Optimizing communication in brain-scale multi-area model simulations

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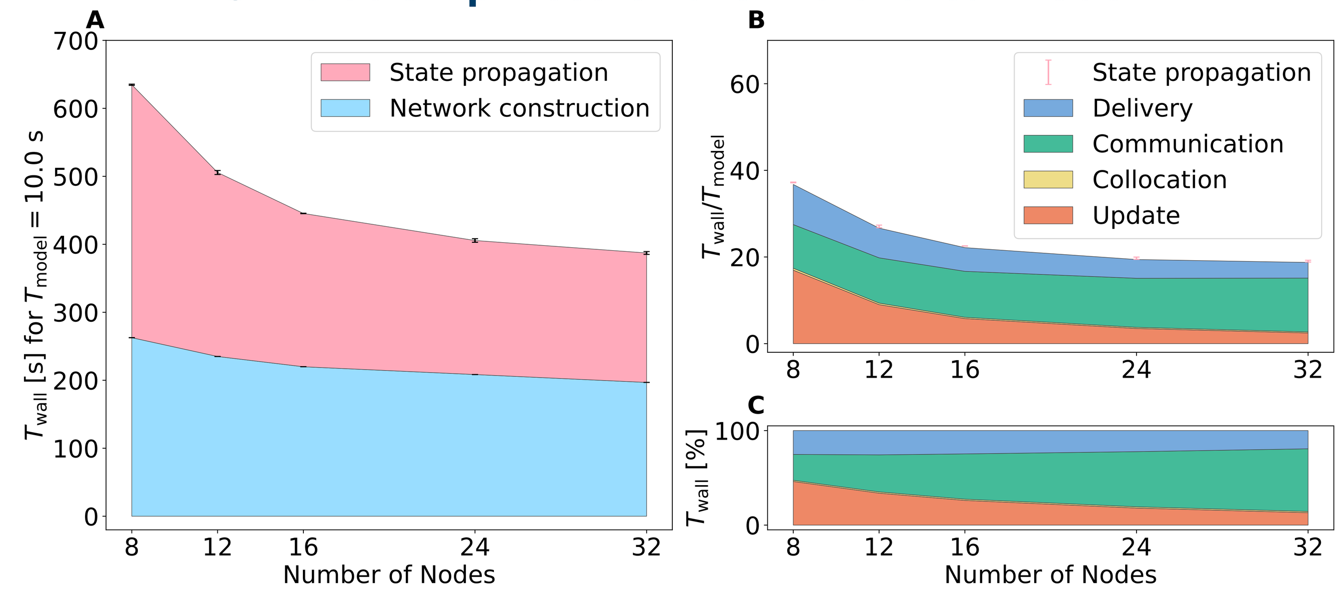
Motivation

- continuous improvement of CPU-based simulation techniques create challenging benchmarking targets for neuromorphic platforms
  - neuronal simulations on conventional hardware still maintain higher flexibility at potentially lower cost compared to novel dedicated hardware [1]
- spike communication is the bottleneck in simulations of brain-scale networks [2]
- e.g. the multi-area model of macaque visual cortex [3]
  - 32 interconnected areas modelled as microcircuits [4]
  - realistic connectivity
  - single neuron resolution

⇒ structure-aware neuron distribution scheme combined with optimized spike-communication framework to speed up neuronal simulations

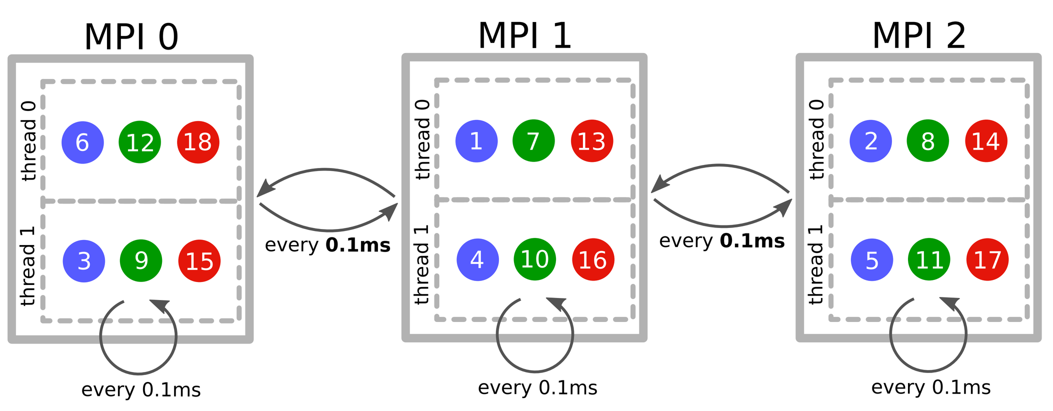
Simulation phases of the multi-area model



Strong-scaling benchmark of macaque multi-area model performed with NEST v3.6 on Jülich Supercomputer JURECA.

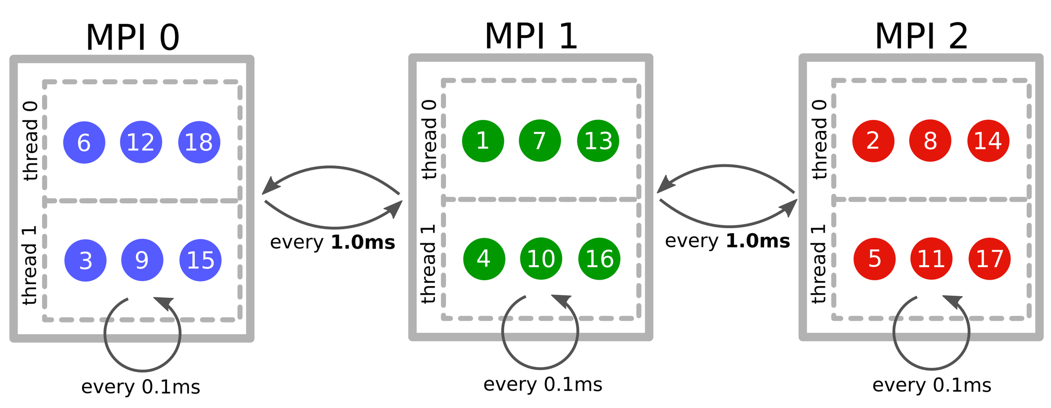
Algorithm

Conventional neuron distribution scheme



- uniform occupation of compute nodes: "round-robin"
- neurons of the same area are spread out on the hardware
- communication between compute nodes every smallest delay of e.g. 0.1 ms

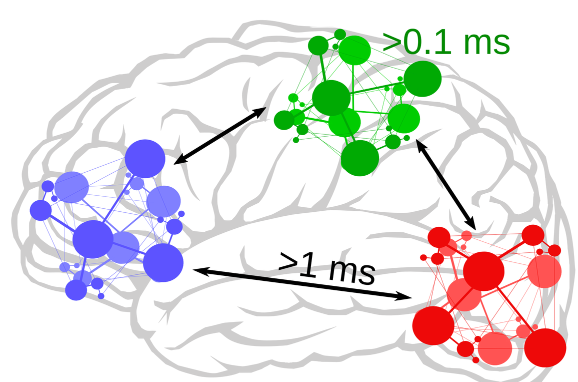
Structure-aware neuron distribution scheme



- one/few compute nodes per area
- two communication pathways
  - within an area: short delays (e.g. 0.1 ms)
  - between areas: long delays (e.g. 1.0 ms)

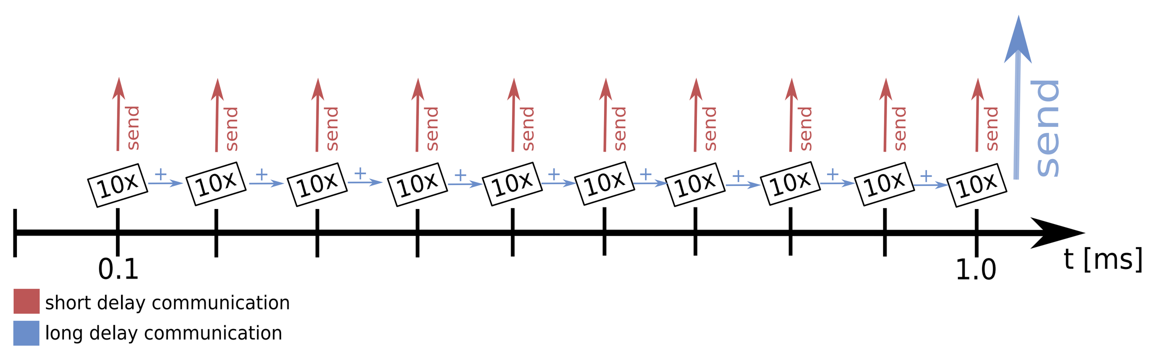
⇒ faster communication within areas

⇒ fewer communication between areas



Example: structure-aware approach

- 10.000 neurons per area; average firing rate 10 spikes/s

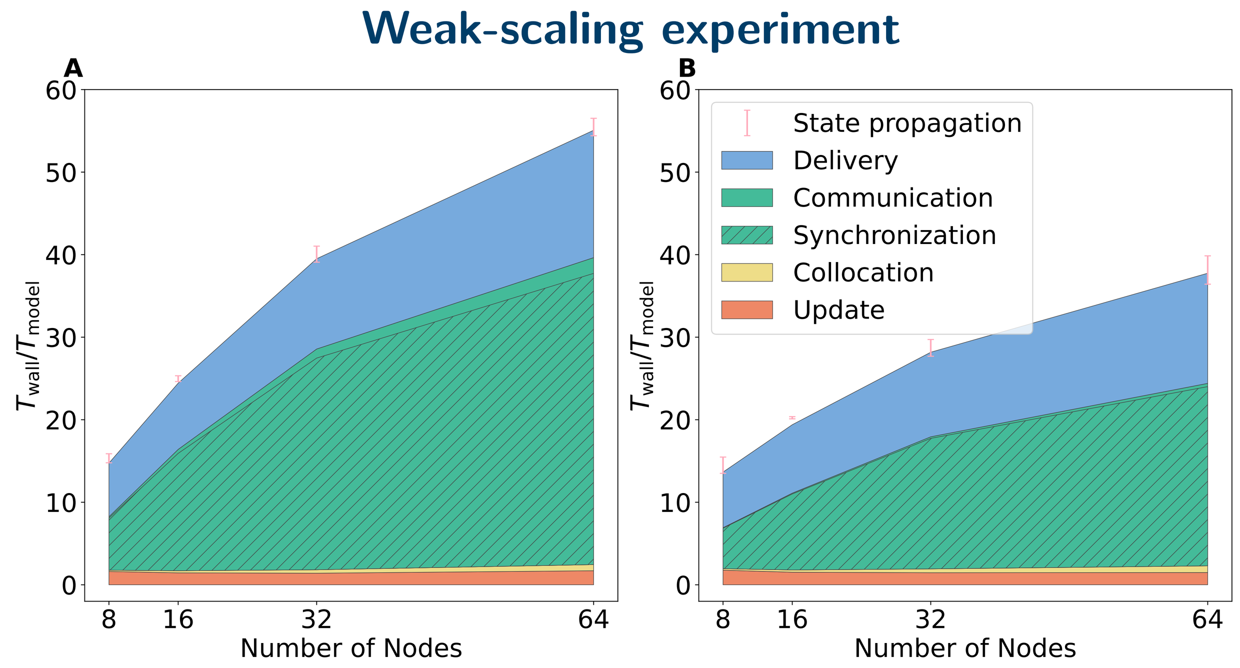


Results

Setup

- neuronal simulator tool NEST [5,6]
- benchmarking model
  - similar to macaque multi-area model in connectivity and work load
  - easily scalable while retaining constant activity levels
  - ≈ 130.000 neurons per area
  - ≈ 3000 inter- and intra-area connections per neuron, respectively
  - average spike rate of 2.5 spike/s
- Jülich Supercomputer JURECA
  - 2 areas per compute node
  - 2 MPI process per node; 64 threads per MPI Process
- communication phase
  - synchronization between all compute nodes (only long-range communication)
  - spike data exchange (both short-range and long-range communication)

Weak-scaling experiment

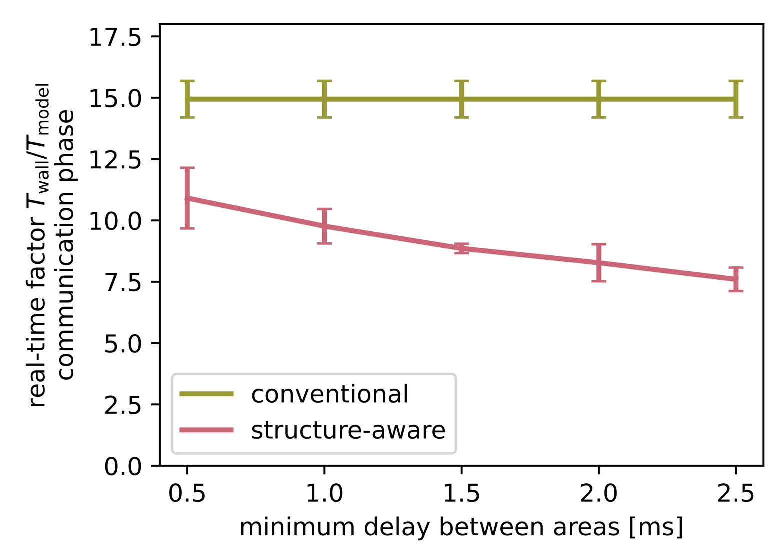


A Conventional round-robin neuron distribution with single communication pathway.

B Structure-aware neuron distribution with separate communication pathways for short- and long-range connections.

- significant speed up of spike communication
- speed of other simulation phases is maintained
- benefit lies in reduced time spent on compute node synchronization
- promising scaling behavior for large number of areas and compute nodes

Delay dependence



- delay distr. within an area: $\mathcal{N}(1.25, 0.625)$
- delay distr. between areas: $\mathcal{N}(5.00, 2.50)$
- lower cutoff of inter-area delay distribution defines inter-node communication frequency in structure-aware approach

⇒ benefit of implementation increases with decreasing amount of inter-area communication

References

[1] Kurth AC, Senk J, Terhorst D, Finnerty J, Diesmann M (2022) Sub-realtime simulation of a neuronal network of natural density. Neuromorphic Computing and Engineering, 2:021001. doi: 10.1088/2634-4386/ac55fc

[2] Albers J, Pronold J, Kurth AC, Vennemo SB, Haghighi Mood K, Patronis A, Terhorst D, Jordan J, Kunkel S, Tetzlaff T, Diesmann M and Senk J (2022) A Modular Workflow for Performance Benchmarking of Neuronal Network Simulations. Front. Neuroinform. 16:837549. doi: 10.3389/fninf.2022.837549

[3] Schmidt M, Bakker R, Hilgetag CC, Diesmann M and van Albada SJ (2018) Multi-scale account of the network structure of macaque visual cortex. Brain Structure and Function, 223: 1409 https://doi.org/10.1007/s00429-017-1554-4

[4] Potjans TC, Diesmann M (2014), The Cell-Type Specific Cortical Microcircuit: Relating Structure and Activity in a Full-Scale Spiking Network Model. Cerebral Cortex, 24 3 785–806 https://doi.org/10.1093/cercor/bhs358

[5] Gewaltig M-O and Diesmann M (2007) NEST (Neural Simulation Tool) Scholarpedia 2(4):1430

[6] https://nest-simulator.readthedocs.io/en/latest

Outlook

- benchmarking of networks with inhomogeneous activity or size
- benchmarking state of the art models (e.g. multi-area model of macaque visual cortex)

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