PHYSICAL OSCILLATOR MODEL FOR PARALLEL DISTRIBUTED COMPUTING

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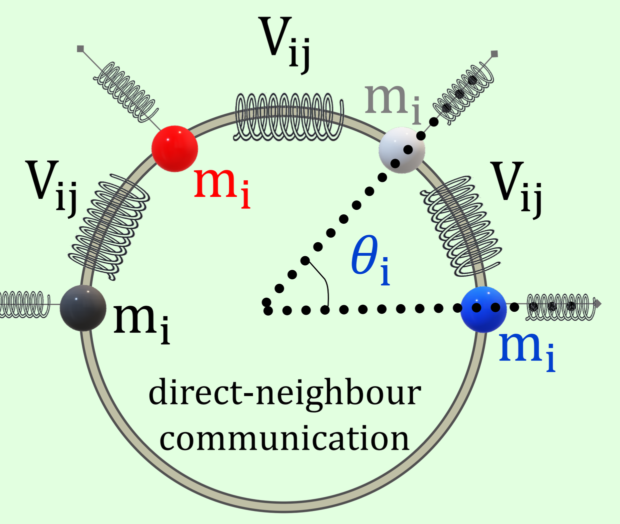
MOTIVATION

Analytic, first-principles performance modelling of distributed-memory applications is not available due to a wide spectrum of effects cause by noise and complex interplay between code, message passing library and cluster

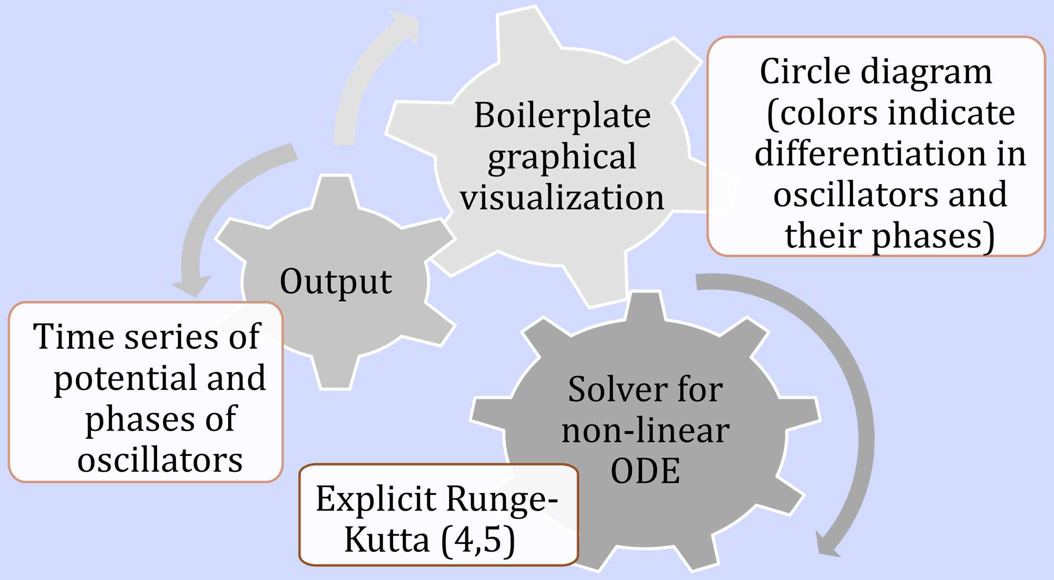
We propose a non-linear physical coupled phase oscillators model

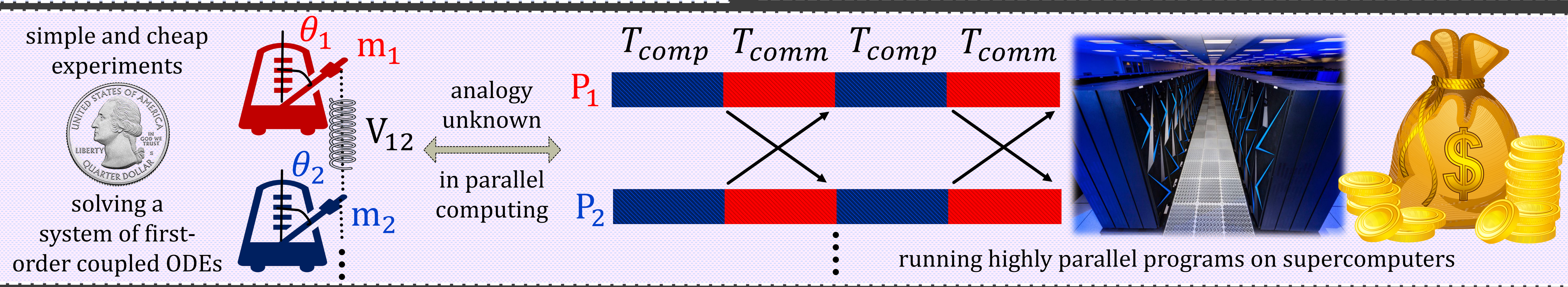
Bridging the gap: a theoretical model for a comprehensive insight of global consequences on performance in (non-)equilibrium states of (ir)regular applications



The phenomenology of distributed applications suggests a physical interpretation of individual processes as point masses moving in the potential that accelerates or slows down the oscillation

MODEL IMPLEMENTATION





ANALOGY COMPARISON

Parallel Programs		Physical Model
number of processes $Comm\_size$	⟺	number of oscillators N
alternate back-and-forth $1/(T_{comp}+T_{comm})$	⟺	intrinsic natural frequency ω_i
variability in T_{comp} and T_{comm} of processes	⟺	phase differences (noise) or frequencies spread (load imbalance) of oscillators
delay propagation speed (the distance in ranks travelled in one time step)	⟺	coupling strength K

$$\dot{\theta}_i = \underbrace{\omega_i}_{\text{Inverse time step}} + \underbrace{\zeta_i(t)}_{\text{Noise}} + \underbrace{\frac{\sigma.\kappa}{sum(T_{exec},T_{comm}).comm\_size}\sum_{j=1}^{N} T_{ij}\,V_{ij}(\theta(t,\tau))}_{\text{Interaction term}}$$

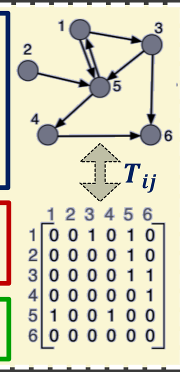
$comm\_size$: system size

T_{exec}, T_{comm}: execution time, communication time

σ, κ and T_{ij} (dimensionless): depend on the communication protocol, concurrency, and topology

$V_{ij}(\theta)$: coupling potential reflects bottleneck structure

$\zeta_i(t)$: local noise; τ: interaction noise



MODEL COMPARISION

Kuramoto Model		Coupled Oscillator Model
$\dot{\theta}_i = \omega_i + \frac{K}{N}\sum_{j=1}^{N} sin(\theta_j - \theta_i)$		
global full-connectivity	⟺	topology-aware pairwise local interactions
no delay propagation over timestep	⟺	delay propagation over timestep
period of an oscillator (one revolution) = 2π	⟺	period of a process (one timestep) = $T_{comm} + T_{comm}$
too continuous Ansatz causing built-in noise	⟺	discrete Ansatz
equilibrium state and its stability is governed by sinusoidal potential	⟺	equilibrium state and its stability is governed by bottleneck structure

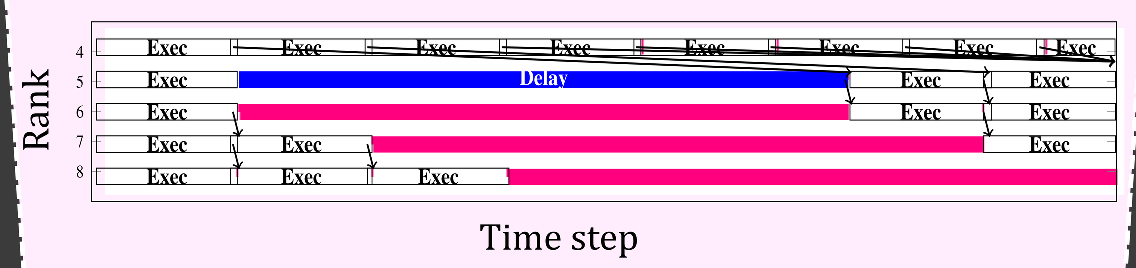
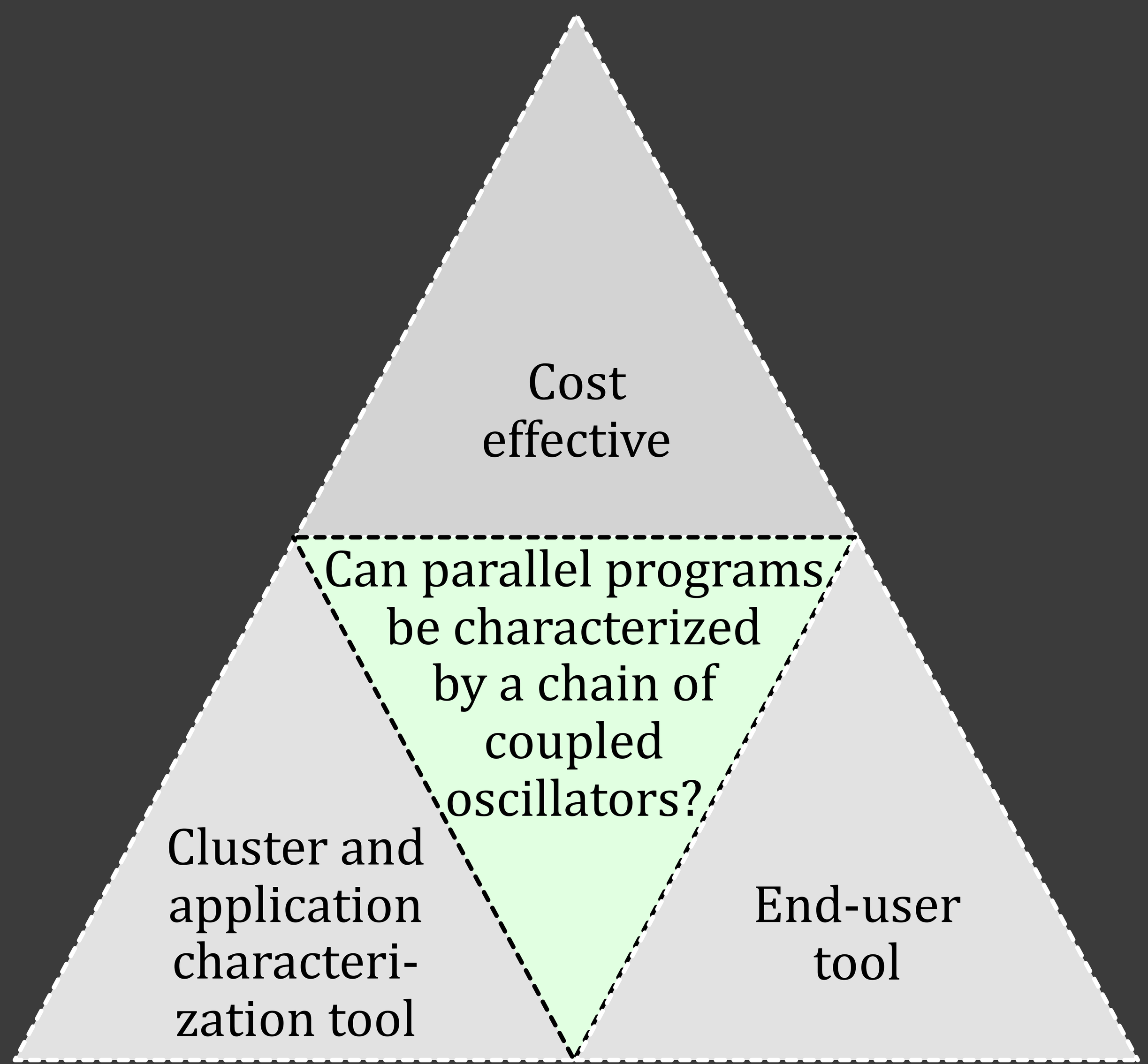
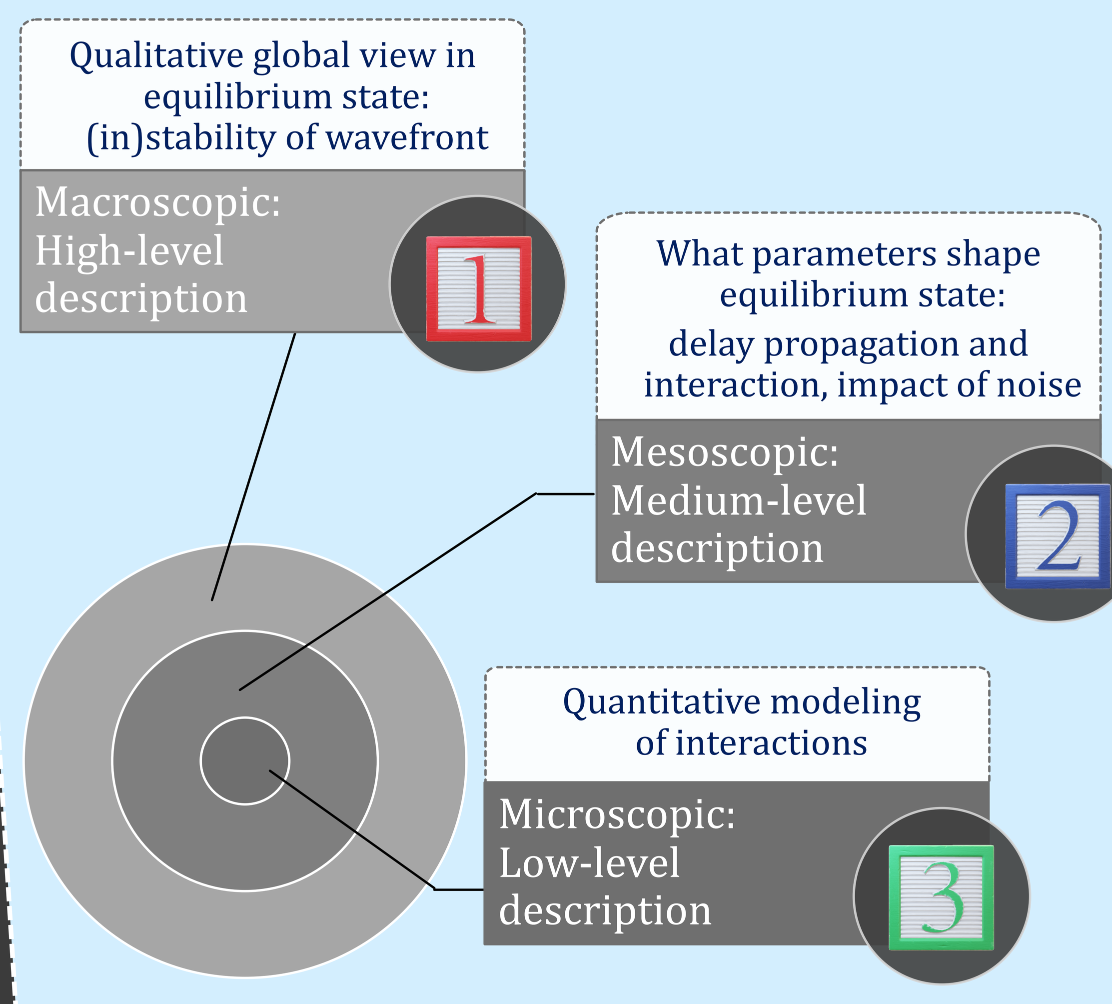


Fig: Delay propagation in MPI parallel programs

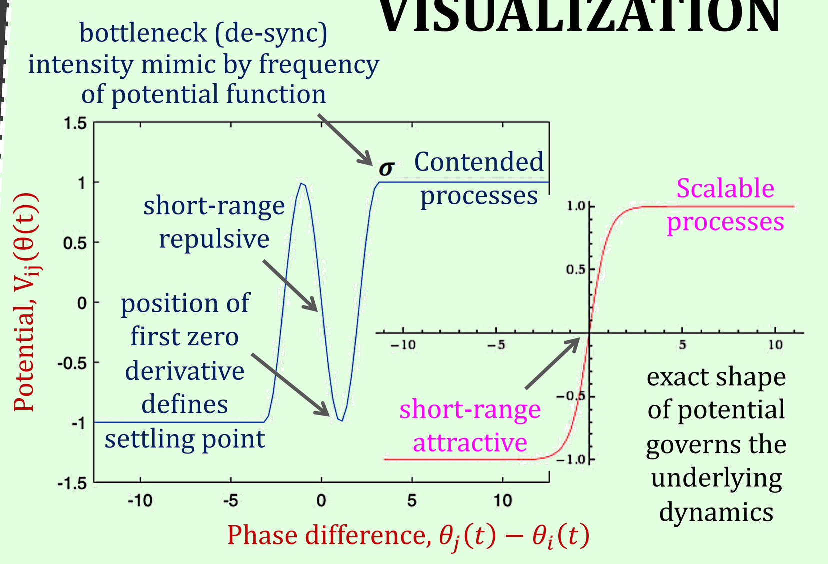
USEABILITY AND GENERIZATION



MODEL APPLICABILITY



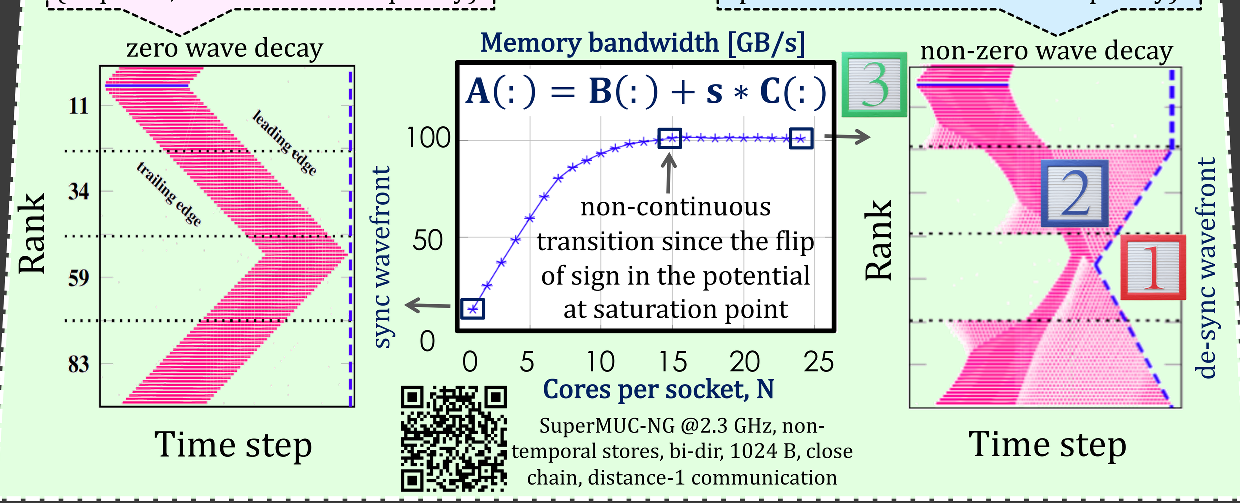
POTENTIAL VS. SCALABILITY VISUALIZATION



"Goldstone boson" for Spontaneous symmetry breaking is the state where waves travel and eliminate the system with computation-communication overlap and bottleneck evasion

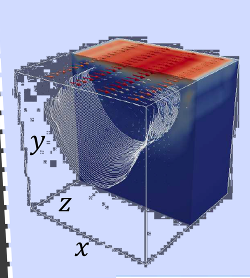
Scalable processes
Strong coupling favors close proximity of oscillators and with a a little wiggle, the system evolves to make it loose and snaps back to an ultimate re-sync state of oscillators (in-phase, same natural frequency)

Contended processes
If a sync state deviates a bit from zero potential with a little wiggle, its blow up, gets bigger and bigger, and a stable phase-locked desync evolves with bottleneck evasion(equidistant out-of-phase oscillators of same frequency)

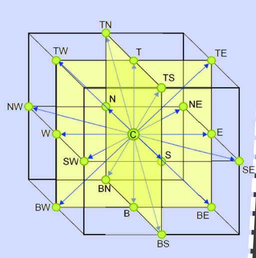


SuperMUC-NG @2.3 GHz, non-temporal stores, bi-dir, 1024 B, close chain, distance-1 communication

MODELLING EVALUATION
USE CASE: LATTICE BOLTZMANN FLUID SOLVER



Validation by applying one-to-one mapping between simulated ODE system model and practical application traces ported into same graphical visualization



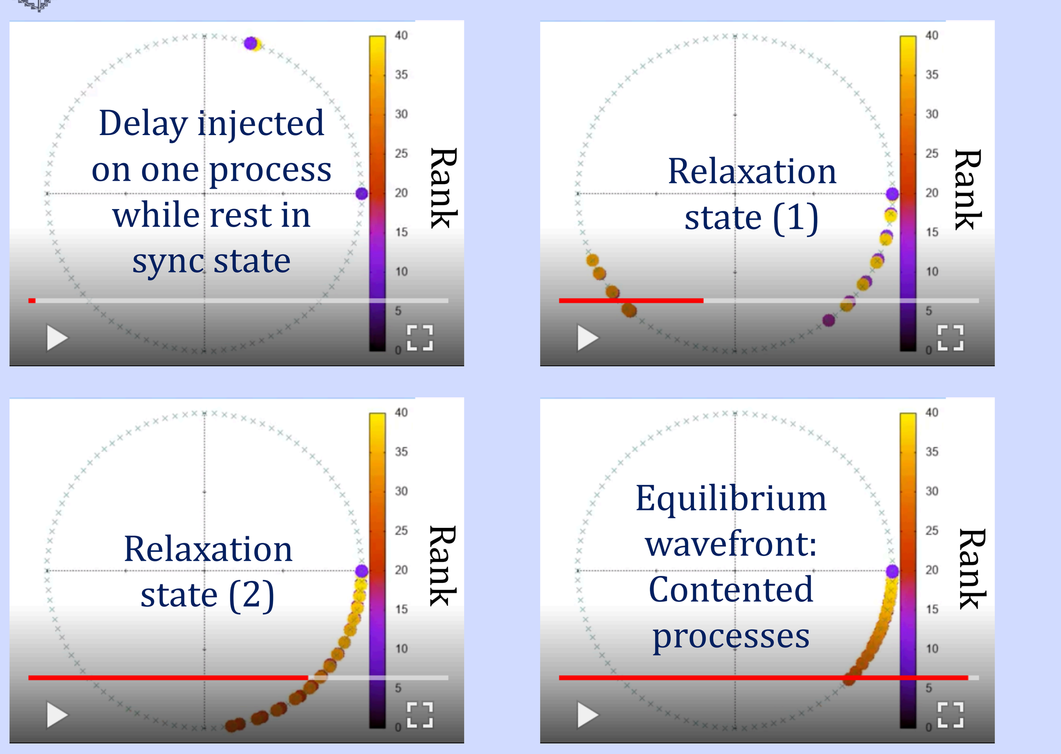


Fig: Modelled runtime per time step normalized to slowest process at first, two intermediate and last time steps. MPI program results were similar and thus not added here

302^3 lattice cell, 8 GB data set, close chain, non-blocking, distance-1 communication, 4 sockets on Emmy system@2.2GHz

OUTLOOK
CONCLUSIONS AND LIMITATIONS

Our model is a novelty and opens possibilities for future research in new directions

Works at macroscopic (1) and mesoscopic (2) levels

Limitations at microscopic (3) level

since non-differentiable nature of the compute-communicate oscillation

Model Modification for best interaction term

for accuracy and further useability is intended as future work

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DOI:10.1109/CLUST ER.2019.8890995
DOI:10.13140/RG.2.2 .28259.50726
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