Analysis and Improvment of Corner Force Computation in BLAST

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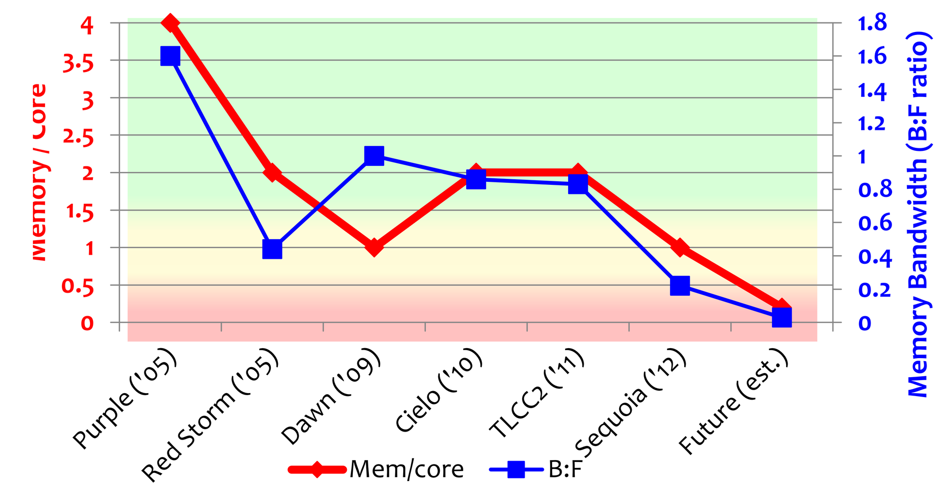
Abstract

The goal of the SHOCX project is to develop a new multiphysics coupled rad-hydro code based on higher-order finite elements. The BLAST code is the ALE portion of this project and uses both sparse and dense matrix solves for kernels. The computation of the corner-forces is a dense matrix calculation within BLAST which consumes a large percentage of the runtime. Our results show that

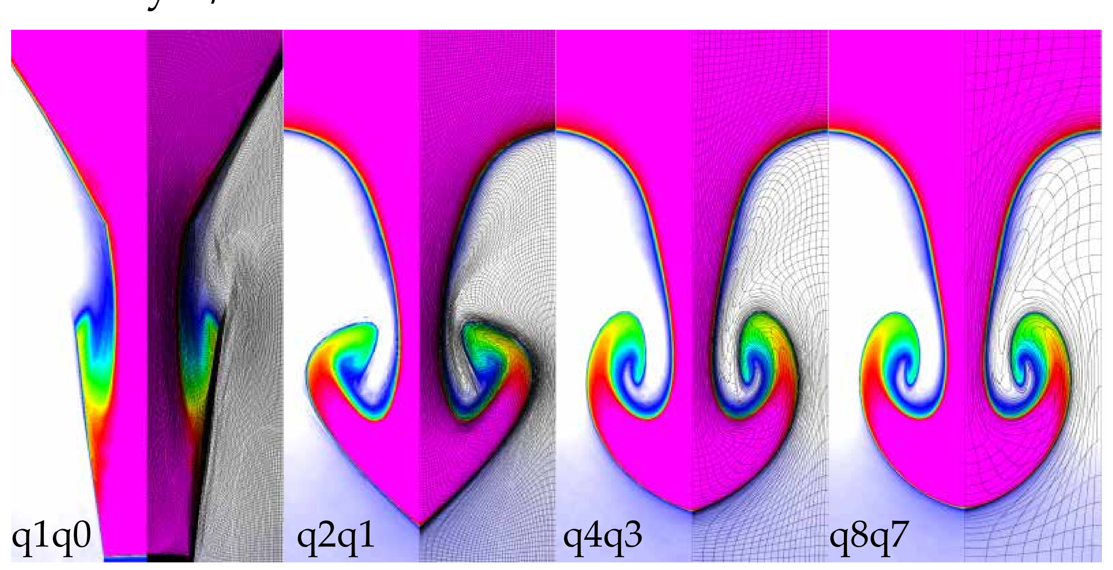
Background

Current hydrodynamics algorithms only obtain a small fraction of peak computation performance due to low arithmetic intensity (the ratio of FLOPs to number of bytes transferred). This ratio becomes more important as we look towards exascale.

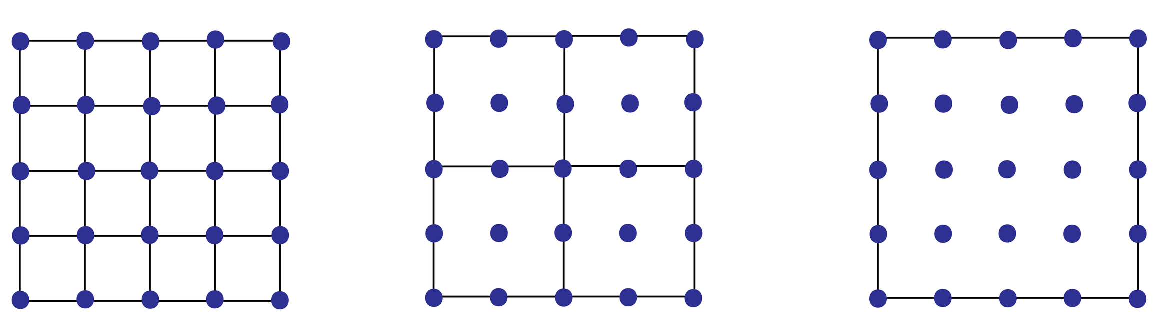


BLAST

- BLAST uses higher-order finite elements. This allows the zones to develop large curvatures while still delivering accurate results.
- BLAST can run much longer between ALE remaps than a traditional staggered grid code when it uses high order elements. BLAST executes more FLOPs per unknown as the order increases. The extra FLOPs may be "free" on future systems with low byte/FLOP ratios



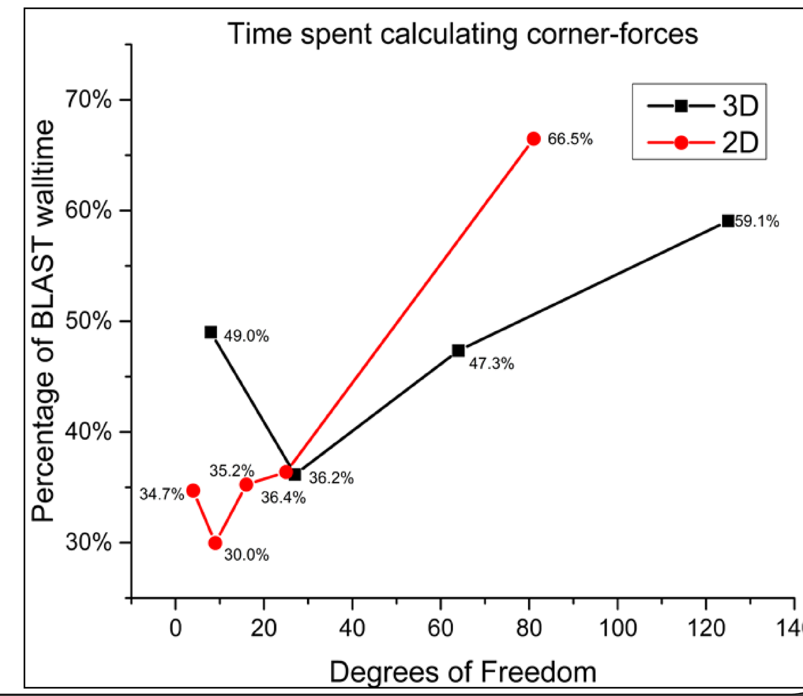
- The various methods indicate the number of kinematic degrees of freedom contained within each zone



Method	q1q0	q2q1	q4q3
2D DoFs / Zone	4	9	25
3D DoFs / Zone	8	27	125

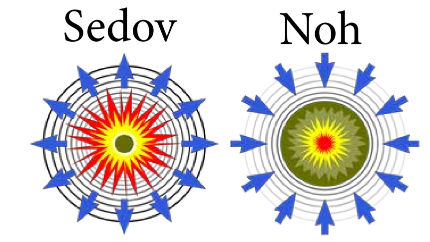
Corner Forces

One of the most computationally expensive kernels within BLAST is the calculation of the interactions between forces at the intersection of zone boundaries.



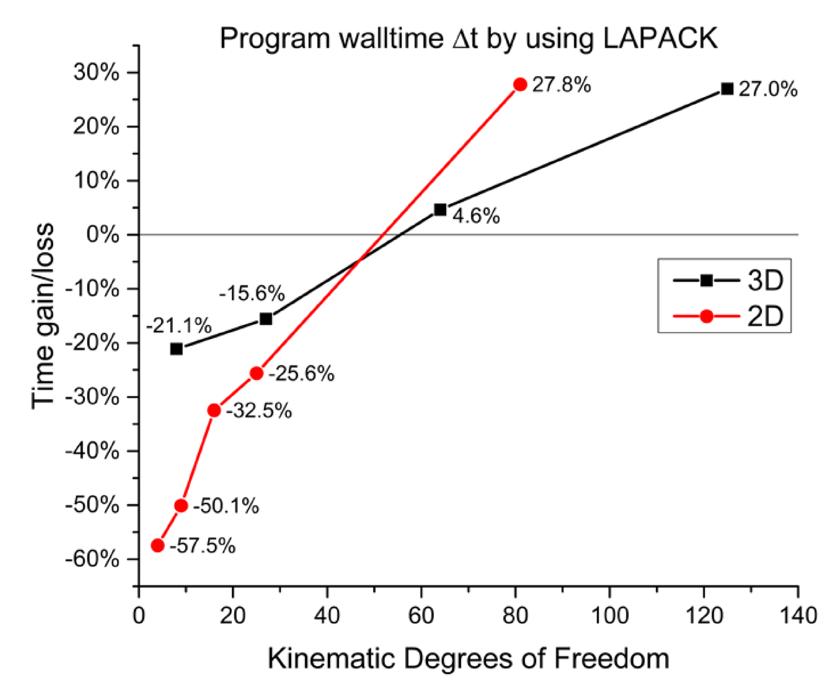
Testing Procedure

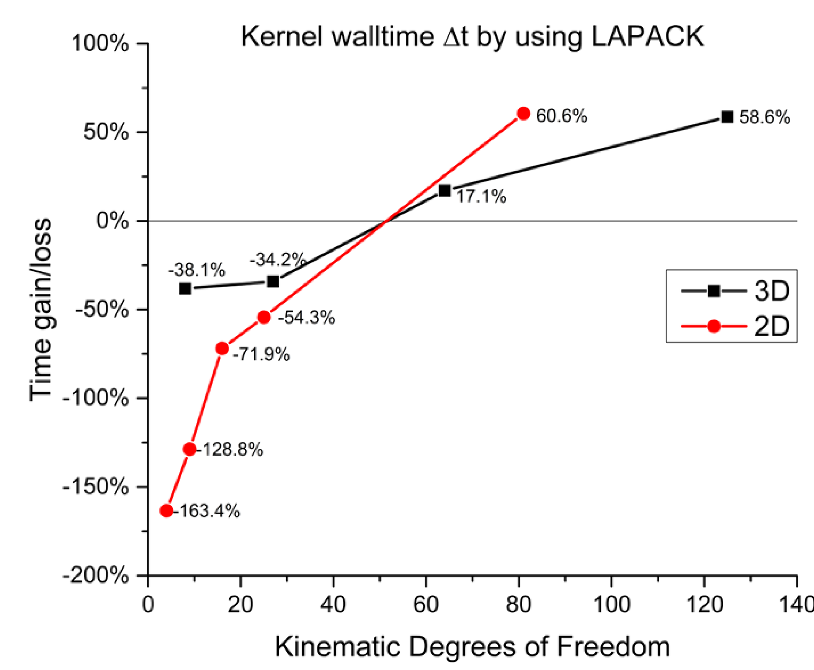
- Intel Xeon E5-2670 Sandy Bridge
- One node, 16 cores, 16 MPI tasks
- 10 Time steps at 1E-7 secs each
- Noh 3D, Sedov 2D test problems
- Results are averaged across 6400, 25600, 102400 zones for 2D
- Results are averaged across 256, 2048, 16384 zones for 3D



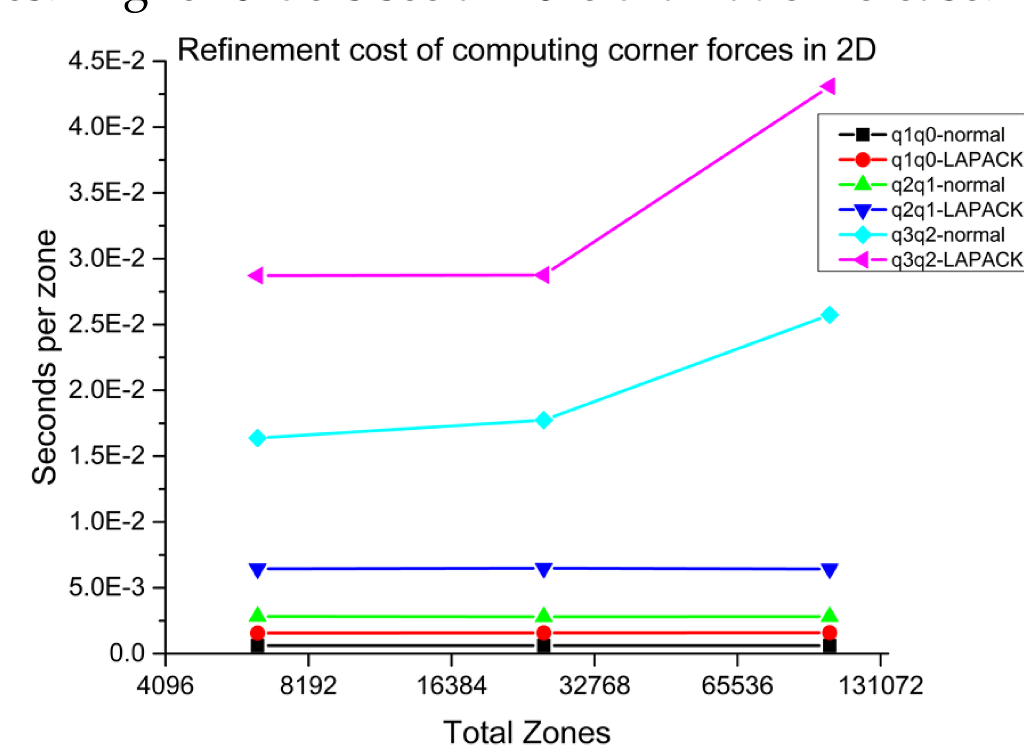
Results with Existing LAPACK Build

- LAPACK improves kernel and application execution time in higher orders, this comes with a high overhead for low orders.



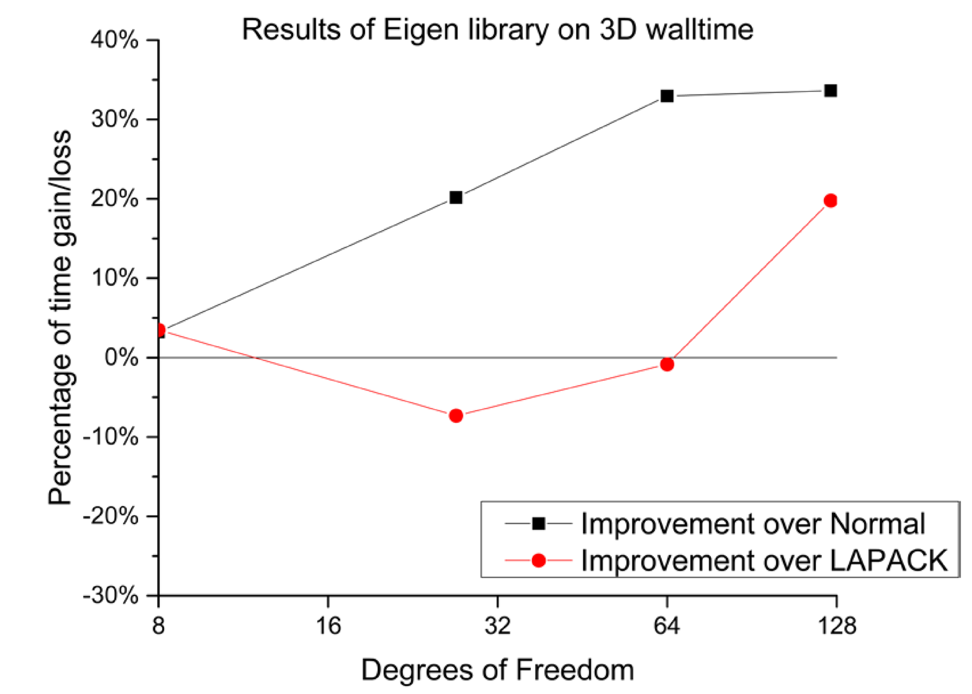


- As the mesh is refined, the amount of time spent computing the kernel forces per zone increases. Higher orders see a more dramatic increase.



Results with New Eigen Build

- The Eigen library is yet another collection of linear algebra solvers designed for HPC. By replacing only one of our dense matrix-multiply codes to use Eigen we saw noticeable improvements in 3D at higher-orders.
- Next steps will be to replace all of the major linear algebra calls with Eigen to have a more complete understanding of its impact.



Conclusions

The initial results indicate that the optimized matrix operations in LAPACK provide significant speedup at high orders (q4q3, q8q7) when overhead is not important. At higher-orders, the matrix-matrix multiplies are large enough to run at a significant fraction of peak, due to increased arithmetic intensity. However, at lower-orders a heavy weight library has too much overhead.

Future Work

- BLAST should be adaptive based on a given problem. Combining the optimized linear algebra kernels of highly-tuned libraries for large matrices with the existing hand-rolled optimizations for smaller matrices.
- Other linear algebra libraries should be examined and compared with LAPACK for a possible performance gains at higher-orders, regardless of low-order overhead. Conversely, lighter libraries should be looked at for possible use at lower-orders.
- Replace linear algebra calls with Eigen to determine its effectiveness when used throughout the code-base.
- BLAST currently relies on MFEM for many of its mathematical kernels. There is a need to examine MFEM more closely for overhead occuring from numerous nested function calls, size extraction, and inefficient loop structures.

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