Simulation technology for brain-scale neuronal networks at single neuron resolution – Part 2

Geilo Winter School 2020

Susanne Kunkel

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Overview

NEST: One simulator, …

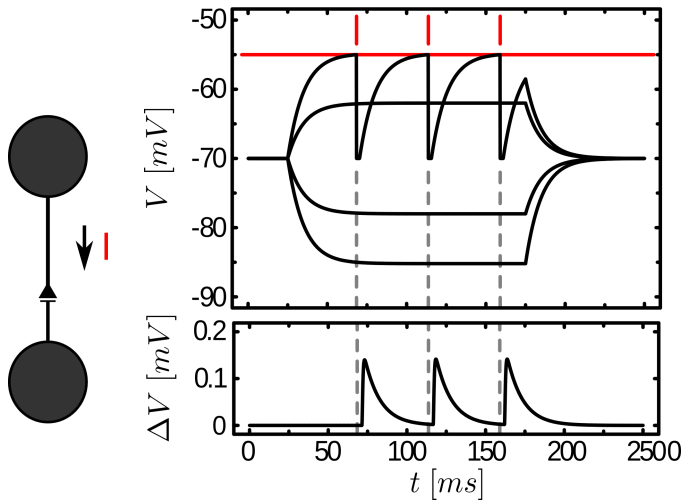
… many models

… many scales

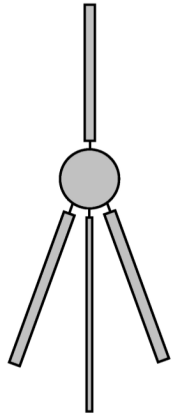
NEST: One simulator, many models

Neuron models

- Point-neuron models
  - Linear subthreshold dynamics
    - → Exact integration
  - Non-linear dynamics
    - → Numerical solver (e.g. GSL)



- Few-compartment neuron models
  - → Not distributed



Dayan & Abbott (2001)

NEST: One simulator, many models

Neuron models

- Point-neuron models
  - Linear subthreshold dynamics
  - → Exact integration
  - → Optimization: Pre-compute exponentials if spikes are constrained to time grid

$$\dot{I}_\mathrm{x} = 0$$

$$\dot{I}_\mathrm{syn} = -\frac{1}{\tau} I_\mathrm{syn} + \xi$$

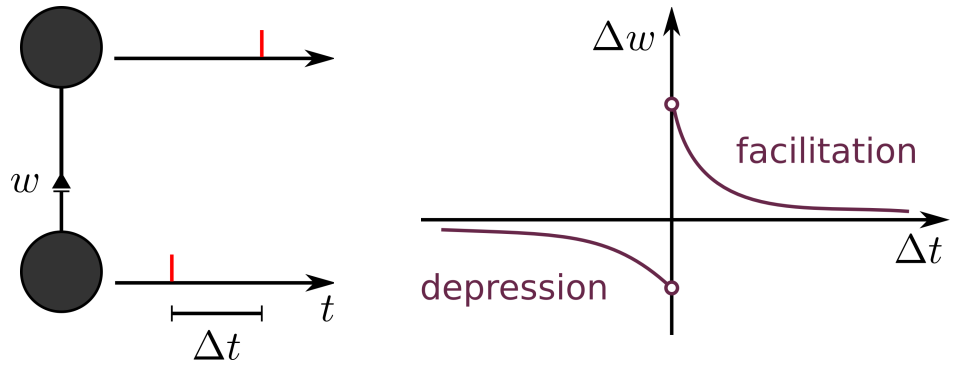
$$\dot{V} = -\frac{1}{\tau_\mathrm{m}} V + \frac{1}{C_\mathrm{m}} I_\mathrm{syn} + \frac{1}{C_\mathrm{m}} I_\mathrm{x}$$

$$[V(t) = \begin{pmatrix} \frac{1}{C_\mathrm{m}} \tau_\mathrm{m} \left(1 - e^{-\frac{t}{\tau_\mathrm{m}}}\right) \\ \frac{1}{C_\mathrm{m}} \frac{\tau_\mathrm{m} \tau}{\tau_\mathrm{m} - \tau} \left(e^{-\frac{t}{\tau_\mathrm{m}}} - e^{-\frac{t}{\tau}}\right) \\ e^{-\frac{t}{\tau_\mathrm{m}}} \end{pmatrix}^\mathrm{T} \begin{pmatrix} I_\mathrm{x} \\ I_\mathrm{syn}(0) \\ V(0) \end{pmatrix}]$$

NEST: One simulator, many models

Synapse models

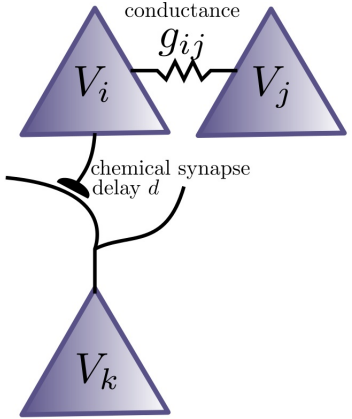
- Synapse models
  - Static weights
  - Dynamic weights
    - spike-timing dependent plasticity (STDP)
      (Morrison 2007)



NEST: One simulator, many models

Synapse models

- Synapse models
  - Static weights
  - Dynamic weights
    - spike-timing dependent plasticity (STDP)
      (Morrison 2007)
    - Short-term plasticity
      (Tsodyks et al., 2000)
    - Interaction with neuromodulators
      (Potjans et al., 2010)
  - Structural plasticity
    (Diaz et al. 2016)
  - Gap junctions
    (Hahne et al., 2015)
  - Rate-based models
    (Hahne et al., 2016)



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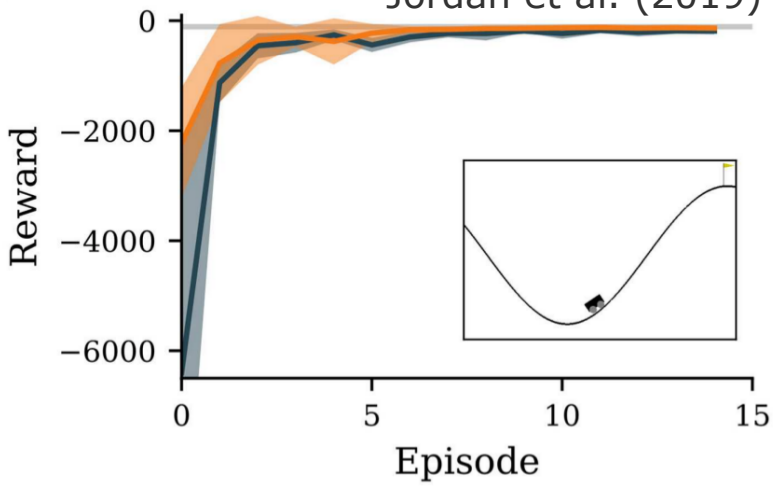
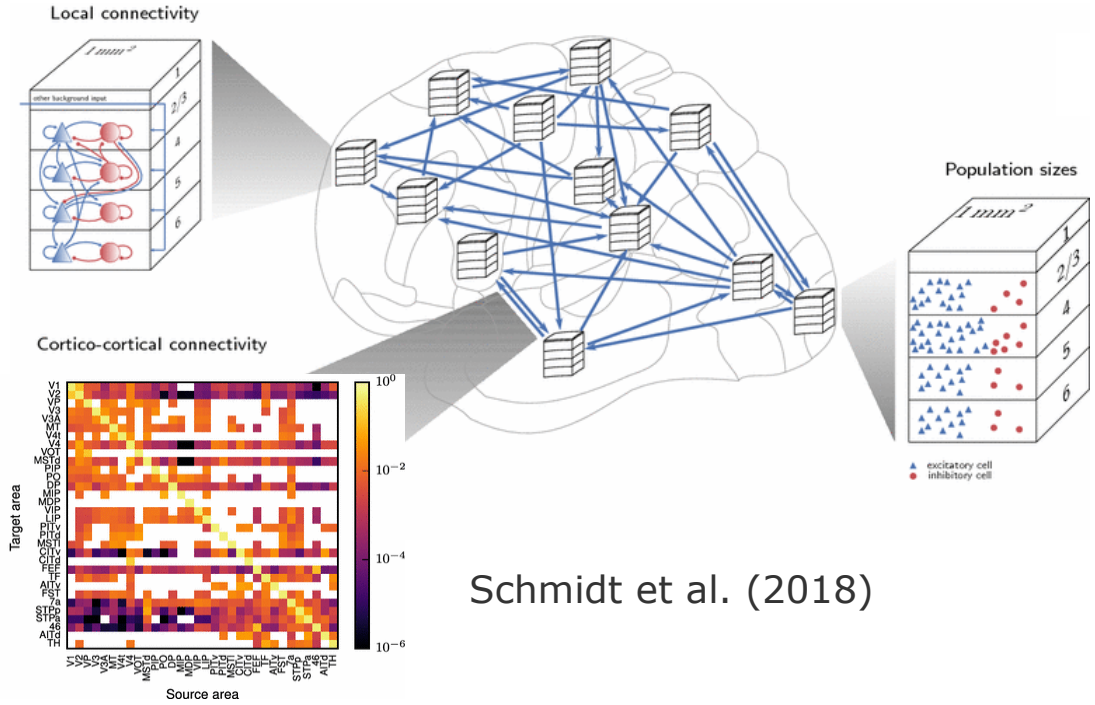
Limitations of previous simulation technology (4g kernel)

Network models

Jordan et al. (2019)





Schmidt et al. (2018)

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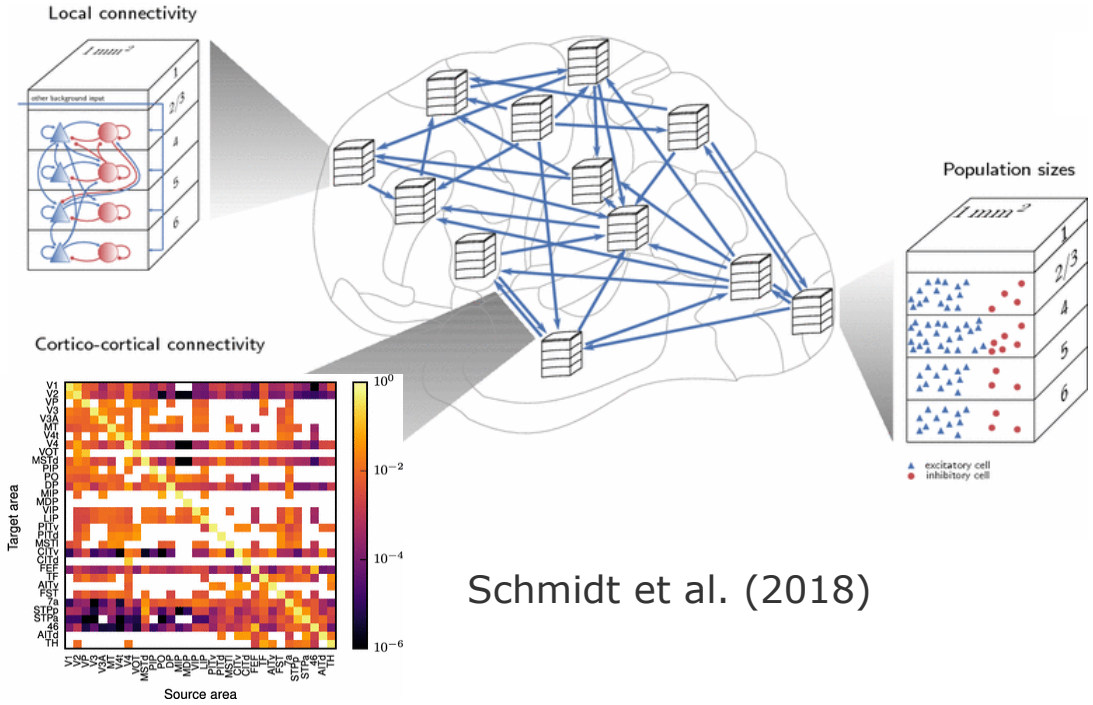
NEST: One simulator, many scales

From laptops to supercomputers



Schmidt et al. (2018)

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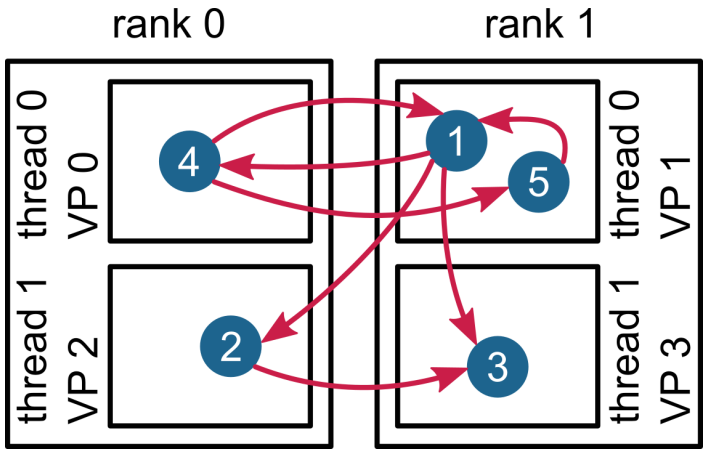
NEST: One simulator, many scales

Hybrid parallelization scheme MPI/OpemMP

- Balanced work load
  - Neurons:

    round robin
  - Synapses:

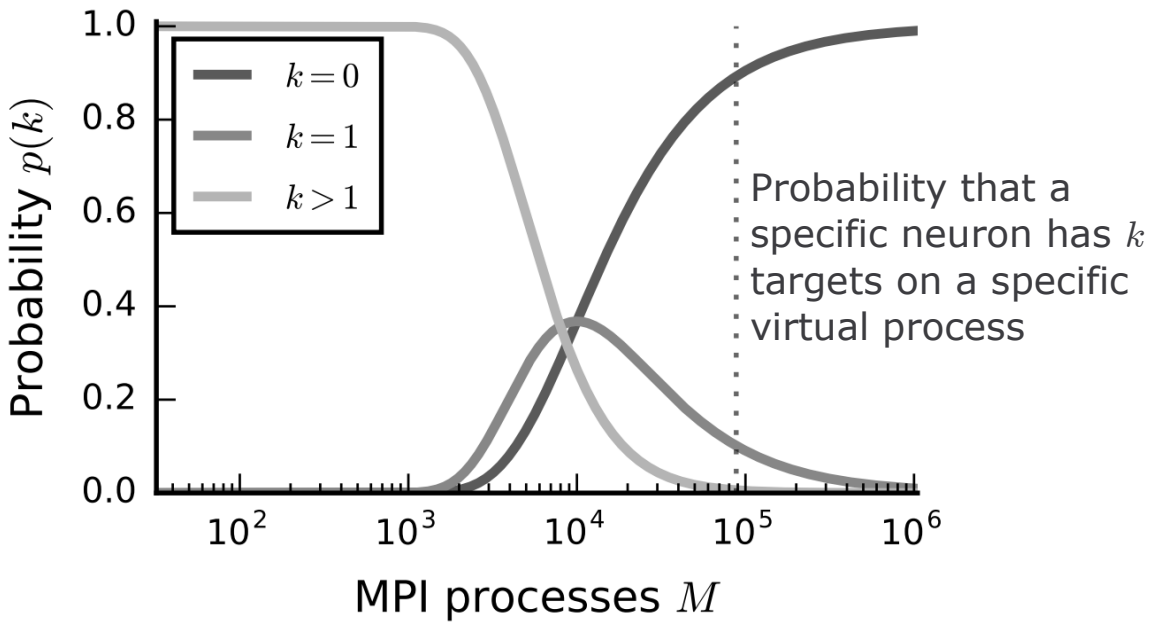
    thread of postsynaptic neuron
- Frequent communication of spikes using MPI collectives



NEST: One simulator, many scales

Requirements at different scales

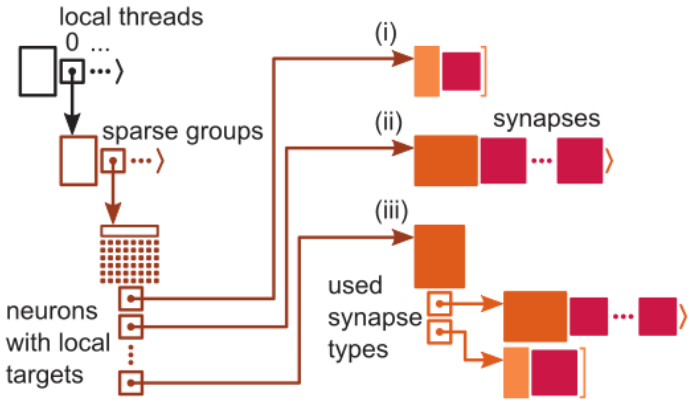
- Limited number of synapses per neuron (10^4)
  - ➔ Number of targets per virtual process decreases

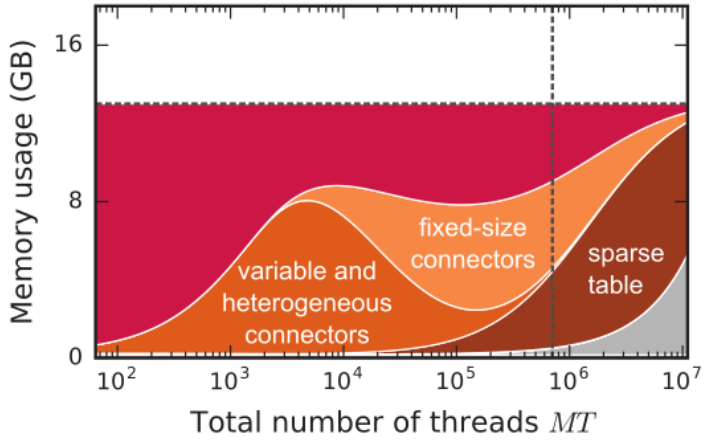


NEST: One simulator, many scales

Limitations of previous simulation technology

- Memory usage of synaptic data structures increases with network size





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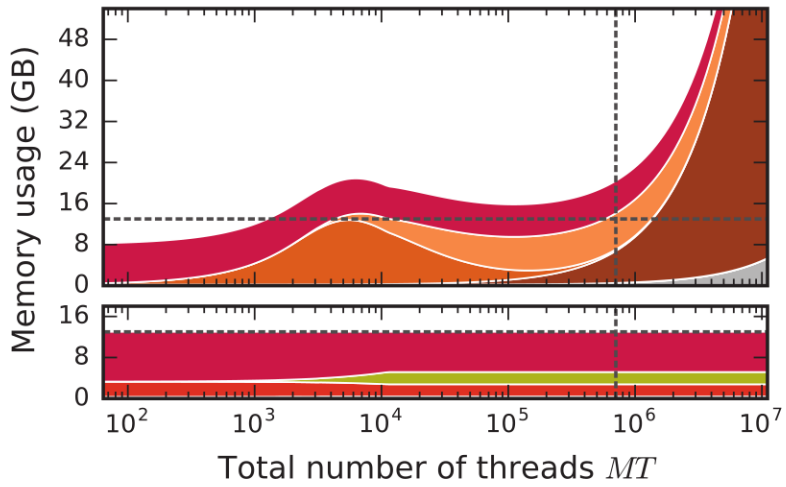
NEST: One simulator, many scales

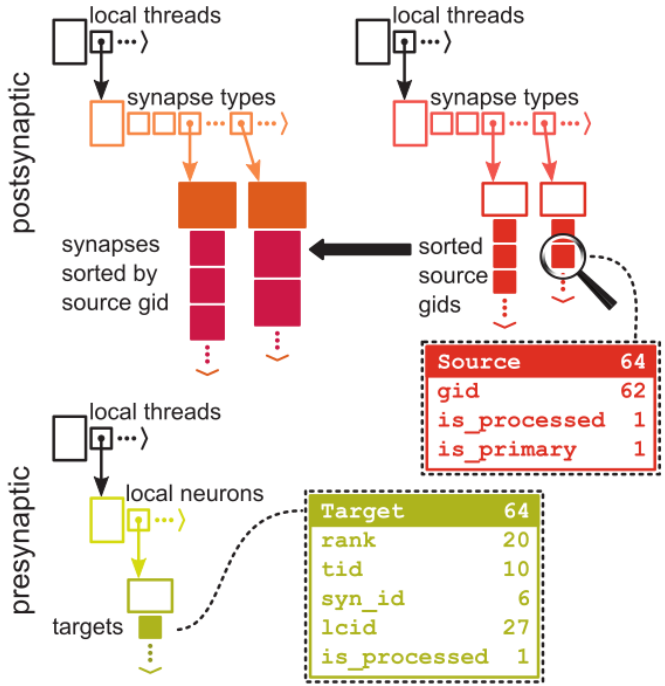
New technology (5g kernel)

Jordan et al. (2018)

Previously:

Now:





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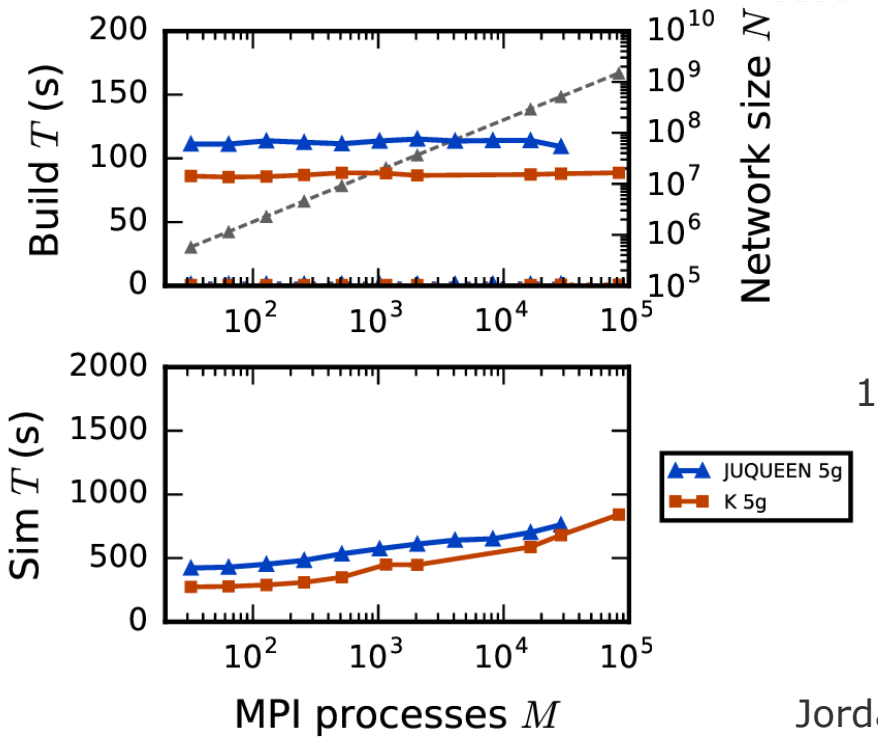
New technology (5g kernel)



18,000 neurons per process
11,250 synapses per neuron

Jordan et al. (2018)

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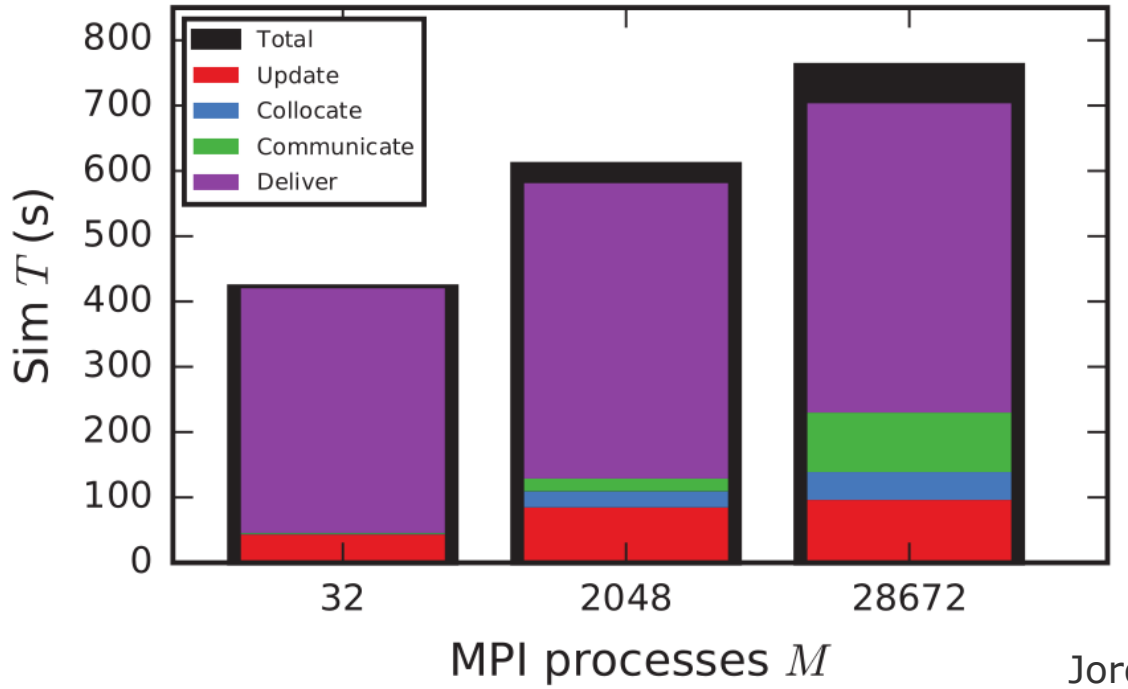
NEST: One simulator, many scales

Limitations of the new technolog (5g kernel)



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