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Heterogeneous Coupling in Computational Aeroacoustics

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ABSTRACT

The coupled simulation of aeroacoustics, generated by the flow of compressible fluid, is a multiscale problem resulting in different numerical requirements for sound generation and sound propagation. For the propagation of the soundwaves it is sufficient to solve the linearized Eulerian equations on a coarse discretization. On the other hand the sound-generating flow includes non-linear effects, maybe also viscosity, i.e. the full compressible Navier-Stokes equations have to be solved. It also has to be computed on a very fine computational mesh, in order to catch all physical phenomena in this flow.

This contribution aims at solving hybrid applications like multiscale aeroacoutics on modern hardware architectures. The basic idea is to map the hybrid applications with their hybrid, maybe competing requirements onto hybrid hardware architectures. This enables us to solve larger problems.

To enable such fluid dynamic simulations including the aeroacoustic field, the coupling code KOP3D [1] was developed at the Institute for Aerodynamics and Gasdynamics, University of Stuttgart. It allows the tight coupling of domains with different equations as well as different discretizations. Several discretization schemes (Finite Volume, Finite Differences, Discontinous Galerkin) are implemented, in two distinct modules, one for unstructured meshes and one for structured. An explicit high order time marching scheme is used to evolve the instationary compressible flows, resulting also in different time steps in the different domains. This is handled by subcycling techniques. The variation of all those parameters results in domains with very different numerical requirements.

The typical setup is an object with arbitrary geometry in a high velocity flow. The flow around the object is computed on an unstructured mesh with high resolution and the Discontinous Galerkin discretization scheme. This domain is kept as small as possible and embedded in a domain with a structured mesh.

Finally this setup is surrounded by a coarse structured mesh with Finite Differences for the linearized Eulerian equations to simulate the propagation of sound waves in the far field.

KOP3D has been parallelized with MPI and has a hierarchy of two levels in the parallelization. The first level is the definition of partitions given by the application and its distinct requirements on equations and/or grid resolution. Each of these partitions forms a natural work package, that might be run in parallel to all other domains. This can be seen as a heterogeneous domain decomposition. The second level is the decomposition of each domain itself into several partitions. These partitions form a (standard) homogeneous domain decomposition. These domains are rather tightly coupled and need to exchange data in each time step. On the other hand, data exchange between the level-1 partitions is necessary only at common time levels, typically determined by the coarser domains.

In this work we map these different requirements onto different hardware capabilities. At HLRS (High Performance Computing Center Stuttgart), different platforms are available, and the idea is to use the optimal platform for each part of the simulation according to its requirements. By using the several resources in an efficient way, we solve large problems, that may not be feasible in any other way.

For the necessary heterogeneous parallelism we use the PACX-MPI library [2], developed at HLRS. This library acts as an intermediate layer between the application and the native MPI library on the involved clusters. It takes care of the communication between the different clusters, including data conversion if neccessary. All this is done transparently, the application has not to be changed. It just has to be re-linked against the PACX-MPI library. With this mechanism it becomes possible to access the processors of different clusters without leaving the MPI context in the application.

Taking advantage of the heterogeneous layout in KOP3D we show in this work, how it is possible to distribute the computation in the heterogeneous super computing environment. The paper shows application examples and performance results. The problem of a suitable load balancing is also adressed. Resulting in a framework that allows us to make use of hardware characteristics as necessary, thus gaining computational efficiency which is needed for applications in aeroacoustics and other multiscale or multiphysics applications.

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