**Microscopic Swimmers**

**pe - Rigid Body Dynamics**
- Framework for physically accurate and virtual reality multibody simulations
- Highly flexible, massively parallel implementation
- Fully resolved objects (e.g., spheres, boxes) ...
  - ... can be easily exchanged
  - ... based on Newton’s mechanics
- Connections between objects can be ...
  - ... soft constraints (e.g., spring-damper systems) or
  - ... hard constraints (e.g., hinges)

**waLBerla - Fluid Simulation**
- Widely applicable Lattice Boltzmann solver from Erlangen
- Framework for physically correct fluid simulations
- Large-scale, MPI based parallelization
- Equidistant, (block-)structured lattice grid
- D3Q19 velocity phase discretization model
- No-slip walls for the channel domain

**Coupling pe and waLBerla**
- Algorithm 1: Coupled LBMPE solver for the swimmers
  1. \( \text{Mapping step} \)
  2. for each swimmer \( i \) do
  3. Map \( R_i \) to lattice grid
  4. end for
  5. \( \text{Reynolds number constraint} \)
  6. for each lattice cell \( x \) do
  7. \( \text{Stream and collide} \)
  8. end for
  9. \( \text{Time step in the single swimmer simulation} \)
  10. for all rigid bodies \( x \) do
  11. \( \text{Apply external forces} \)
  12. \( \text{for each contact} k \) do
  13. \( \text{Determine action constraint forces} \)
  14. \( \text{end for} \)
  15. \( \text{Time integration} \)
  16. for each rigid body \( x \) do
  17. \( \text{Apply forces} \)
  18. \( \text{Update position and velocity} \)
  19. \( \text{end for} \)
  20. \( \text{end for} \)

**Results**
- Largest multibody simulation: 2 billion rigid bodies!!
- Largest fluid simulation: 32 billion fluid cells!!

**Prerequisites**
(exemplified on a three-sphere swimmer)
- Connections between objects are most commonly modeled as ...
  - Stiff rods ...
  - Springs
  - We have: Spring-damper systems
  - Force protocol
  - Cycling strategy

**Modeling of the Swimmer**
(exemplified on a three-sphere swimmer)
- External force pulse

**Stability and Validity**
- Propulsive motion

**Design Parameter Study**
- Total swimming distance after 5 swimming cycles with appropriate Reynolds number \( \text{Re} \) of each of the three bodies and of the total swimming device
  \[ \Delta t = \text{covered distance of the swimmer after one swimming cycle} \]

**Outlook**
- Investigate behavior of more than one swimmer
- Resulting large flow field (no wall effects) needs to be capable of handling parallelized springs
- Determine fastest configuration of one single swimmer (e.g., optimal armlength) with help of several parameter studies
- Detailed validation in fluid

**Contact:** Kristina.Pickl@informatik.uni-erlangen.de

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A. Najafi and R. Golestanian: Simple swimmer at low Reynolds number: Three linked spheres.
C.M. Pooley and J.M. Yeomans: Lattice boltzmann simulation techniques for simulating microscopic swimmers.

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