2018-00391 - PhD - Fluid-Structure Monolithic Models on Parallel Hierarchical-Chimera Grids

Level of qualifications required : Graduate degree or equivalent
Function : PhD Position

About the research centre or Inria department
We aim at a step change in numerical modeling in order to answer actual industrial needs. Our goal is to implement these new models in performing codes on HPC infrastructures and to make them available to respond to societal needs. We do that by developing two fundamental enablers: reduced-order models and Cartesian grid methods. Thanks to these enablers it will be possible to transfer complexity handling from engineers to computers, providing fast, on-line numerical models for design and control.

Context
The methods developed in the MEMPHIS team allow the simulation of complex multi-physics phenomena by appropriate modelling [1-5], automatic implicit geometry representation, hierarchical Cartesian schemes and parallel simulations.

Hierarchical Cartesian schemes allow the multi-scale solution of PDEs on non-body-fitted meshes with a drastic reduction of the computational setup overhead. These methods are easily parallelizable and can efficiently be mapped to high-performance computer architectures. They avoid dealing with grid generation, a prohibitive task when the boundaries are moving and the topology is complex and unsteady. Moreover, they simplify the data management, reduce the memory footprint and enhance the parallel performance. Indeed, in the linear octree framework that we develop, only the tree leaves are stored in a linear array, with a considerable memory advantage. The mapping between the tree leaves and the linear array as well as the connectivity graph is efficiently computed thanks to an appropriate space-filling curve. Concerning parallelization, linear octrees guarantee a natural load balancing thanks to the linear data structure, whereas classical non-structured meshes require sophisticated (and moreover time consuming) tools to achieve proper load distribution (SCOTCH, METIS etc.). On the other side, using unfitted hierarchical meshes requires further development and analysis of methods to handle the refinement at level jumps in a consistent and conservative way, accuracy analysis for new finite-volume or finite-difference schemes, efficient reconstructions at the boundaries to recover appropriate accuracy and robustness.

Assignment
Work Plan :

Task 1 : We intend to conceive schemes that will simplify the numerical approximation of problems involving complex unsteady multimaterials [2-4] together with multi-scale physical phenomena. The core idea is to use an octree [1] background grid for the field solution and an overset body-fitted mesh near the relevant boundaries. The geometries of interest will be captured by level set functions and local body fitted meshes. A first goal of the PhD is to generate this grid will be to handle ray-tracing and the distance function equation and the surface triangulation. In the linear octree framework that we develop, the tree leaves are stored in a linear array, with a considerable memory advantage. The mapping between the tree leaves and the linear array as well as the connectivity graph is efficiently computed thanks to an appropriate space-filling curve. Concerning parallelization, linear octrees guarantee a natural load balancing thanks to the linear data structure, whereas classical non-structured meshes require sophisticated (and moreover time consuming) tools to achieve proper load distribution (SCOTCH, METIS etc.). On the other side, using unfitted hierarchical meshes requires further development and analysis of methods to handle the refinement at level jumps in a consistent and conservative way, accuracy analysis for new finite-volume or finite-difference schemes, efficient reconstructions at the boundaries to recover appropriate accuracy and robustness.

Task 2 : As for the models to be solved, the thesis will be focused on the common modelling issues of compressible [5] and incompressible materials [6], in particular for the transmission conditions at the octree/body-fitted mesh interfaces and their efficient parallel implementation. A second task will be thus to carefully investigate these transmission conditions at the octree/body-fitted mesh using appropriate interpolation (possibly conservative) methods that can be derived as a starting point from our previous experience in non-fitted body boundary conditions.

Task 3 : The octree/overset approach modeling will be applied to multi-material models that are fully Eulerian and where the hyperelastic constitutive laws are classical (Neo-Hookean/Mooney-Rivlin). There are applications where the different physical phenomena are affected by drastic changes of the sound speed or, in general, of elastic waves speeds. These waves can travel at different speeds due to the local stiffness of the material. We are currently developing multimaterial schemes capable of dealing with such difficulties and the last task of the thesis will be to extend these approaches on non-uniform overset meshes.
This work plan will be adjusted with the PhD student.

The developments will be perpetuated in a unified computational framework that has recently been developed within the Memphis team at Inria (please see examples of realizations at https://team.inria.fr/memphis/).

Main activities

Keywords: Hierarchical meshes, overset meshes, multimaterial models

References:


Skills

Required knowledge: master in applied mathematics, engineering with scientific computing background.

Benefits package

- Subsidised catering service
- Partially-reimbursed public transport

Remuneration

1982€ / month (before taxes) during the first 2 years, 2085€ / month (before taxes) during the third year.