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CASE STUDY REPORT

Parallel Solution of Compressible Navier-Stokes Equations

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***Company** accepts that the Case Study Report is shared with the EuroCC Project and the community through the EuroCC@Turkey awareness creation activities and platforms.

1 Problem Identification

Currently, companies are investing millions of dollars on commercial CFD software licenses, with this case study we plan to investigate the capabilities of open source CFD tool (OpenFOAM) compared to experimental data available in the literature. To investigate this, we are planning to use transonic ONERA wing problem. We are also

going to study the robustness and parallel scalability of the existing sparse linear system solvers in OpenFOAM (an open source CFD code) for ill-conditioned problems that arise in the numerical solution of compressible Navier-stokes equations on TRUBA HPC platforms. In this case study we will not develop a new code. Solution of ill-conditioned sparse linear system of equations is often a bottleneck in numerical study of compressible flow problems. This is true both for direct and iterative linear system solver. For the direct solvers, ill-conditioning implies an excessive need for pivoting which hampers the parallel scalability. The preconditioned iterative solvers, on the other hand, are likely to fail converging or require an excessive number of iterations.

In this case study, the two faculty members will be advising/consulting the company.

2 First Suggestion

We expect to follow the following steps and the timeline for the duration of the case study (total 6 months):

a Getting an account on TRUBA, installing the latest version of OpenFOAM and testing the installation (0.5 month) .
b Identifying challenging compressible Navier-Stokes problems and setting up OpenFOAM to solve them (1.5 months).
c Studying the robustness and parallel scalability of the existing linear system solvers in OpenFOAM for the test problems (3 months).
d Studying the results further in order to suggest improvements for sparse linear system solvers (1 month).

3 Solution Stage – I

a Installation of OpenFOAM
b Testing the installation on TRUBA
c Setup of the OpenFOAM compressible solver
d Extraction of the sparse linear systems and applying existing solvers
e According to the final output, suggesting how to improve the sparse linear system solvers

4 Solution Stage – II

We do not foresee a second solution stage.

5 Results and Achievements

Krylov subspace methods based on Generalized Conjugate Residual method as outer iteration provides speed improvement over the inner Krylov subspace method [3]. Although there are flexible preconditioned and other variations of GCRO method given in [4], [5] and various papers, the GCRO-DR method[1] is implemented in HiSA and Octave. Numerical experiments are performed on a finite volume method (FVM) discretized matrix Venkat01, and a Jacobian matrix of the FVM discretization (GT01R) which are obtained from the SuiteSparse matrix collection [2]. The computing platform is TRUBA's Barbun cluster with max. 3 nodes and in each node there are Intel Xeon Scalable Gold 6148 processors with 384 GB of memory. The cluster is connected via EDR(100GBS) Infiniband network cards with non-blocking structure.

Sparsity pattern of Venkat01 and test results are given in Figures 1 and 2, respectively. As seen in Figure 1, a slight speed improvement is achieved using GCRO-DR method.

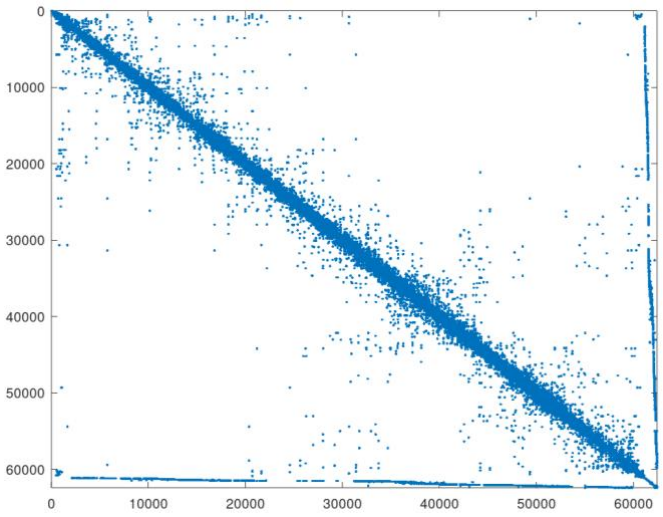

Figure 1. Sparsity pattern of Venkat01

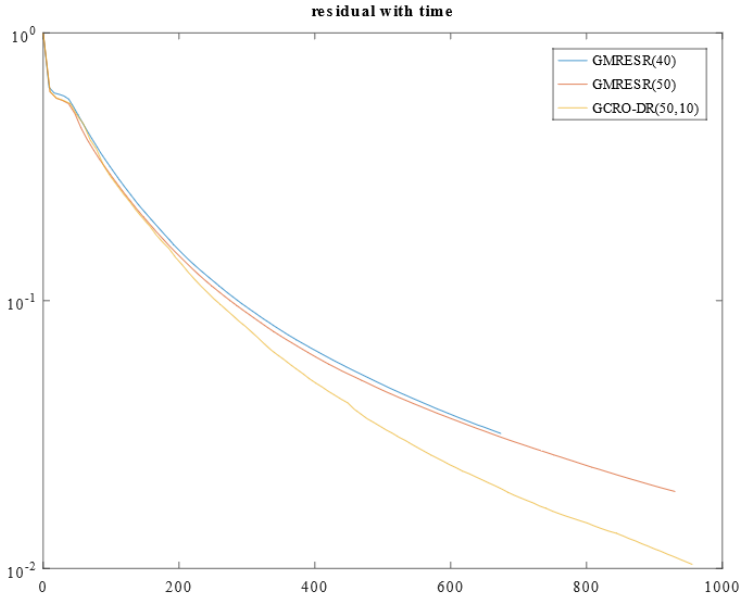

Figure 2. Residual history of Venkat01 while solving the system with GMRES and GCRO-DR (in pharanthesis restart and recycled subspace dimensions are given)

Sparsity pattern of GT01R and test results are shown in Figures 3 and 4, respectively. Since Jacobian matrices are nearly singular as a characteristic, GMRES and GCRO-DR solvers stagnate and do not converge. Using ILU(0) preconditiner on the matrix results in the divergence of both solvers. The preconditioned system can only can be solved by increasing the restart value substantially. Hence, increasing cost per iteration as well as the memory requirement.

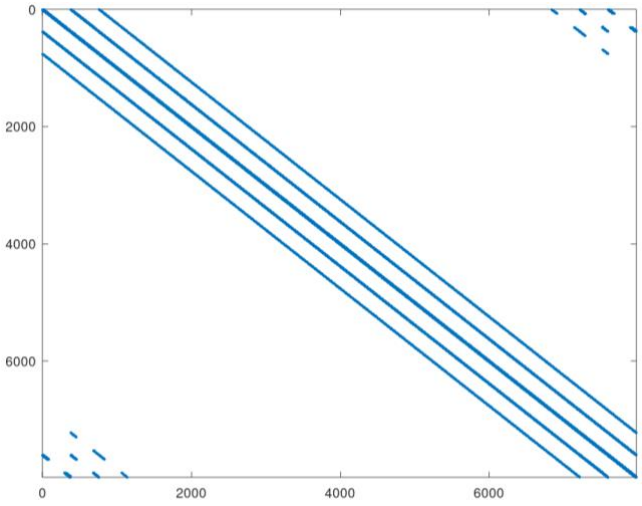

Figure 3. Sparsity pattern of GT01R

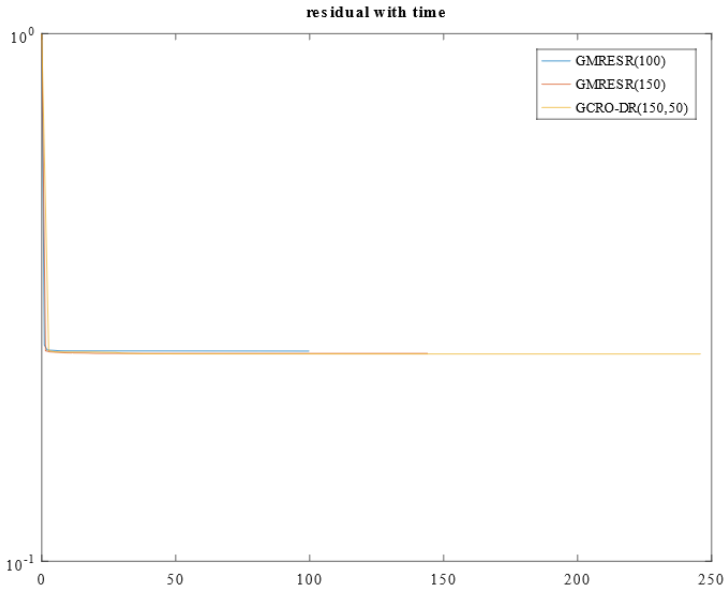

Figure 4. Residual history of GT01R while solving the system with GMRES and GCRO-DR

HiSA's GMRES solver scalability is studied using a RAE case. Case is modeled with Spalart Allmaras turbulence model using a first order convective scheme, and second order cell to face interpolation scheme. Discretized geometry has 5 million cells and far-field velocity is 0.9 Mach. Figure 5 shows almost linear speedup proportional to parallel solver process count.

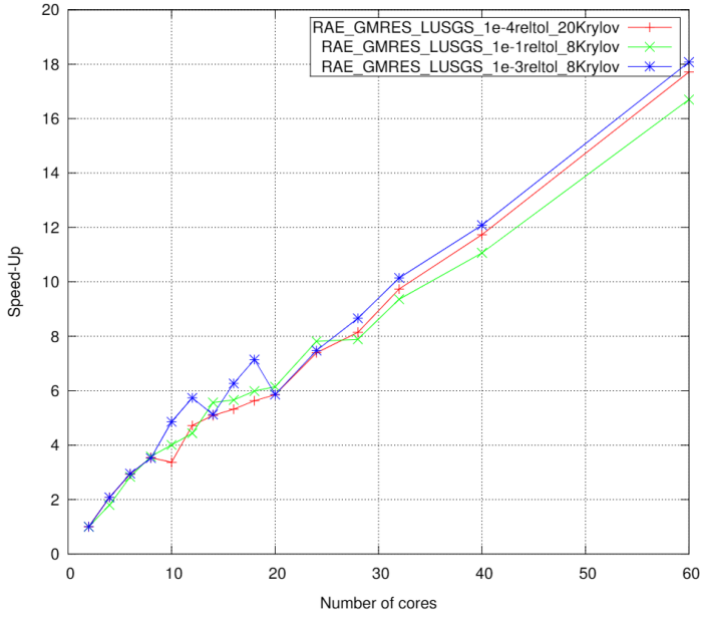

Figure 5. HiSA GMRES solver speedup with parallel process count

In this case study, we have studied the parallel solution of venkat01 and GT01R problems using an alternative Krylov subspace method, namely GCRO-DR. We have compared GCRO-DR against restarted GMRES for the test problems and observed that it has some advantage in terms of the number of iterations for solving venkat01 problem. The results show that GCRO-DR could be a viable alternative to GMRES and could be implement in parallel as a future work. Furthermore, we have also demonstrated the parallel scalability of the existing parallel GMRES implementation in HiSA on TRUBA's computing platform.

References

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