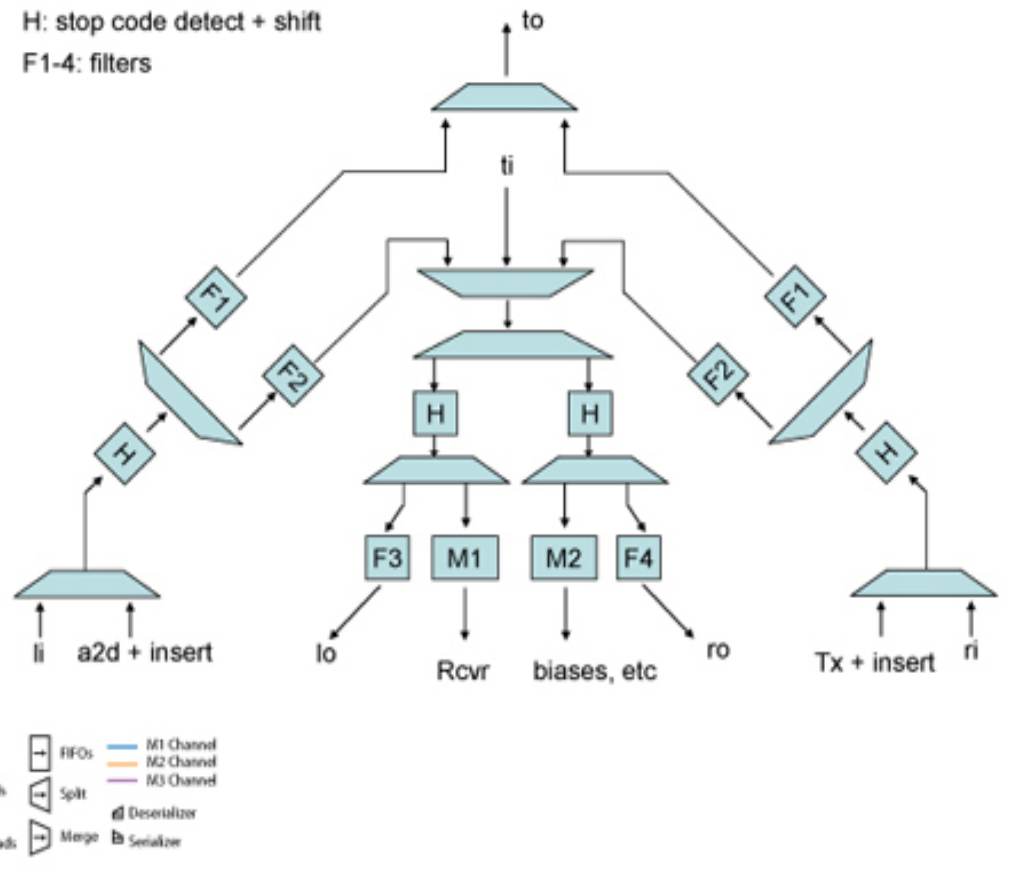
Adjustable electro-
tonic spread
($f \sim 100$)

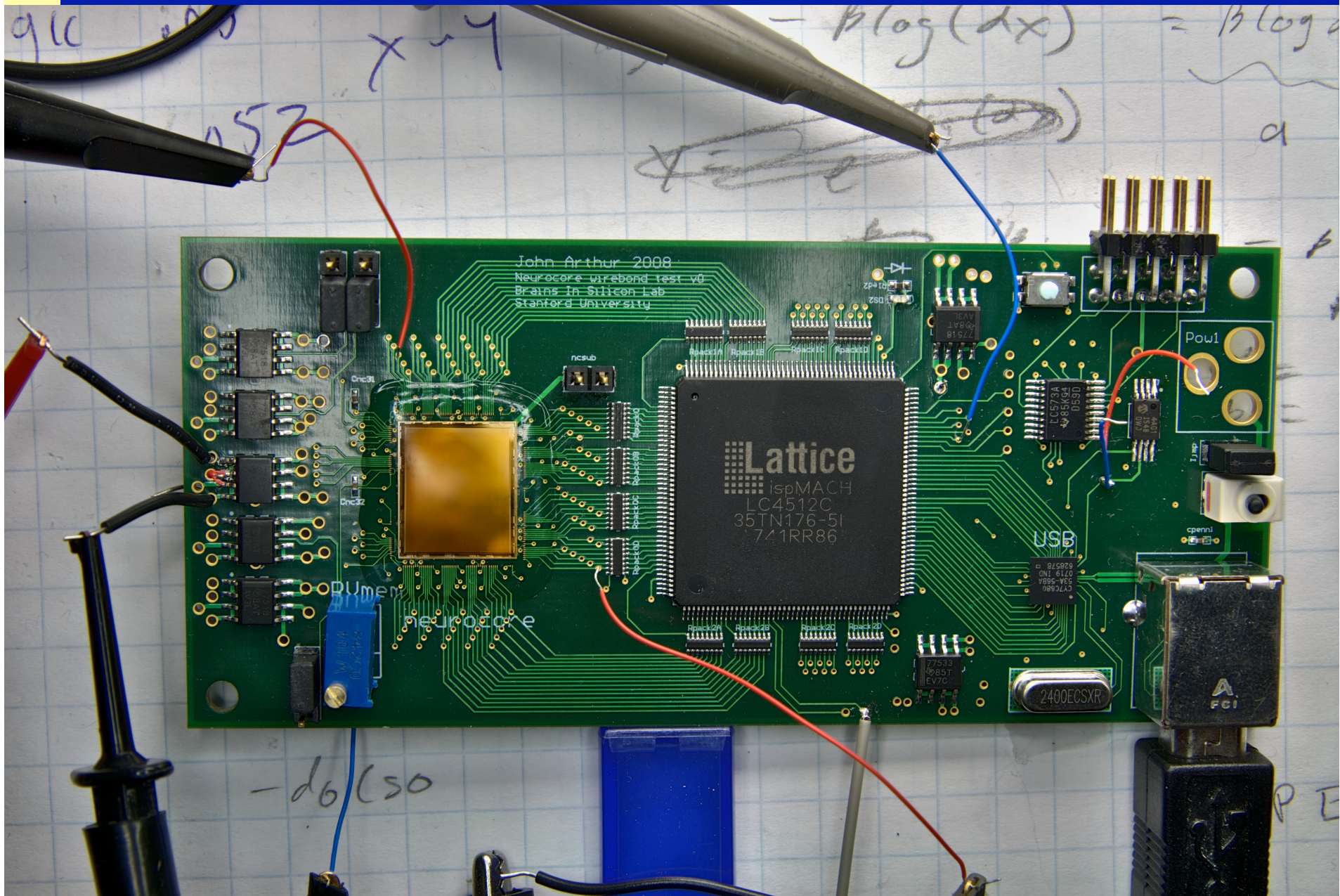




H: stop code detect + shift

F1-4: filters





Summary: We have developed three enabling technologies for Neurogrid

Analog VLSI for real-time simulation

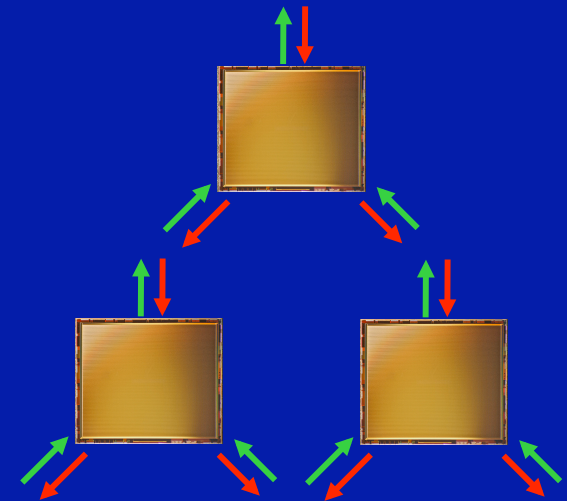
- ❖ Models any ion-channel population

Digital VLSI for programmability

- ❖ Configures synaptic connections

Grid network for expandability

- ❖ Relays spikes from chip to chip



Putting supercomputers on neuroscientists' desks with real-time cortex-scale simulation is feasible in 2yrs.

BrainsInSilicon.stanford.edu



Collaborators

Bert Shi

Rajit Manohar

Support

Packard Foundation

NSF CAREER, BITS & EMT

ONR YIP & MURI

NIH CRCNS & Pioneer