CoreNeuron: Morphologically Detailed Neuron Simulations

Building, Simulating and Optimizing Large Neuron Networks on GPUs

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Understanding Brain..

IBM: Cat’s brain scale simulation on BG-P

Izhikevic: brain scale simulation on cluster

Brain/MINDS 2014

Human Brain Project 2013

BRAIN Initiative 2013

2009

2007

1 million cells

1.5 billion cells

Better understanding of brain

See source1
Brain Simulations

Point Neurons

Morphologically Detailed Neurons
Blue Brain Project, EPFL

Molecular Level

See source 3
See source 4
Reverse Engineering Brain (10000 feet view)
Reconstruction Workflow

- 15+ years of Experiments
- 14,000 Neurons recorded and labeled
- 2,052 Classified neurons
- 1,009 Reconstructed neurons
- 2,000+ Ion channel recordings
- 4,000+ Electrical recordings of single neurons
- 5,000+ Synaptic recordings of pairs of neurons

Markram et al. 2015, Cell
Modeling Neuron

\[
C \frac{dV}{dt} = \left[ I_{\text{inj}} - g_{Na} n^3 h (V - V_{Na}) - g_K n^4 (V - V_K) - g_L (V - V_L) \right]
\]

\[
\frac{dn}{dt} = \alpha_n(V)(1 - n) - \beta_n(V)n \\
\frac{dm}{dt} = \alpha_m(V)(1 - m) - \beta_m(V)m \\
\frac{dh}{dt} = \alpha_h(V)(1 - h) - \beta_h(V)h
\]

See source7

See source8

HH, 1952
Ion Channels

- Prominent components of nervous system
- More than 300 ion channels

Biologist view: compartment model

Every channel is a compute kernel, no single hotspot!
NMODL: Source to Source Compiler

- Lexical Analyzer
  - tokens
- Syntax Analyzer
  - parse tree
- Semantic Analyzer
  - parse tree
  - Intermediate Representation
- backends

- C
- OpenACC
- Cuda
- Cyme: SIMD DSL

Portable Performance
OpenACC Kernels

```c
_PRAGMA_FOR_VECTOR_LOOP_
for( i = 0; i < count; i++) {
    int idx = node_index[i];
    v = vec[idx];

    p3[i] = data[ion_index[i]];
    double gNaTs2 = p0[i]*p1[i]*p1[i]*p1[i]*p2[i];
    double ina = gNaTs2*(v-p3[i]);

    data[ion_index1[i]] += gNaTs2;
    data[ion_index2[i]] += ina;
    vec_rhs[idx] -= ina;
}
```

auto-generated kernel wrap OpenACC and vectorisation hints related pragmas

AoS/SoA, Vectorisation, Memory Coalescing etc..

User defined DS: Major challenge for many application

```c
for (tml = nt->tml; tml; tml = tml->next) {
    /*copy all double data for thread */
    d__data = (double *) acc_copyin(nt->_data,
                                  nt->_ndata*sizeof(double));

    /*update d_nt._data to point to device copy */
    acc_memcpy_to_device(&d_nt->_data, &d__data,
                         sizeof(double));
}
```

OpenACC API’s to copy the complex data structure
bksub: for(i = x; i < nodes; i++) {
    rhs[i] -= b[i] * rhs[parent[i]]
    rhs[i] /= d[i]
}
Cell Interleaving

Nodes: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9
Parents: -1, 0, 1, 2, 3, 4, 5, 6, 7

Permutations: ions, synapses, areas, point processes..

Memory addresses

Warp
Spike Exchange

- Electrical diversity: 11 e-types; 207 me-types
- Number of connections increases exponentially
- Different types of events
CoreNeuron

Compute engine of NEURON simulator

Being developed for large scale simulations (28 racks BG-Q)

Ion Channels: ~ 85% time

Linear Algebra: ~ 5-7%

Spike Exchange: 7-10%
Timeline

GPU
- copy
- initialize
- current
- solve
- state
- threshold

CPU
- load

MPI queue

setup

dt

mindelay
Toolchain
Simple model...
Ion channels are 4-8x faster in all models!

Varying #: Rings, Cells, Branches, Compartments

Performance

- K20x vs 8-core Xeon
- Cray (OpenACC)
- Cuda 7
- No “hand” tuning yet
- Optimized CPU code with vectorization

Kernels with cell level parallelism, low occupancy!
Performance

- 8-core Xeon / 8 MPIs
- BG-Q Node / 32-64 threads
- Xeon Phi 61 core @ 1.23 GHz, 180-240 threads
- K20X GPU
- Optimized Xeon/MIC code with vectorization (XLC issue)
Cell Interleaving and Exposing Parallelism

How much parallelism?  How much imbalance?

Homogenous

Ideal

Heterogeneous

ill - suited
Morphological diversity challenge

“Morphology Aware Scheduling of Kernels using Isomorphic Subtrees”
Graphical Abstract

Microcircuitry Reconstruction and Simulation of Neocortical

Simulations reproduce in vitro and in vivo experiments part of neocortex

The Blue Brain Project digitally reconstructs and simulates a neocortical volume of 0.29 mm³. An objective anatomical method defines organizing principles to algorithmically reconstruct constructed neurons are positioned in the volume and electrical neuron subtypes. When digitally reconstructed, their overlapping arbors form a vast network that cellular and synaptic mechanisms dynamically reconfigured around this transition, supporting the network to support diverse information processing strategies.

INTRODUCTION

A digital reconstruction and simulation of the anatomy and physiology of juvenile rat somatosensory cortex, access to experimental data sets used in the reconstruction, and the resulting models. The following functionality is provided through this portal to support community engagement to use and refine the reconstruction.

- Neocortical Microcircuit - an interactive browser of the anatomical and physiological properties of the reconstructed microcircuit, which includes facts and figures, detailed analyses, simulation videos, model and data downloads.
- Literature Consistency - a database of published experimental papers that were used either to constrain parameters of the reconstruction directly, or against which the reconstruction was assessed to be quantitatively or qualitatively consistent. This is intended to be an active list that can be discussed and extended by the community.
- Videos - a collection of computer generated visualizations of in-silico experiments.
- Images - a collection of images illustrating the various steps in the reconstruction process.
- Experimental Data - experimental data sets used in the reconstruction process.
- Tools - tools and documentation for reconstructing, simulating and analyzing the reconstruction.
- Downloads - downloadable models from the reconstruction.

A quick guide to navigating the portal
THANK YOU!
Explanatory Graphic Sources

- source 1: dgallery.s3.amazonaws.com
- source 2: clipartbest.com/cliparts, scaryforkids.com, geniusawakening.com
- source 3: developer.humanbrainproject.eu
- source 4: nature.com
- source 5: deviantart.net, squarespace.com
- source 6: lcn.epfl.ch
- source 7: nature.com
- source 8: genesis-sim.org
Backup

low occupancy!

**Model A**
**Model B**
**Model C**
**Model D**
**Model E**

larger cells

65536
2048
1024