Large scale rigid body dynamics simulation on HPCs with distributed memory architecture

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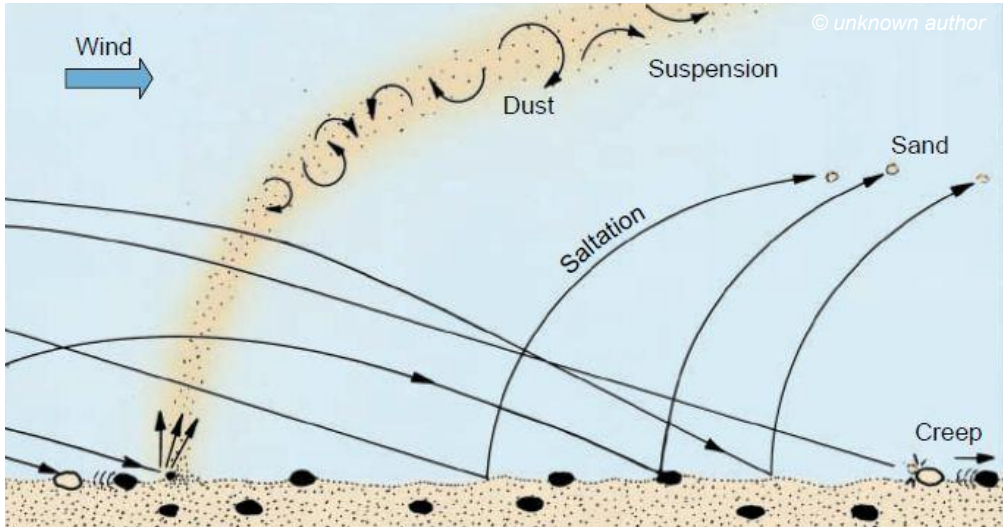
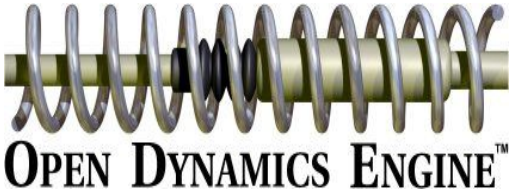
Saltation:

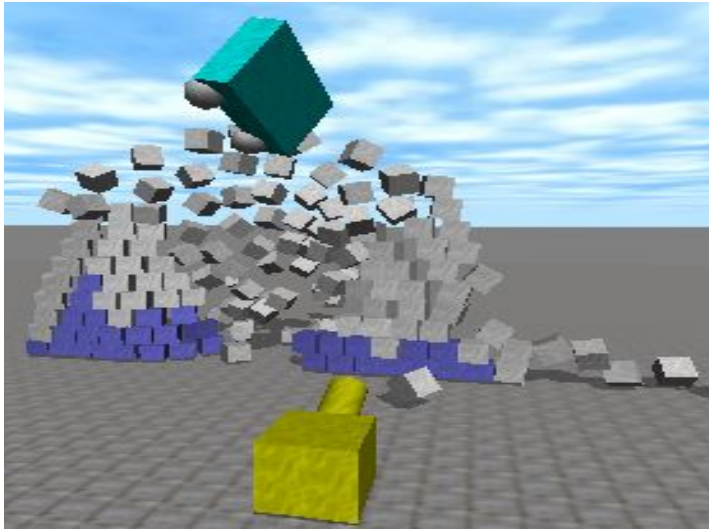
- movement of particles by a series of bounces along the surface of the ground, and dislodging additional particles with each impact.
- accounts for 50-90% of the total movement of soil by wind

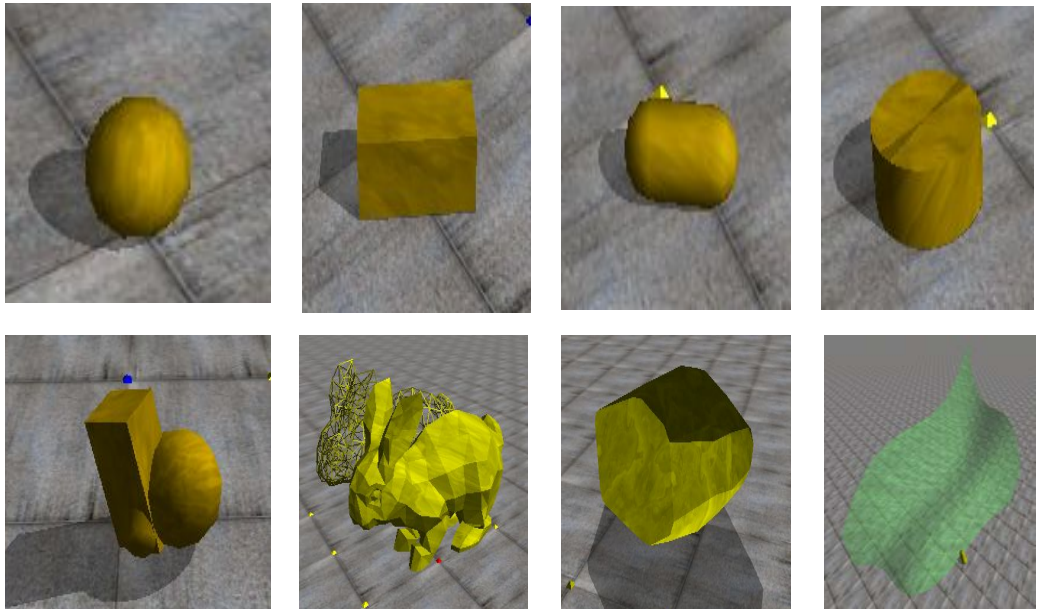




The Open Dynamics Engine (*ODE*):

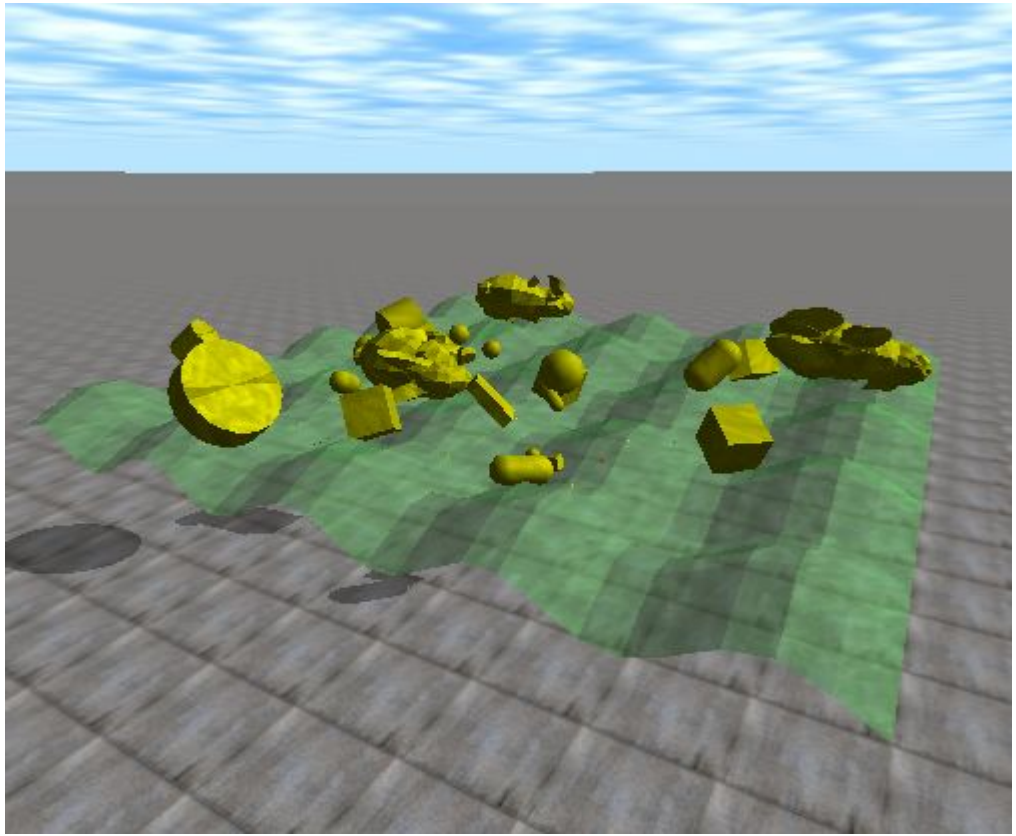
- rigid body dynamics;
- collision detection.





ODE supports bodies of different shapes:

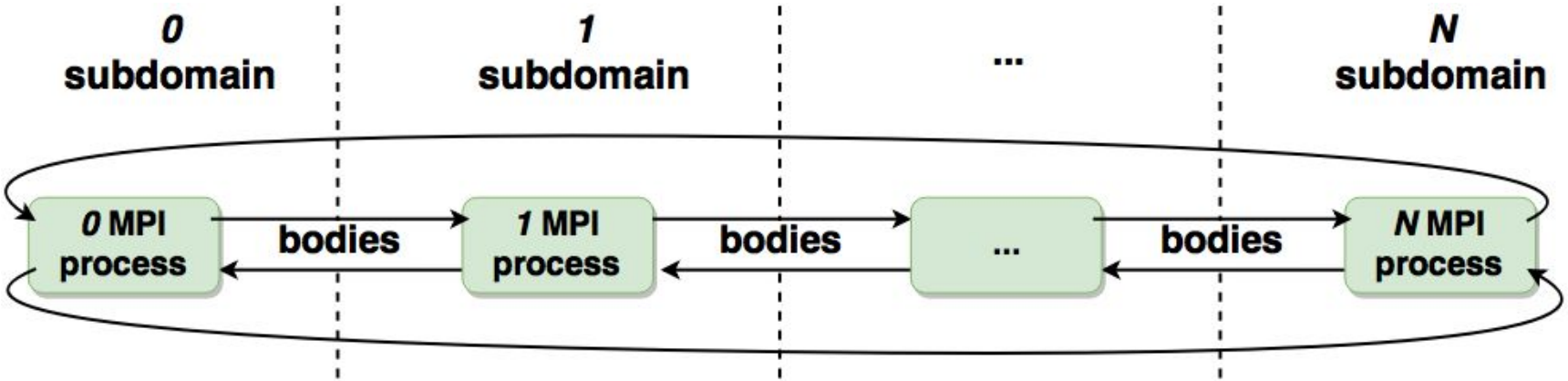
sphere, box,
capsule, cylinder,
composite body,
triangle mesh, convex body.



ODE resolves collisions between these objects of different shape.

BUT! The *ODE* does not support parallelism.

We extended the *ODE* by implementing an MPI communication layer and by deploying a spatial decomposition approach



We developed a computational framework which couples two open source codes:

1. Particle code (*Open Dynamics Engine (ODE)*)
2. CFD code (*OpenFOAM*)

OpenFOAM

The Open Source CFD Toolbox

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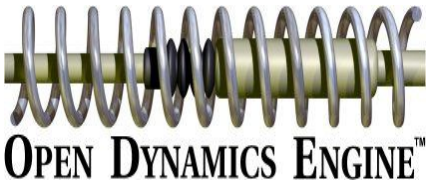


OPEN DYNAMICS ENGINE™

To describe the motion of the fluid phase in the presence of a particulate phase the modified set of Navier-Stokes Equations is used:

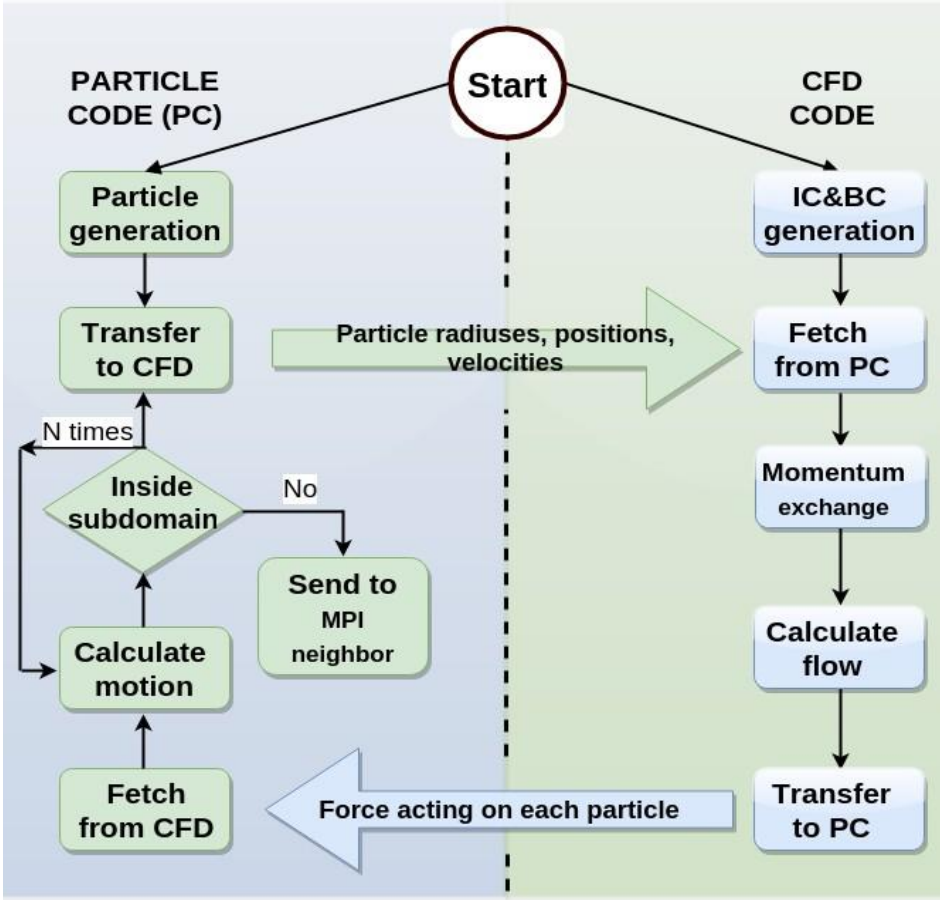
$$\frac{\partial \alpha_f \rho_f}{\partial t} + \nabla \cdot \left(\alpha_f \rho_f \mathbf{u_f} \right) = 0$$

$$\frac{\partial \left(\alpha_f \rho_f \mathbf{u_f} \right)}{\partial t} + \nabla \cdot \left(\alpha_f \rho_f \mathbf{u_f} \mathbf{u_f} \right) = -\alpha_f \nabla p + \nabla \cdot \left(\alpha_f \tau_f \right) + \alpha_f \rho_f \mathbf{g} - f_{drag}$$

$$\alpha_f = 1 - \sum_{k=1}^{n_p} V_{pk} / \Delta V, \qquad f_{drag} = \frac{1}{\Delta V} \sum_{i=1}^{n_p} \boldsymbol{F}_{drag,i}$$

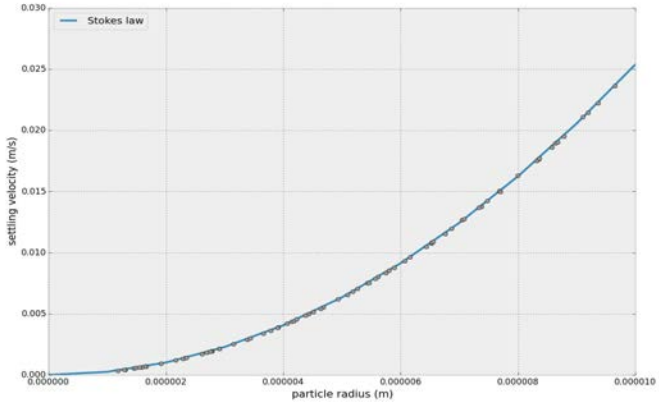
α_f – fluid volume fraction;
$\boldsymbol{u_f}$ – fluid velocity;
ρ_f – fluid density;
p – pressure;
$\boldsymbol{\tau}$ – stress tensor;

V_{pk} – volume of k-particle;
n_p – number of particles;
ΔV – cell volume;
$\boldsymbol{f_{drag}}$ – fluid-solid momentum exchange term.

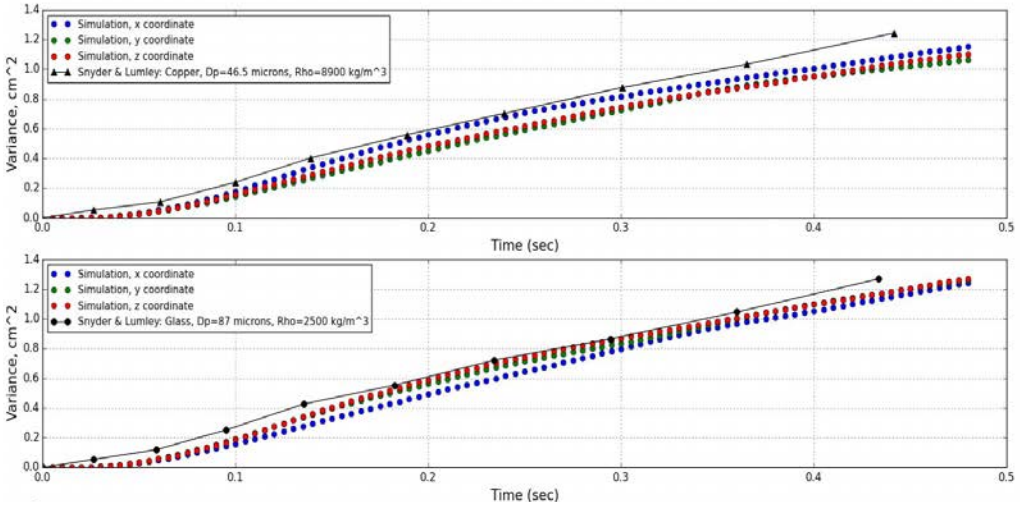


1) Particles properties are transferred to the CFD part;
2) For each CFD cell, the volume fraction is determined;
3) The momentum exchange term between the airflow and particles is evaluated;
4) Fluid flow is calculated;
5) The forces acting on the particles are calculated and sent to the Particle part;
6) The Particle part calculates new particles positions using updated velocities and resolves collisions.

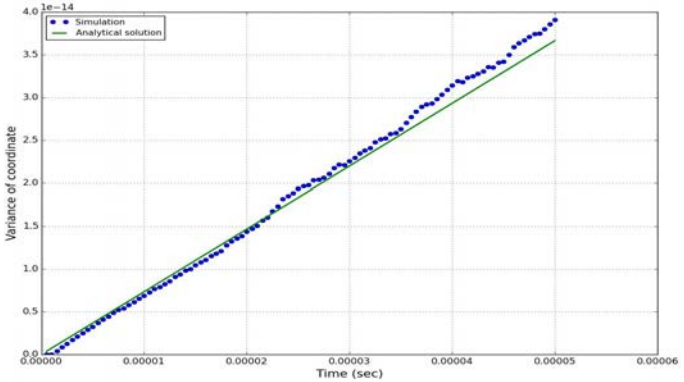
Validation of physics processes.



Stokes drag

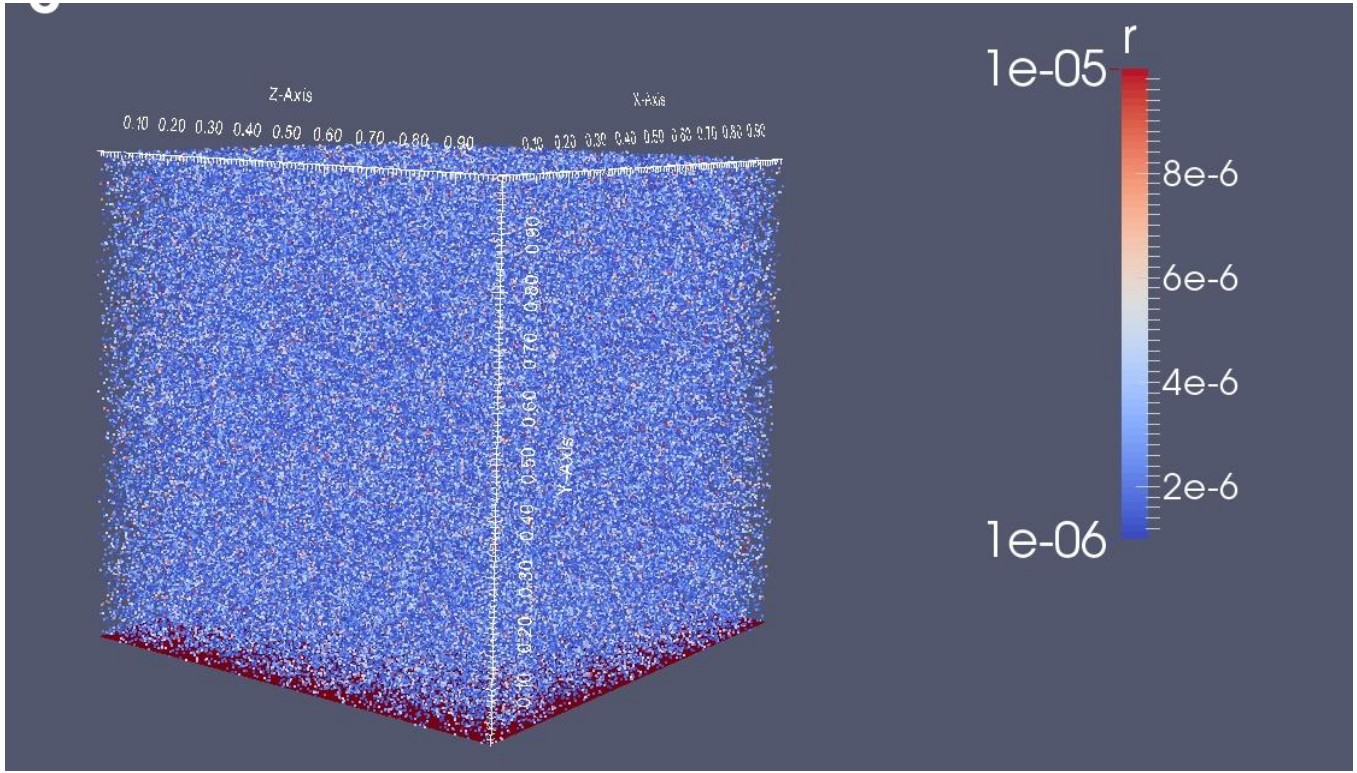


Turbulence dispersion effect

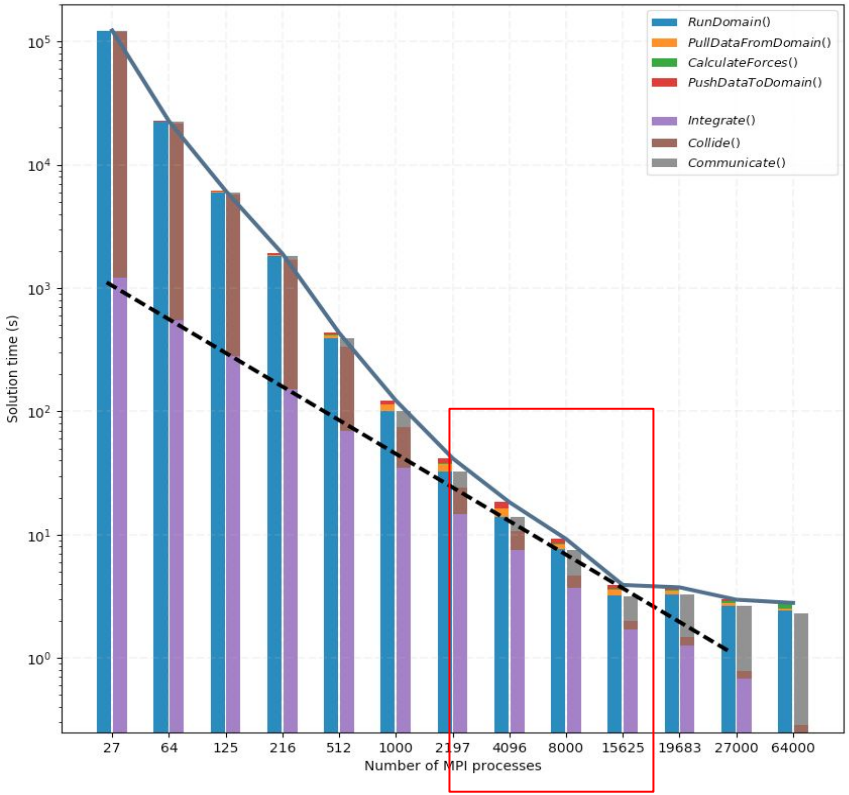


Brownian force

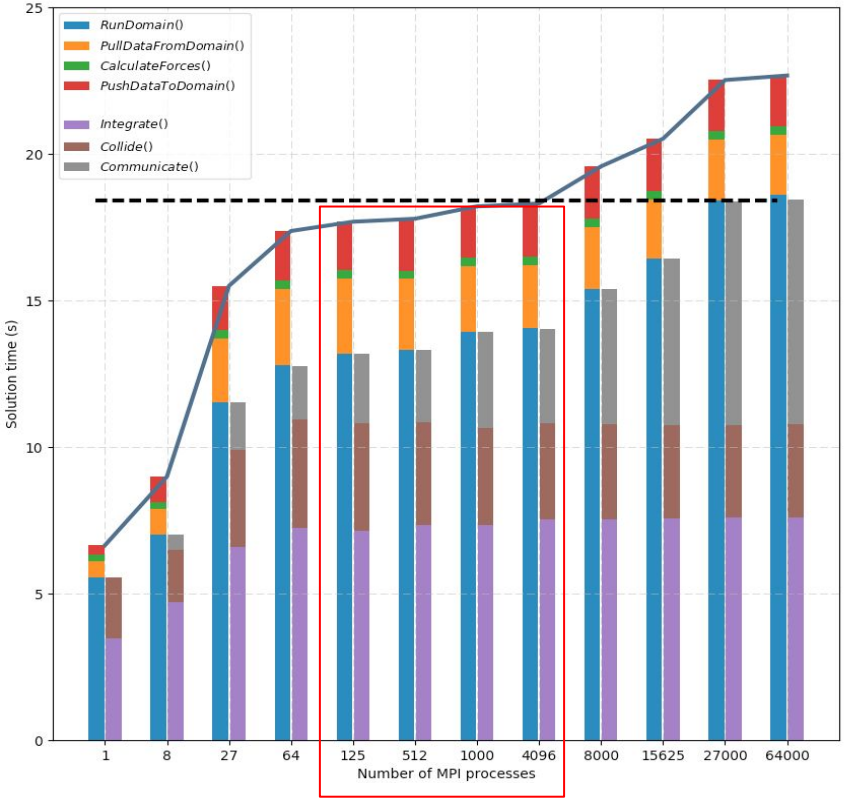
Scaling study



Scaling study



Strong scaling



Weak scaling

Thank you!