Large-scale neural modeling

Kwabena Boahen
Stanford Bioengineering
boahen@stanford.edu

Goal: Link structure to function by developing multi-level computational models of neural systems.

We’re acquiring brain data at an unprecedented rate

Dendritic recording
Serial Scanning EM
Ca++ imaging

Reid et al 2005
Ca++ imaging

Computational primitives + Microcircuitry = Functional behavior

Now all we have to is connect the dots...

Multi-level simulations can link structure to function

The problem is one of scale

- 7 levels of investigation
- 10 orders of magnitude

Option 1: Experiment
- Difficult to control

Option 2: Theory
- Ignores details

Option 3: Simulation
- Include all details
  - Complements theory
- Control all parameters
  - Complements experiment

Levels of Investigation

Churchland & Sejnowski 1992

Churchland & Sejnowski 1992
The fastest supercomputers can simulate only 10,000 neurons in real-time

- 8M neurons connected by 4B synapses
- 9° visual field in V1
- 1 sec of activity took 1 hr 20 mins to simulate
- 4750× slower than real-time
- Had to perform 38 trillion evaluations

Ion-channel

Blue Gene supercomputer

Lansner et al. used one 2048-processor rack (3Tflops, $2M)

- 8M neurons × 6 comp. × 8 eq. × 10⁵ steps/sec

Physicists revolutionized astrophysics by building their own supercomputer

- Two spiral galaxies
- Point mass approx.
- Law of gravity

F = Gm \sum \frac{m}{r^2}

- Hardwired to calculate gravitational force
- A third as fast as Blue Gene rack (1Tflop)
- Sixteen times more cost-effective ($42K)

- First to show gravothermal oscillations
- Resulted in 40 papers in 2000 alone

Neurogrid—an affordable supercomputer for neuroscientists

- Neurogrid: Board with grid of chips
  - Programmable connections
  - One chip per cortical cell-layer or type
- Neurocore: Chip with array of neurons
  - Programmable ion-channel properties
  - Multiple compartments per neuron

<table>
<thead>
<tr>
<th></th>
<th>2008 (!)</th>
<th>2011</th>
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<tbody>
<tr>
<td>Neurogrid (chips)</td>
<td>4×4</td>
<td>8×8</td>
</tr>
<tr>
<td>Neurocore (neurons)</td>
<td>256×256</td>
<td>1K×1K</td>
</tr>
<tr>
<td>Total (neurons)</td>
<td>1M</td>
<td>64M</td>
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<tr>
<td>Speed (TF)</td>
<td>280</td>
<td>18,200</td>
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Don’t evaluate equations—emulate physics

Emulate ionic currents with electronic currents

- Exploit physical analogy
  - Including stochastic behavior
- Analog VLSI
  - Very Large Scale Integration
- Runs in real-time
  - Takes 1 sec instead of 1 hr and 20 mins

BioE332’s thousand-neuron baby

The chip: Spike-timing dependent plasticity

- 1024 excitatory principle cells
  - 21 plastic synapses each
- 256 inhibitory interneurons
- 750,000 transistors
- 10.2 mm² in 0.25 μm CMOS

Visual areas

Feedforward view of motion

- V1: Parts
- MT: Object

Anatomy has feedback

- MT projects to V1

Hypotheses about feedback:

- Aggregates parts into coherent object
- Composes cues into unambiguous percept
The GUI: Memorizing patterns

Before learning
- Neuron array
- Spike trains

After learning
- Neuron array
- Spike trains

Synaptic strengths
- LTP
- LTD

Lab 1: Synapse Model

Lab 2: Neuron Model

Lab 3: Adaptation and Bursting