Benchmarks, Fixed-Dt, SDEs

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Arbor

Arbor is a library for the simulation of morphologically-detailed neuronal networks on HPC systems.

- **key aim:** enabling simulation on all HPC systems.
- **key aim:** providing rich interfaces and enabling diverse use cases.

**All features** are implemented and optimised on **all platforms**

- GPUs (CUDA, Clang-CUDA, HIP)
- SIMD CPU backends: (AVX, AVX2, AVX512, Neon, SVE).
- Distributed simulation (MPI).
Benchmark Case: Busyring

- Arrangement of spiking cable cells in multiple rings
- Each ring propagates a single spike indefinitely
- Rings are interconnected using zero-weight synapses
- Cells are based on Allen mechanisms, and have complex geometry
Single Node Benchmarks

- Different Architectures
- 10k cells
- Each ring comprised 10 cells
- 4000 Synapses per cell
- $dt = 0.025$
- Min-delay=2
- Long runtime

$\Rightarrow$ 10000 cells; 172958 branches; 1897208 compartments
Single Node Results

- Haswell Xeon E5-2690 12 cores
- Broadwell Xeon E5-2695 2x18 cores
- Graviton 3E 64 cores
- Epic 7713 64 cores + P100
- Haswell Xeon E5-2690 12 cores + A100
- Epic 7713 64 cores + 4xA100

run time (normalized)
Multi Node Benchmarks

- Piz Daint GPU partition
- Between 2000 and 32000 cells
- Ring sizes: 10, 100, 1000
- 2000, 4000 synapses per cell
- $dt = 0.025$
- Min-delay=2
- Long runtime
- Up to 6M compartments
Strong Scaling

busyring run time on Piz Daint GPU partition

synapses=2000 | ring=10

synapses=2000 | ring=100

synapses=2000 | ring=1000

synapses=4000 | ring=10

synapses=4000 | ring=100

synapses=4000 | ring=1000

run time [s]

nodes

num_cells

2000

4000

8000

16000

32000
Can we improve performance?

- Bottlenecks
  - spike event processing
  - Many tiny time steps (time step size governed by events)

⇒ Fixed timestep
  - events are gathered per time step
  - more efficient spike event processing
  - simplifies code base
Strong Scaling
Runtime improvements

busyring speedup with fixed time steps on Piz Daint GPU partition

- synapses=2000 | ring=10
- synapses=2000 | ring=100
- synapses=2000 | ring=1000
- synapses=4000 | ring=10
- synapses=4000 | ring=100
- synapses=4000 | ring=1000

speedup [%]

nodes: 1, 2, 4, 8, 16

num_cells: 2000, 4000, 8000, 16000, 32000

Arbor: a neuroscience library for HPC
SDEs in Arbor

- Mechanisms now support stochastic processes
- Independent of domain decomposition/MPI distribution
- Independent of architecture (CPU/GPU)
- Simple to describe in Nmodl DSL
- Handles non-linear (systems of) SDEs
- Supports multiple noise sources
Example: Spike Timing-dependent Plasticity Curve

- reproduction of single cell model from Brian2
- written by Sebastian Schmitt
- Goal: simulate spike timing-dependent plasticity curve
- stochastic calcium-based synapse dynamics
- described by Graupner and Brunel Graupner and Brunel, PNAS 109 (10): 3991-3996 (2012)
**STDP: Synapse Dynamics**

\[
c'(t) = -\frac{1}{\tau_{Ca}} c + C_{pre} \sum_i \delta(t - t_i - D) + C_{post} \sum_j \delta(t - t_j),
\]

\[
\rho'(t) = -\frac{1}{\tau} \left[ \rho(1 - \rho)(\rho^* - \rho) - \gamma_p (1 - \rho) H (c - \theta_p) + \gamma_d \rho H (c - \theta_d) \right] + \frac{\sigma}{\sqrt{\tau}} \sqrt{H (c - \theta_p) + H (c - \theta_d) W}.
\]

- \(c\): calcium concentration
- \(i, j\): enumerate pre- and postsynaptic spikes
- \(C_{pre}, C_{post}\): concentration jumps after spike
- \(D\): presynaptic spike delay
- \(\rho\): synaptic efficacy
- \(\tau_{Ca} \ll \tau\): calcium decay time, synaptic time scale
- \(p, d\): potentiation, depression (rates and thresholds)
- \(W\): white noise
STDP: Synapse Dynamics

Requirements for experiment:

- simulate stochastic synapse mechanism
- accumulate statistics over a large enough ensemble of initial states

WHITE_NOISE { W }
BREAKPOINT { SOLVE state METHOD stochastic }
DERIVATIVE state {
  LOCAL d
  LOCAL s
  d = ...
  s = ...
  rho’ = d + s*W
  c’ = ...
}
NET_RECEIVE(weight) { c = c + C_pre }
POST_EVENT(time) { c = c + C_post }
Comparison of this simulation with reference simulation for a simulation duration of 60 spikes at 1 Hertz, ensemble size of 2000 per initial state and time step $dt=0.01$ ms. The shaded region indicates the 95% confidence interval.
Thank You