- 5 watts
- 1M neurons
- 6B synapses
- 10 spikes/s each
NEUROGRID = 22 BG RACKS

<table>
<thead>
<tr>
<th></th>
<th>Chip</th>
<th>Board</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neurons</td>
<td>65K</td>
<td>1.0M</td>
</tr>
<tr>
<td>Syn/s</td>
<td>3.9G</td>
<td>63G</td>
</tr>
<tr>
<td>Watts</td>
<td>150m</td>
<td>5.0</td>
</tr>
<tr>
<td>Syn/s</td>
<td>1</td>
<td>63G</td>
</tr>
<tr>
<td>Flops</td>
<td>1K</td>
<td>63T</td>
</tr>
<tr>
<td>Bytes/s</td>
<td>66</td>
<td>4.2T</td>
</tr>
<tr>
<td>Watts</td>
<td>10µ</td>
<td>0.63M</td>
</tr>
</tbody>
</table>

- 5W vs. 630,000W
TOPICS COVERED

• What does a Neurogrid neuron have?
  • Upto four types of gating-variable populations
    • Every neuron in a chip have the same four types
  • Upto four types of synaptic populations
    • Every neuron in a chip have the same four types
  • Soma and dendrite

• How do Neurogrid neurons communicate?
  • Vertical, horizontal connections
  • Dendritic arbor
  • Bouton clusters
NEUROGRID NEURON
Ion-channel population

A first in silicon!

Transistor analog

Huguenard & McCormick 1992

Hynna & Boahen 2006
One synapse circuit replaces all three

Produces their summed output if $T_{ISI} \gg T_{rise}$
SOMA CIRCUIT

\[ \tau \dot{v} = -v + \frac{1}{2} v^2 + i_{in} \]

Quadratic neuron
DENDRITE CIRCUIT

$$\tau \dot{v} = -v + i_{in}$$

Passive dendrite
65,536 neurons
23M transistors
160 mm²
0.18 um CMOS
50-150 mW
MODELING CORTICAL CELL TYPES

- Fast spiking
- Regular spiking
- Intrinsic bursting
- Chattering
MODELING CORTICAL CELL TYPES

Fast spiking

Regular spiking

Intrinsic bursting

Chattering
NEUROGRID COMMUNICATION
Neuromorphic chip

Repeating group

Cortex

Vertical  Horizontal  Arbor

Sivilotti 1992
Mahowald 1994
Deiss et al. 1999
Boahen 2001
Boahen 2004
Merolla et al. 2007
Cortex 1D grid

On-chip RAM  x6  Off-chip RAM  Leaky cables

Cell parameters

10  ×  6  ×  100  =  6,000

Cortex

Model with 65K neurons and 70M synapses
Computer

CPLD/FPGA

USB

RAM

Neurogrid

Daughter Board with 32MB of RAM
EXAMPLE

SIMULATING A V4-FEF CORTICAL MODEL ON NEUROGRID
Possible projections subserving spatial attention in V4

V4-FEF Model

V4-FEF Group

External Input

FEF, LIP, IT, Pulvinar
IT, Pulvinar
V1, V2
FEF, IT
FEF, LIP, IT
Programming the model on Neurogrid

**Step 1: Describe Neuron Model**

```python
feff_layer1_soma = Soma("quadratic", {"tau_ref": 1e-3, "tau":
feff_layer1_neuron = Neuron("quadratic", fef_layer1_soma)
```

**Step 2: Describe Network Hiearchy**

```python
feff_v4_group = Group("FEF V4 Group")
feff_layer1 = Pool(fef_layer1_neuron, width, height)
feff_layer2 = Pool(fef_layer2_neuron, width, height)
v4_layer1 = Pool(v4_layer1_neuron, width, height)
v4_layer2 = Pool(v4_layer2_neuron, width, height)
feff_v4_group.AddChild(fef_layer1)
feff_v4_group.AddChild(fef_layer2)
feff_v4_group.AddChild(v4_layer1)
feff_v4_group.AddChild(v4_layer2)
```

**Step 3: Describe Connections**

```python
feff_v4_group.VerticalProject(fef_layer1.Output(0), v4_layer1.
```
Running the model on Neurogrid
John Arthur
Paul Merolla
Anand Chandrasekaran
Chris Sauer
Jean-Marrie Bussat
Rodrigo Alvarez
Kai Hynna
Ben Benjamin
Peiran Gao
Nick Steinmetz
Daniel Niel
Emmett McQuinn
Swadesh Choudhary
Tirin Moore

NIH Director’s Pioneer Award
FOR THIS CLASS

- Single-compartment, fast or regular-spiking neuron with quadratic or cubic positive feedback
- Conductance-based synapses with arbitrary $E_{rev}$
- Local arbors with programmable space-constant
- No dendrite; no channels; no NMDA (not calibrated)
- USB Bandwidth: 2.5 to 10 Mspk/sec (burst mode)
- Daughterboard Fanout x Spike-Rate: 5 Mspk/sec
- Weights using probabilistic synapses