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Fluid-Particle Multiphase Flow Simulations for the Study of Sand Infiltration into Immobile Gravel-Beds

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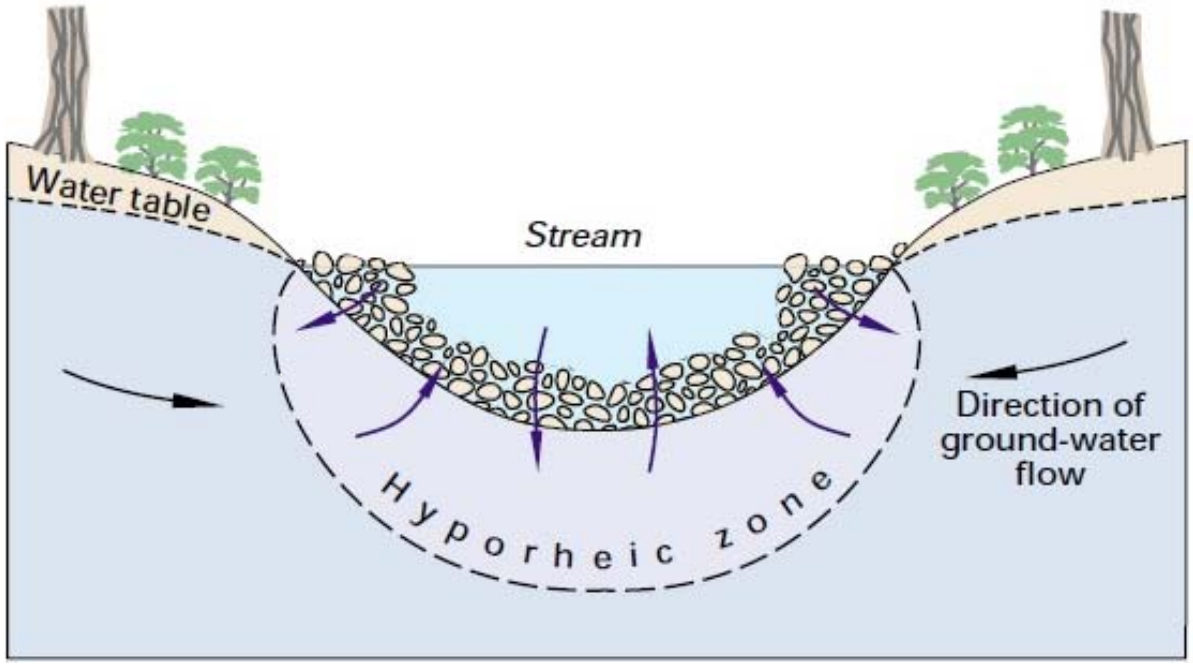
The Riverbed



Quelle: U.S. Geological Survey

Permeability and porosity can be reduced
due to human induced fine sediment infiltration

Conents

- **Objectives**
- **Methods**
  - „The Cube“
  - Particle Flow Simulation
  - Fluid Flow Simulation
  - Fluid-Particle Coupling
  - HPC Performance
- **Simulation Examples**
  - Gravel-Bed Packing
  - Sand Infiltration

State of Research

Major Research Questions…

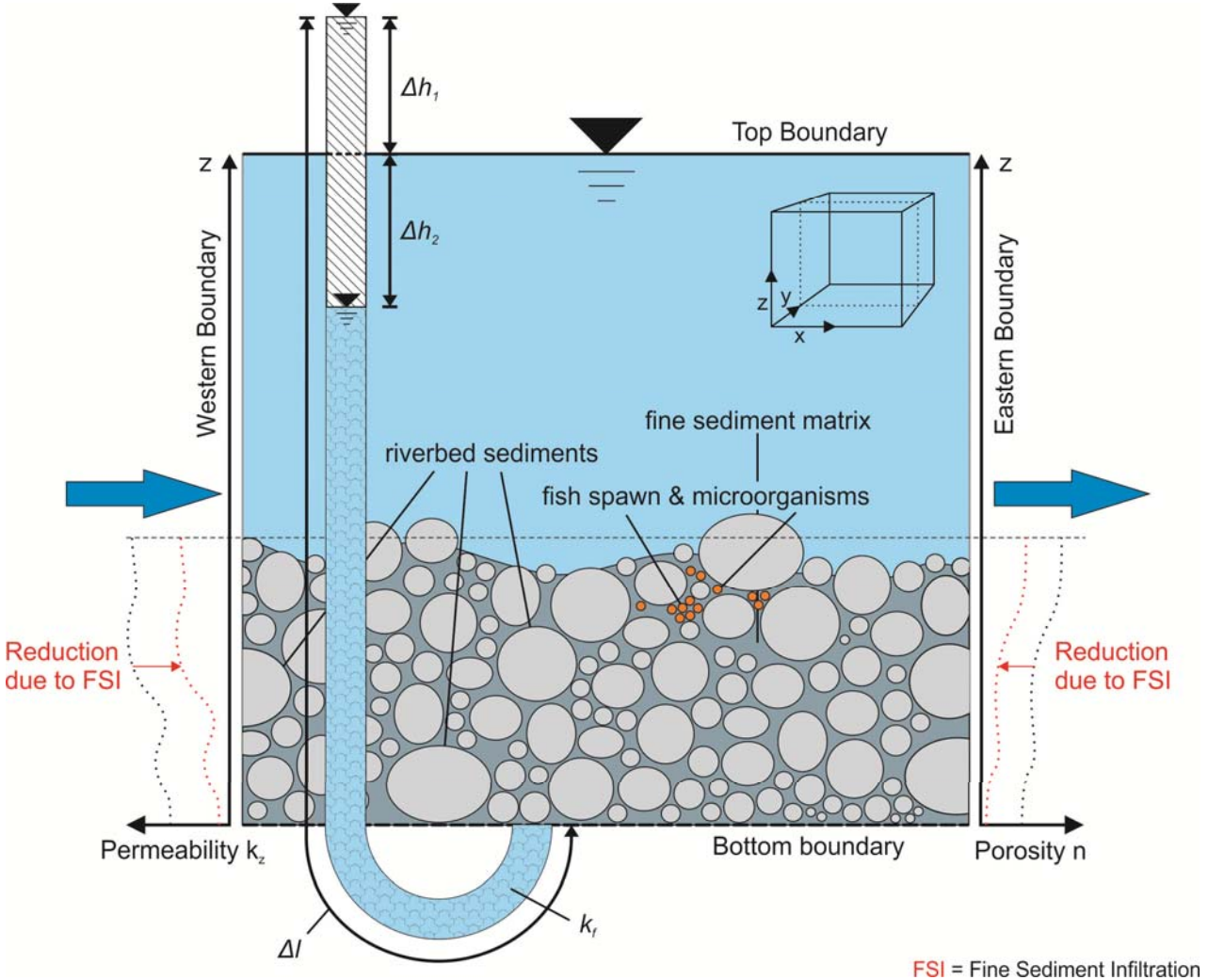
- Which parameters influence fine sediment infiltration?
- How does fine sediment infiltration affect riverbed porosity and permeability?
- …

Answers so far…

- Few case studies

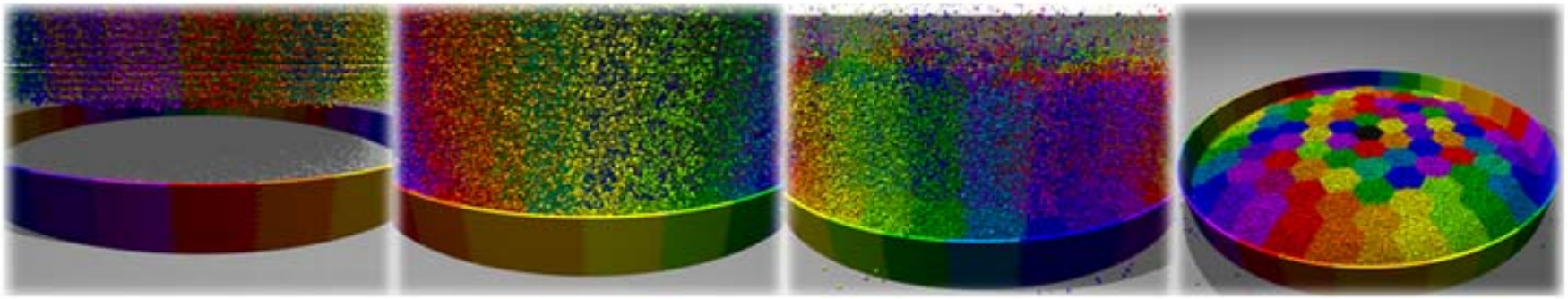
Thereofore **Development of high performance computing numerical model for systematic investigation of fine sediment infiltration process**

Model „The Cube“



Particle Flow Simulation (Sediments)

- Software: **pe** (physics engine)
- C++ framework for massively parallel rigid body simulations
- Support for many parallelization concept (Threads, **OpenMP, MPI**)

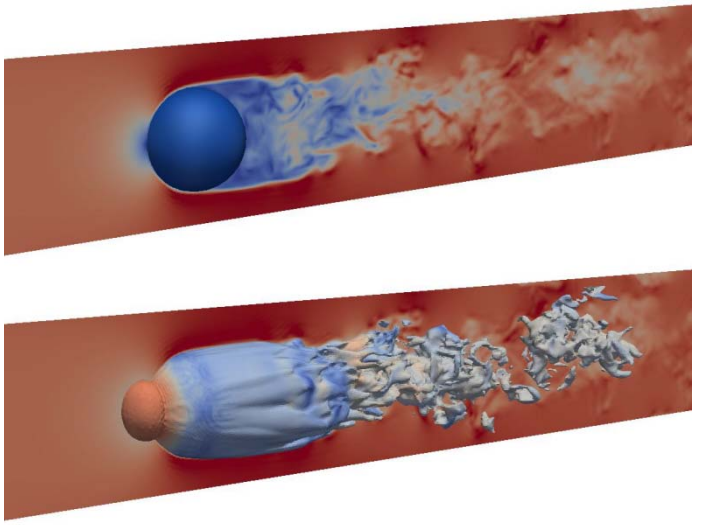


- Software infrastructure for various rigid body simulation algorithms (**DEM**, RBD, …)

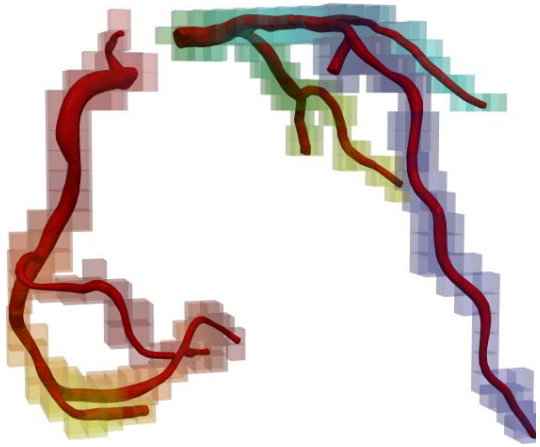
- Developed by Chair for System Simulation, Friedrich-Alexander University Erlangen-Nürnberg (www10.informatik.uni-erlangen.de)

Fluid Flow Simulation (River)

- Software: **waLBerla** (widely applicable Lattice Boltzmann framework from Erlangen)
- Fluid flow simulations based on the **Lattice Boltzmann Method (LBM)**
  - Very good parallel performance
  - Handles complex boundaries easily



turbulent flow (Re ~ 10,000) around sphere

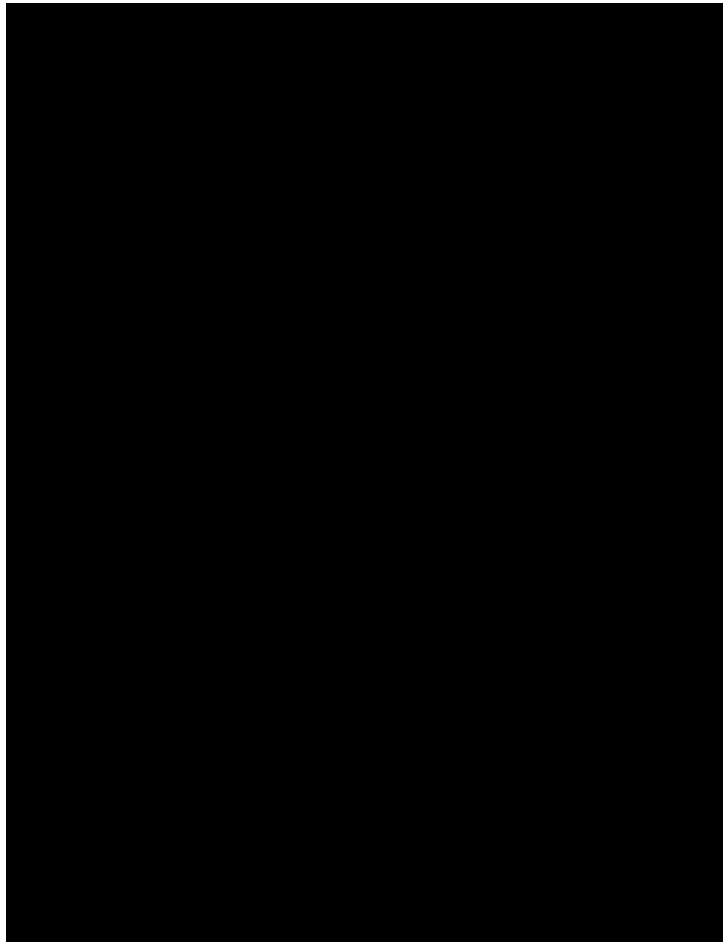


blood flow through artery

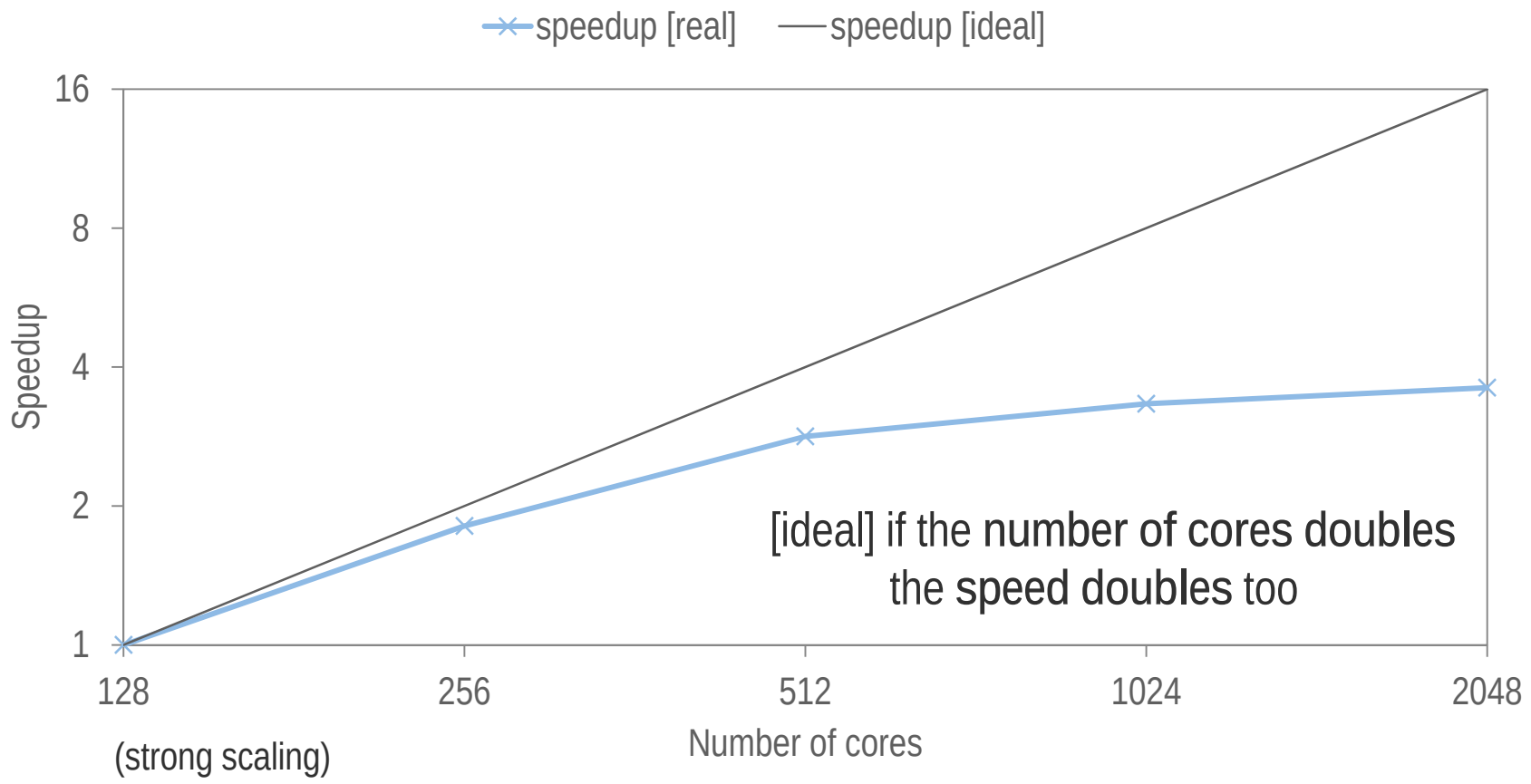
- Designed as an **HPC** software framework
  - Grid refinement
  - Largest simulation: 1,835,008 processes
  - **Hybrid parallelization**: MPI + OpenMP
- **Open source** → http://www.walberla.net

Fluid-Particle Coupling

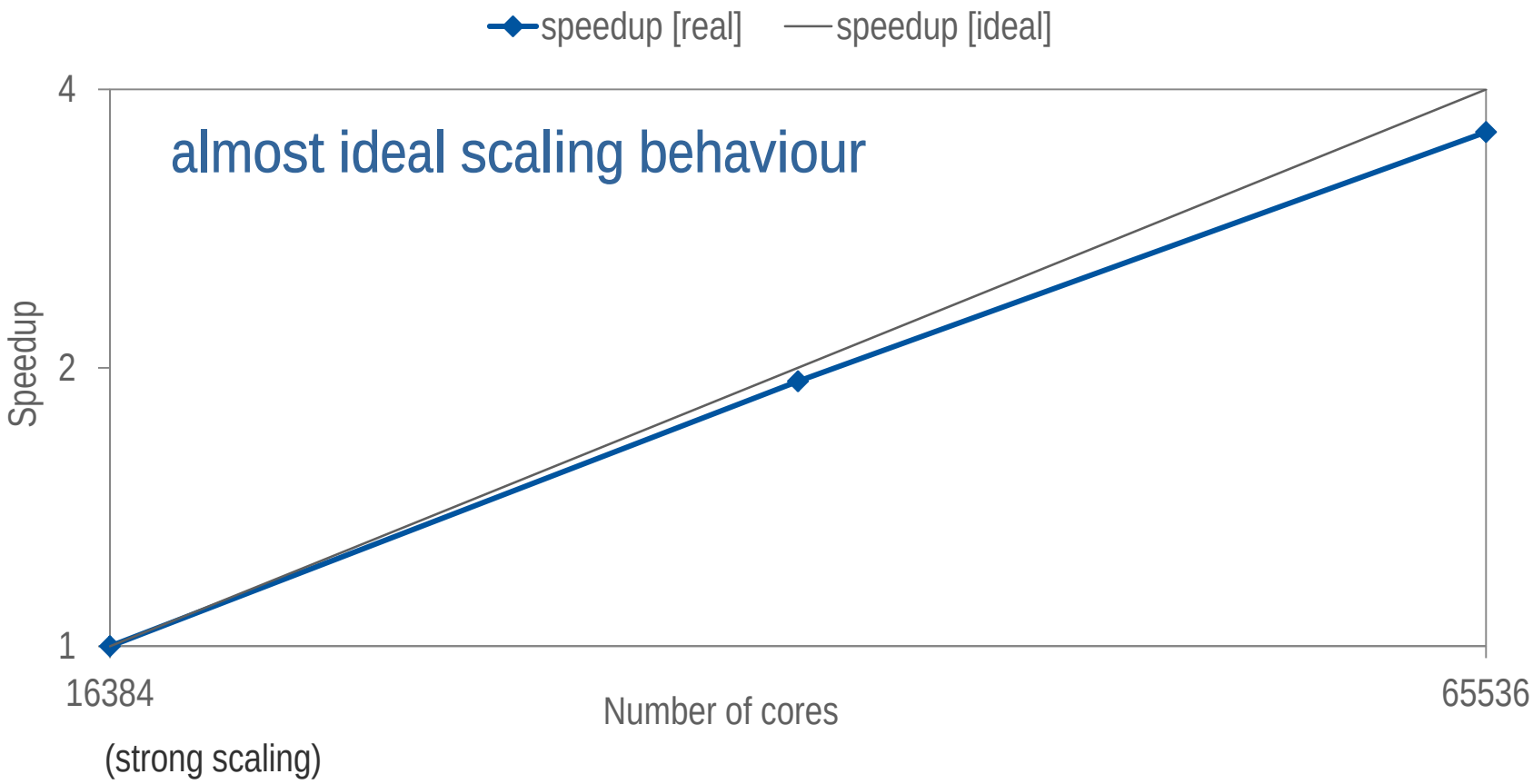
- Particles and fluid are **fully coupled** (4-way coupling)
- Coupling based on (Particulate) **Immersed Boundary Method** (IBM) (Particulate → particles are represented by one Lagrangian point)
- Particles **can** be smaller than one fluid cell
- Fluid and particle simulation **timestep can be tuned individually**



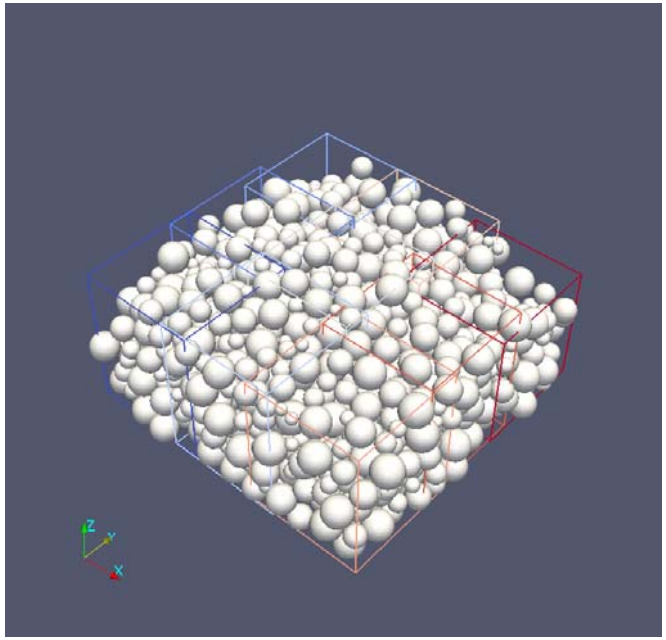
HPC Performance (particle flow only)



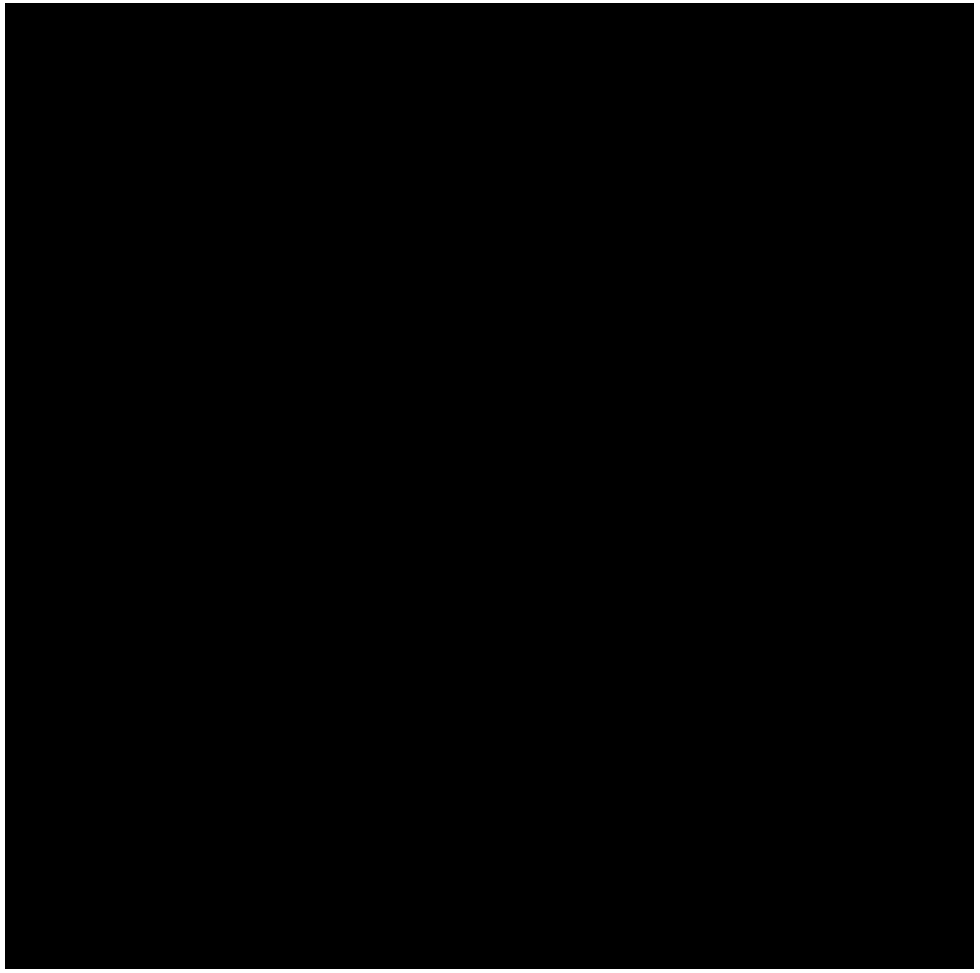
HPC Performance (fluid flow only)



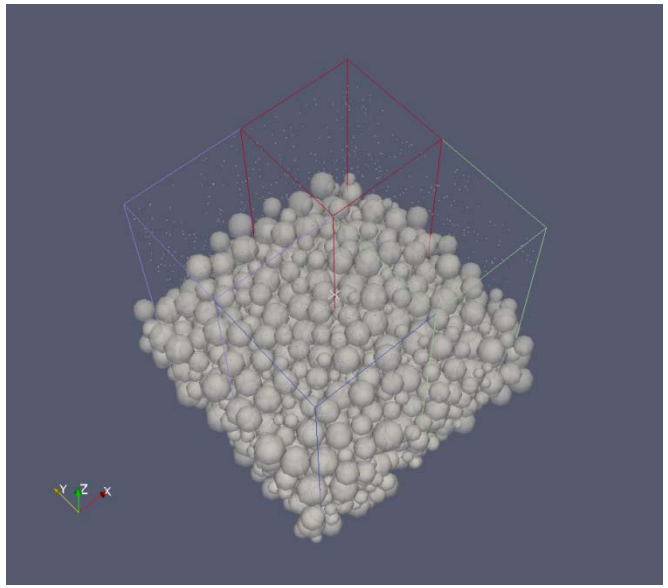
Gravel-Bed Packing



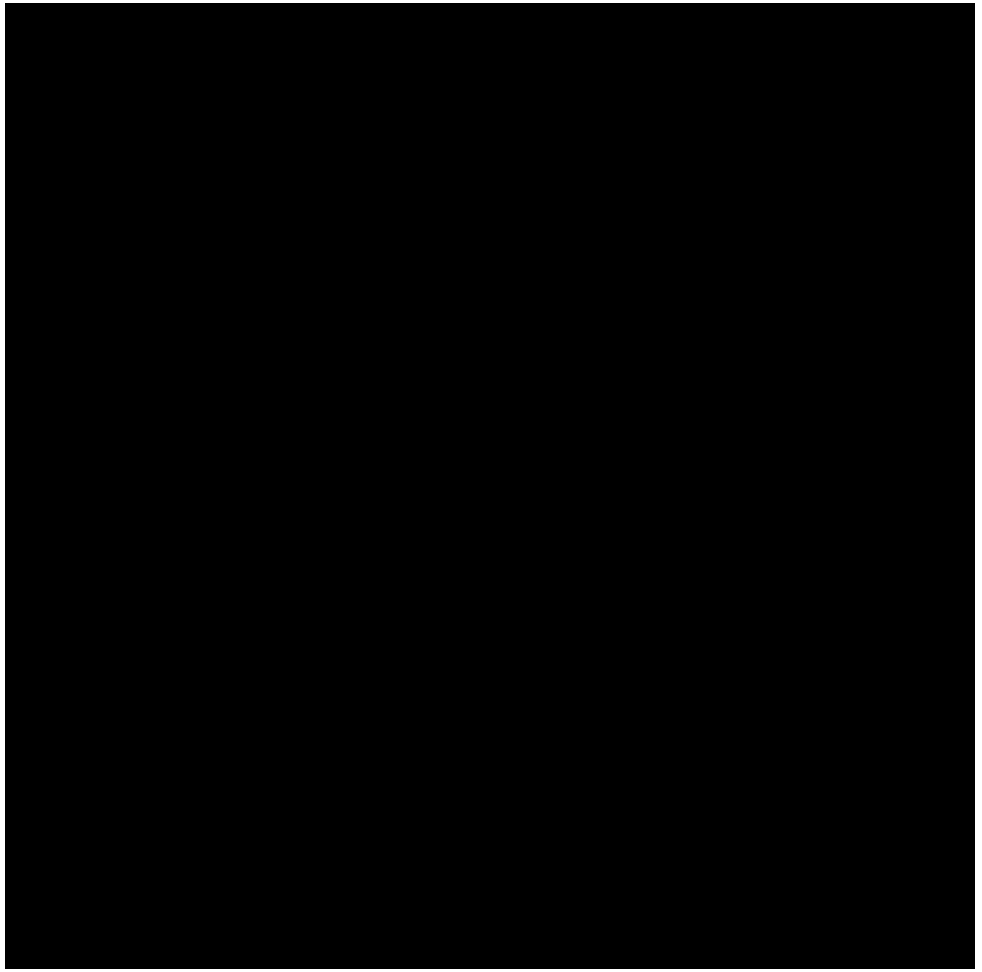
domain decomposition (9 cores)



Sand Infiltration



domain decomposition (4 cores)

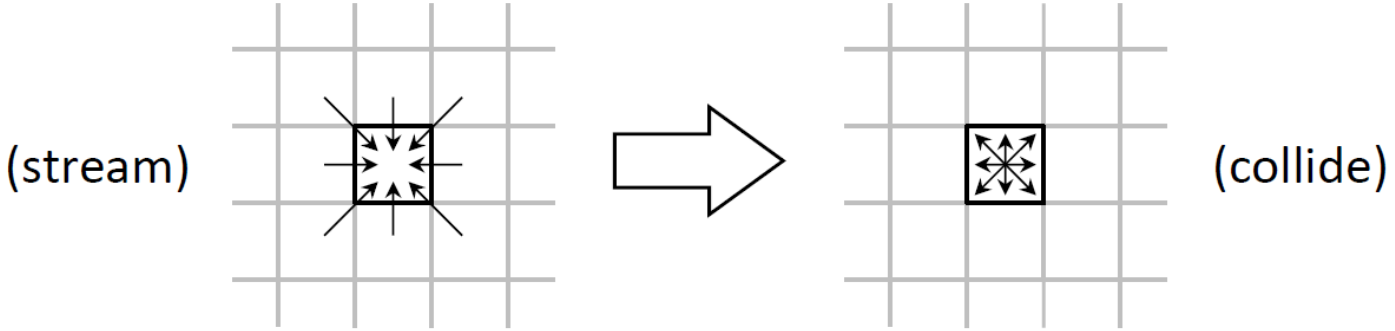


Thanks for your Attention!

??? Questions ???

Lattice Boltzmann Method (LBM)

- Operates on uniform grid with multiple particle distribution functions per cell (D2Q9, **D3Q19**, D3Q27, …)
- Explicit method (no iterations necessary)
- Two steps: **stream** (neighbors) & **collide** (cell-local)



- For the collision, different operators exist: SRT, **TRT**, MRT
- Macroscopic quantities (velocity, density, …) can be calculated from the particle distribution functions