Neurogrid

A million-neuron system with 16 chips (Neurocores) connected in binary tree.

Models ion-channel populations using analog computation
- Based on Hodgkin-Huxley equations
- Each 256x256-neuron chip models a cell-type or layer

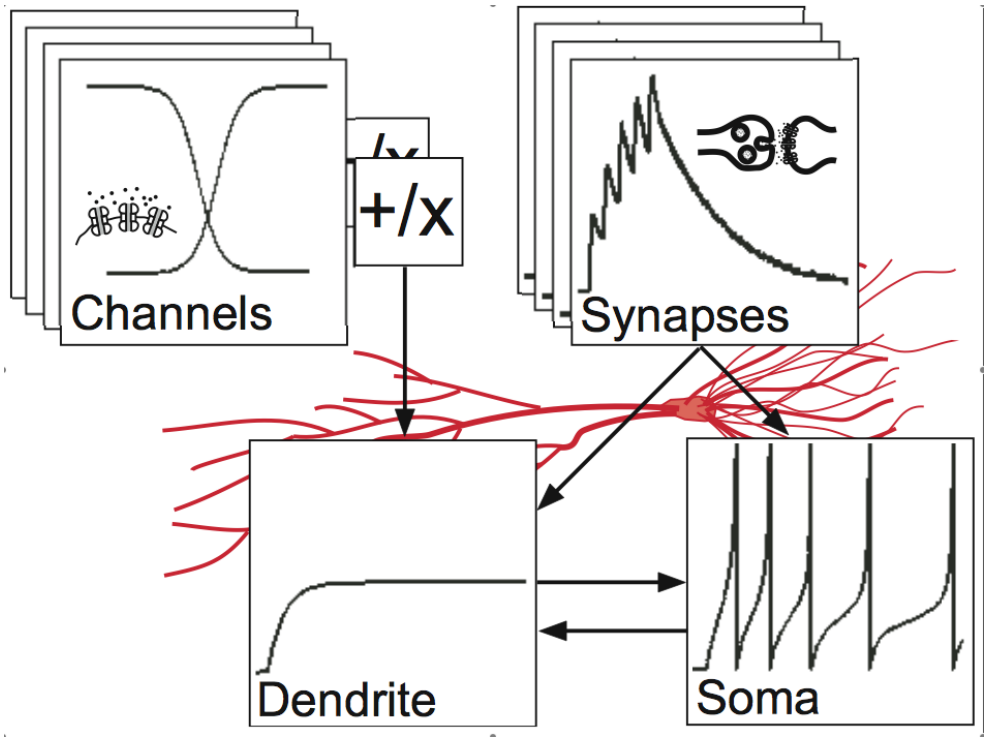
Reconfigures connections using digital communication
- Horizontal—different locations on two chips
- Vertical—corresponding locations on two chips
- Local—arbor centered on target location

Analog Hodgkin-Huxley Model

Silicon model can be tuned to match sigmoidal (in)activation and bell-shaped time-constant [Huguenard92,Hynna06].

A compact analog circuit reproduces the dependence of activation and time constant on membrane voltage by exploiting transistors' exponential current-voltage relationship.

Neuron Model



Two-compartment model with four channel and synapse-types.

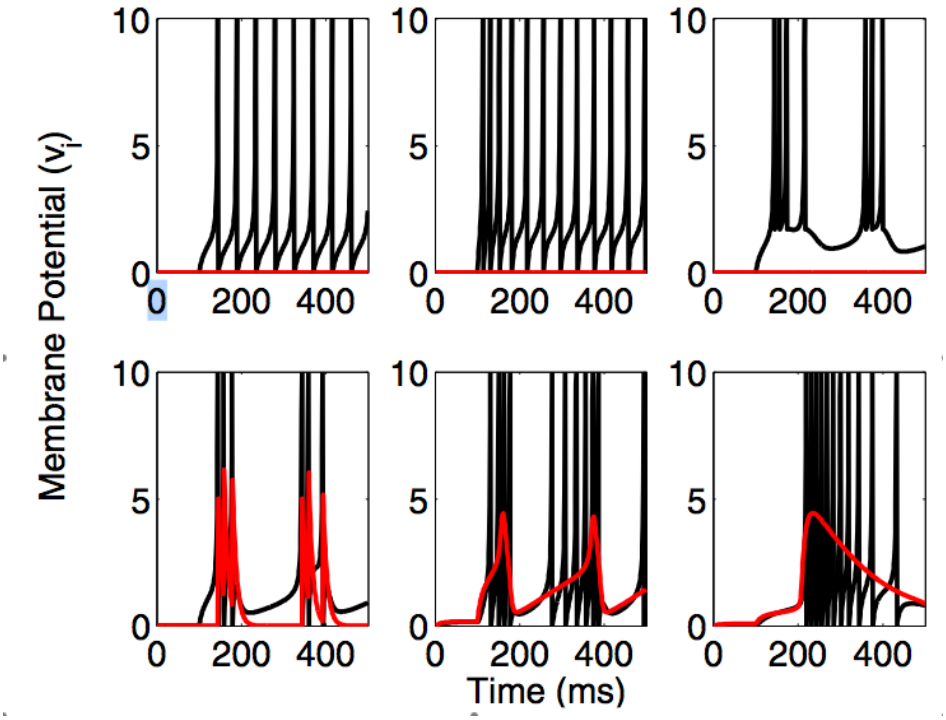
A Neurogrid neuron has a soma, a dendrite, four programmable synapse-types, and two ion-channel gating-variable pairs that can be multiplied or summed.

Multiplication is useful for modeling channels that activate and inactivate (e.g., T-type Ca), for modeling NMDA's voltage-dependence, or for modeling modulation by neurotransmitters like dopamine.

The ion-channels drive the dendrite, which drives the soma; each synapse type can be programmed to drive the soma, dendrite, or a channel population (NMDA, not shown).

The soma is equiped with the Na and K channels responsible for generating spikes as well as an M-current responsible for spike-rate adaptation.

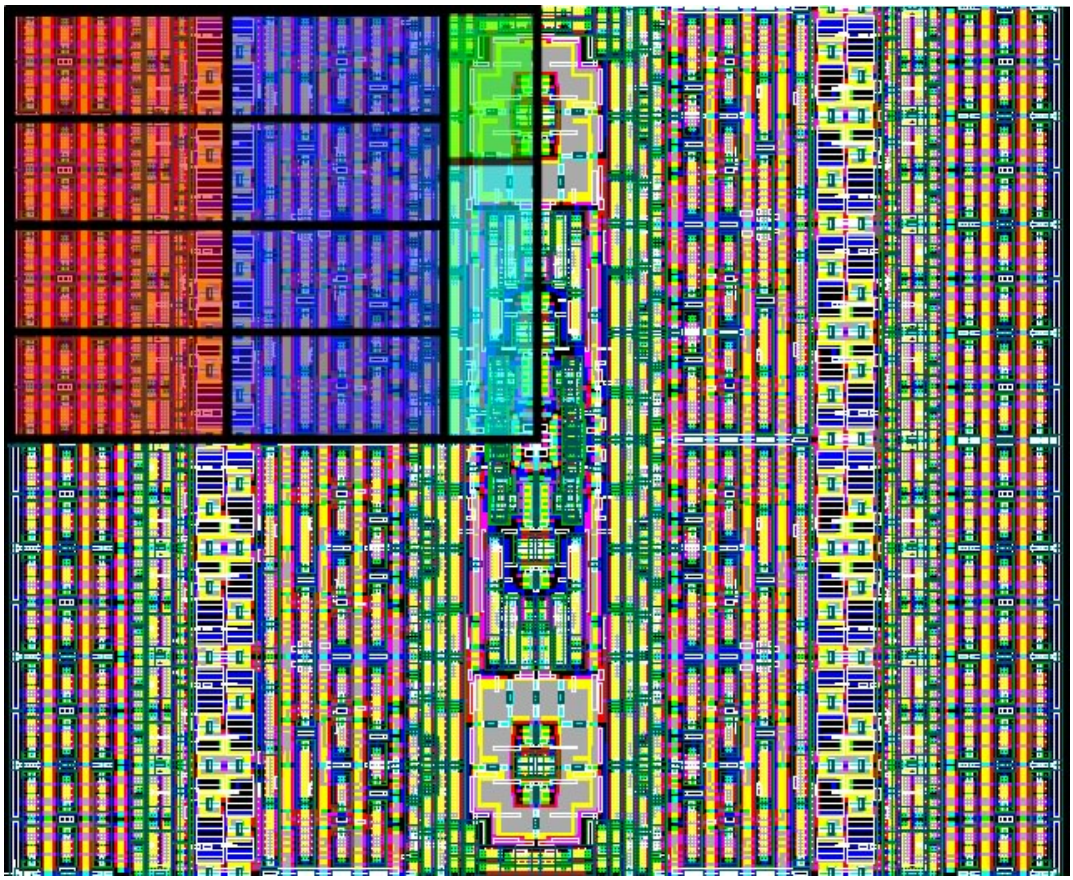
Generates various spiking patterns



Integrate-and-fire, adaptive, square-wave bursting, parabolic bursting, K-Ca bursting, and T-channel bursting (left to right, top to bottom; red, dendrite).

Matlab simulations showing that neuron model can generate various spiking patterns.

Neuron's Layout



Each 41.6 x 50.0 μm neuron in this four-neuron metapixel includes 337 transistors, which implement a soma (cyan), a dendrite (green), four synapses (blue), and four channels (red).

Neurocore

This 65,536-neuron chip squeezes 23M transistors in $160\ \mathrm{mm}^2$ (0.18μm process). Incoming events target the array or the nerve center (red); outgoing events are generated by the array or the ADCs.

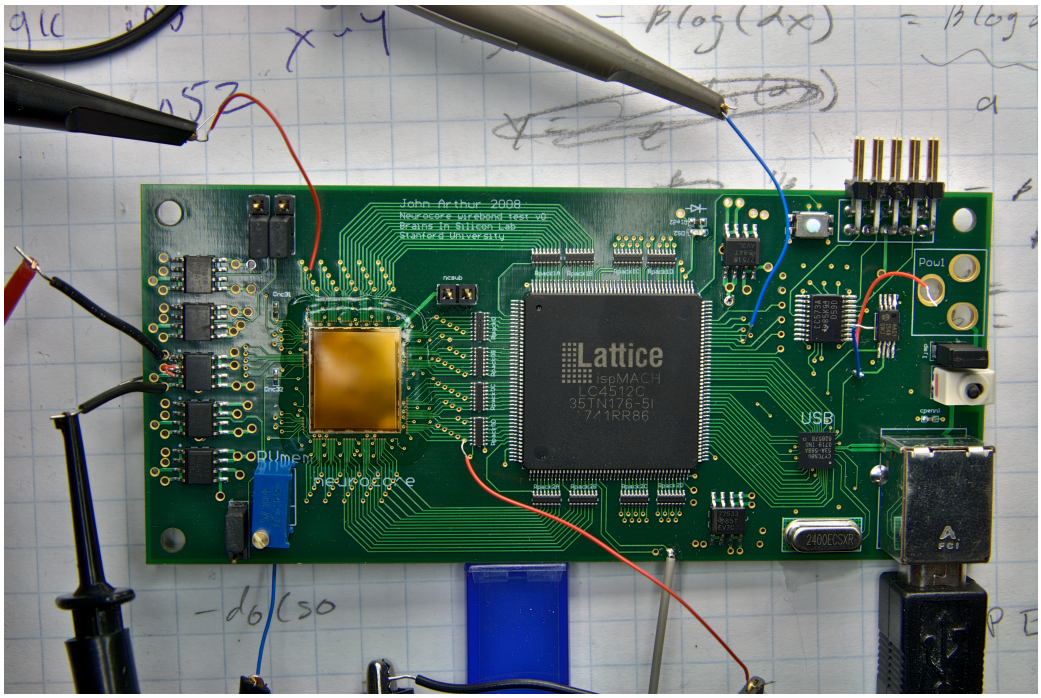
In addition to its 256×256-neuron array, Neurocore includes two RAMs, for programming neuron biases and vertical connections, and routers, for relaying spikes from chip to chip.

Making 6000 synapses

The chip's core is tiled with a regular array of identical *microcircuits*.

An axon can contact 6000 neurons by using 10 horizontal projections, each of which makes 6 vertical connections, each of which 100 arbor contacts.

Single-chip testing



At 45-75 mW/chip, Neurogrid is a million times for power-efficient than Blue Gene.