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A fictitious domain finite element method simulating particulate flows and reactions with overlapping mesh technique and GPU acceleration

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ABSTRACT

The direct numerical simulations of particulate flows and reactions are critical to obtaining detailed insights into many problems in science and engineering. Fully resolved simulations treat the moving particles as finite-size objects instead of point sources to achieve more accurate flow and reaction results. The family of fictitious domain finite element methods are suitable for these occurrences because they are free of remeshing. However, for many flow and reaction problems, resolving the boundary layers around particles' surfaces are significant, so most of the existing fictitious domain method are not well competent because of the lack of body fitted meshes.

To deal with this problem, an overlapping mesh treatment is added to the traditional fictitious domain method in this work. Spherical (circular in 2D) minor mesh is generated on each particle and its vicinity, which is immersed in a Cartesian background mesh. Chorin's projection method is adopted to solve flow, species and energy equations on both minor grids and background mesh. $P2-P1$ finite element spaces are used for velocity-pressure coupling, and other scalars are discretised by $P2$. The information between the two types of grids are transferred as Lagrange multipliers in each time step. This method is of good geometric flexibility, high boundary accuracy and low computational cost.

To achieve higher efficiency, the method is implemented as a GPU program using CUDA. A 14.8 speed-up ratio is observed between GPU program with double precision floating point numbers on a Nvidia(R) GeForce(TM) GTX 460 graphic card and CPU program on an Intel(R) Xeon(R) E5620 CPU.

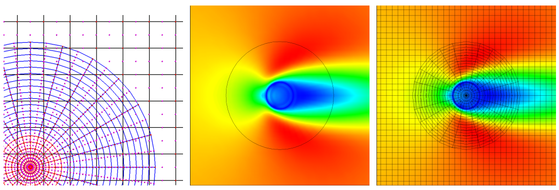

Figure 1. Overlapping mesh and velocity contours of flow past a particle

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