Distributed Memory Fluid-Solid Interaction Simulations via Chrono::HPC

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Research Goal

To design and develop Chrono::HPC. A distributed memory framework for large-scale fluid-solid interaction simulations.

Fluid Model

- Smoothed Particle Hydrodynamics (SPH).
- Runge-Kutta 2nd Order.
- Wall Boundary with Boundary Condition Enforcing (BCE) markers (Figure 6).
- Periodic Boundary Condtion (Figure 1)

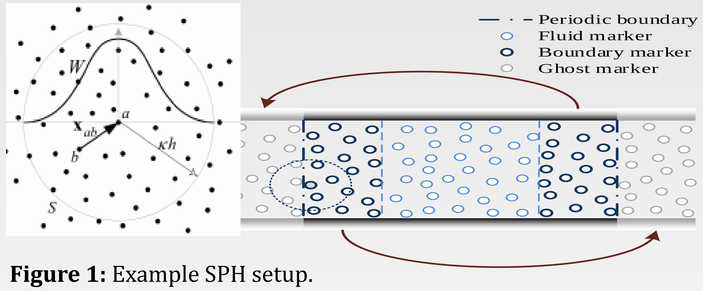


Figure 1: Example SPH setup.

Parallel Model

- *Charm++ Parallel Programming Framework/Paradigms:* Over decomposition, migratability, and message-driven execution.
- *Hybrid decomposition:* Spatial + Force decomposition. Inspired by NaMD.
- *Cell/Bin Chare:* Contains data. Takes care of force reduction, time integration and particle migration to neighbor cells.
- *Compute Chare:* Compute interactions within a Cell or between neighbor cells.

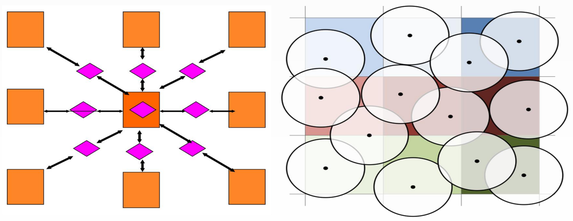


Figure 2: Hybrid decomposition: cell chares (orange) and compute chares (pink) (left). Particle grouped by cell, showing the interaction radius (right).

Experiments and Results

- *Dam Break Simulations*

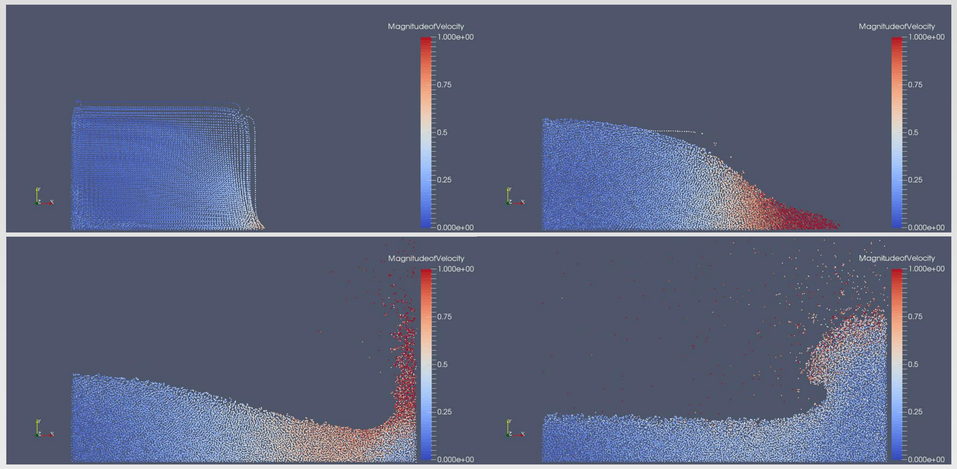


Figure 3: Dam break simulation (139,332 SPH Markers).

- *Hyper Parameter Search*

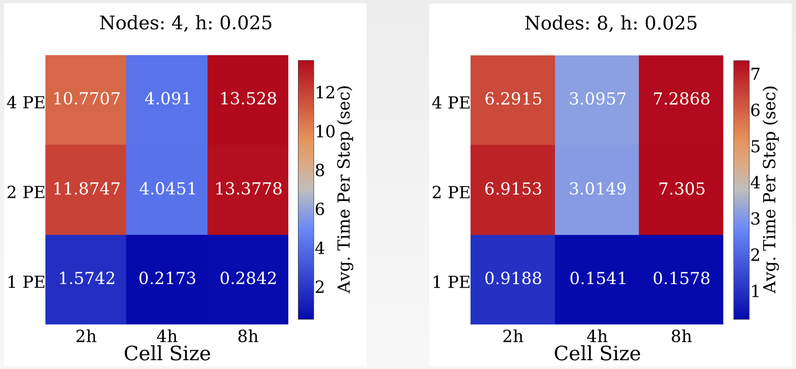
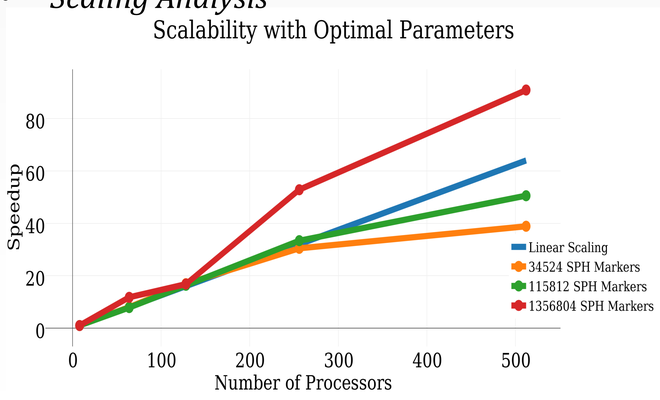


Figure 4: Hyper parameter search for optimal cell size and Charm++ nodes per physical node. Nodes denotes physical nodes (64 processes per node), and h denotes the particle interaction radius.

- *Scaling Analysis*



GPU Speedup	
# Markers	Speedup
34,524	95x
115,812	140x
1,356,804	135x
9,548,644	O.O.M

Figure 5: Speeups calculated with respect to an 8 processors run. *Left*: Scaling analysis from 8-504 processors. *Right* GPU speedups.

Computational Resources

- *Euler at SBEL:* NVIDIA GPU Nodes (14x), AMD CPU Nodes (16x) - 4 x AMD Opteron 6274 2.2GHz 16 core processor
- Tesla K40

Future Work

- Generalized Wall Boundary Condition (Improve Stability and Accuracy).
- Further scaling analysis and comparison with MPI codes.
- Fluid-Solid Interaction leveraging Chrono.

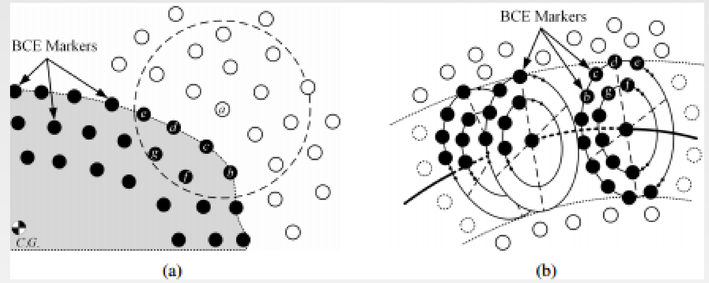


Figure 6: BCE Markers for FSI with rigid (a) and flexible (b) bodies..

References

[1] http://charmplusplus.org

[2] L. Kale, et al. "Charm++ for productivity and performance". PPL Technical Report, 2011.

[3] A. Pazouki, et al. "A high performance computing approach to the simulation of fully resolved coupled fluid-multibody dynamics systems with free surfaces". Archive of Mechanical Engineering, 2014

Acknowledgements

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