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Development of a Multi-Block Interface for a High-Order Compact Scheme Applied to Sound Scattering Problems in Aeronautics

Part II: 2-D Parallelization Strategy and Efficiency

Context

This HPC-Europa2 project follows up from a previous HPC-Europa2 visit (1), to develop a novel computational aeroacoustic code.

Objectives

The objectives of this HPC-Europa2 project are to build an efficient MPI parallelization for a new finite-difference compact two-dimensional code and to test its efficiency and scalability on the CINECA's IBM Power 6 machine.

Methodology

The compact finite-difference approximation of the spatial derivatives in the code makes their parallelization challenging and non-trivial. The parallelization is achieved by domain decomposition, as shown in Figure 1. The x and y axes are divided, respectively, in m and n segments, to obtain a total of $m \times n$ blocks. This

Fig. 1. – Domain decomposition and communication scheme with 4 blocks ($m = n = 2$).

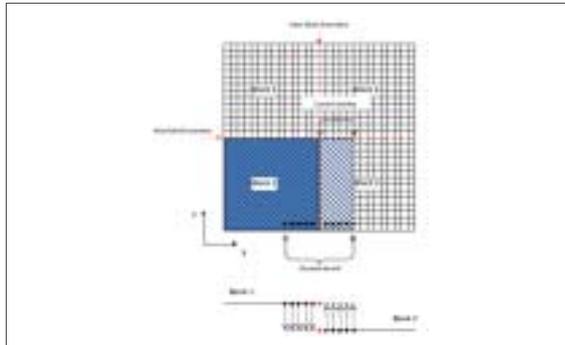


Fig. 2. – L_2 norm error versus N (linear number of grid points).

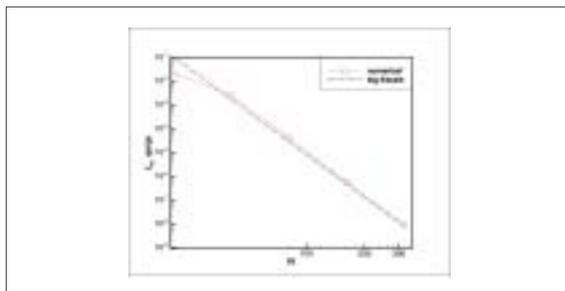
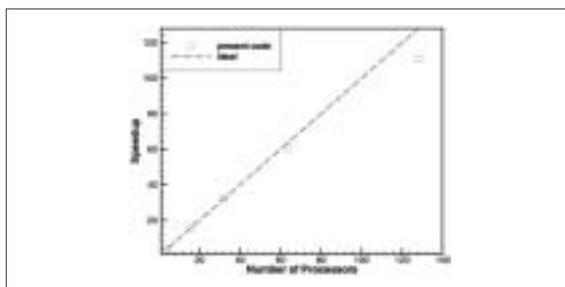


Fig. 3. – Speedup versus number of processors, computational domain with fixed total number of grid points (503×503).



multi-block parallel computation uses one processor per block and the method of communication between adjacent blocks is by finite-sized overlaps. At every time step, the solution is computed independently in each block with individual interior and boundary formulae as in single-block computations. The number of points in the interface overlap region is 5. This is driven by the specific choice of the finite-difference approximation of the spatial derivative along the inter-block boundaries. This is estimated by a central explicit 11-point stencil that mimics the performance of the compact interior scheme over the resolved range of wavenumbers (3). The scheme has been tested to be stable and accurate on general curvilinear meshes and viscous flows (2, 3).

The Linearized Euler Equations (LEE) are time-advanced using an explicit four-stage Runge-Kutta (RK) time marching scheme. Data are exchanged between adjacent blocks at the end of every RK stage. The structured mesh of the finite-sized overlap region gives an envelope of communication of constant size. This enables to use MPI persistent calls, to speed up the communication.

Achievements

Figure 2 shows the L_2 norm error of the non-dimensional density perturbation between the analytical and the numerical solutions of a two-dimensional acoustic pulse propagating in an unbounded domain (1), on progressively refined computational meshes (4). The same results were obtained using the multi-block code with 4 and 16 blocks. The rate of the numerical error roll-off is parallel to the $-6 \log(N)$ black dashed line, showing that the code preserves its design sixth-order accuracy with inter-block boundaries.

Figure 3 shows the computation speedup versus the number of processors on the SP6 machine, measured by instrumenting the code with system clock calls and SCALASCA. The speedup indicates that the wall-clock time decreases almost linearly with the number of processors. This is possible because the MPI time per time step is a small fraction of the computational time and because the communication network of the SP6 uses an Infiniband low latency high bandwidth network.

References

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- (4) I. SPISSO, A. RONA, E.H. GEORGIOULIS, *Towards a monotonicity-preserving inviscid wall boundary condition for aeroacoustics*, AIAA 2009-3179, 15th AIAA/CEAS Aeroacoustics Conference, Miami, FL, May, 2009.