REALISTIC SIMULATIONS OF THE INTERGALACTIC MEDIUM: THE NEED FOR ENZO-P/CELLO

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EXECUTIVE SUMMARY

In the continuing quest for more comprehensive models of the intergalactic medium, our research team is developing Enzo-P/Cello, the petascale fork of the widely used Enzo cosmological adaptive mesh refinement (AMR) code. Unlike Enzo, Enzo-P/Cello employs an array-of-octrees AMR mesh and is parallelized using Charm++. Here, we present the first scaling results of Enzo-P/Cello on Blue Waters showing near ideal scaling on a hydrodynamic AMR test problem to 262,000 floating point cores. This problem generates 1.7 trillion cells at four levels of refinement, making it one of the largest AMR tests ever performed.

RESEARCH CHALLENGE

Improved computational models of the intergalactic medium (IGM) are needed to extract information encoded in the high-resolution optical spectra of distant quasars. Information includes the physical state of the mostly primordial gas pervading the universe, but also the dark matter that shapes the gas into discrete intergalactic absorption line systems (the Lyman alpha forest). Standard computational models disagree with certain aspects of the observational data [1], suggesting there is some key ingredient missing in the models. Previously, we explored whether modeling the population of quasars that provide a photoionizing bath of ultraviolet radiation as discrete point sources rather than a homogeneous background could improve agreement with observations. Using the Enzo hydrodynamic cosmology code [2] enhanced with multigroup flux-limited diffusion radiative transfer, we found this change did not improve the results. We are therefore investigating our next hypothesis: that dense gas bound to galaxies that is unresolved in the Enzo simulations supplies significant absorption of the quasar light and modifies the key observables in such a way to improve agreement with observations.

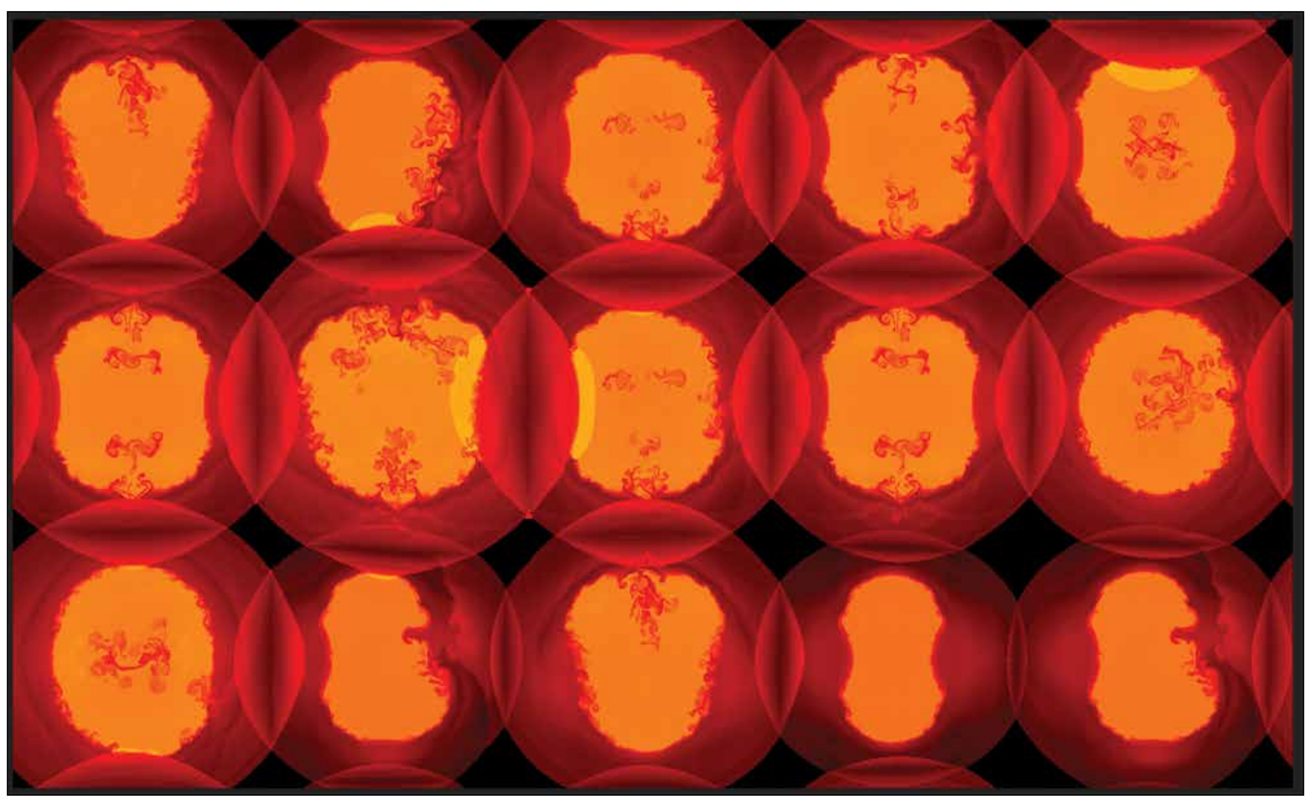

Figure 1: Small section of the Alphabet Soup weak scaling test of the Enzo-P/Cello extreme-scale adaptive mesh refinement code. The image shows interacting blastwaves sourced by an array of high-pressure regions in the shape of letters of the alphabet.

METHODS & CODES

Including galaxies in simulations of the IGM poses severe resolution requirements that can be addressed using adaptive mesh refinement (AMR) around galaxies. Enzo's AMR capability is not sufficiently scalable to permit a full-frontal assault on this problem. For this reason, we have developed a successor to the Enzo code called Enzo-P (for petascale) built on an entirely new highly scalable AMR framework called Cello. The combined code—Enzo-P/Cello [4]—uses the Illinois-developed Charm++ parallel object framework for parallelization. We have implemented the already proven scalable Forest-of-Octrees AMR algorithm [3] on top of Charm++ and have obtained excellent parallel scaling results on Blue Waters as a prelude to our target application problem.

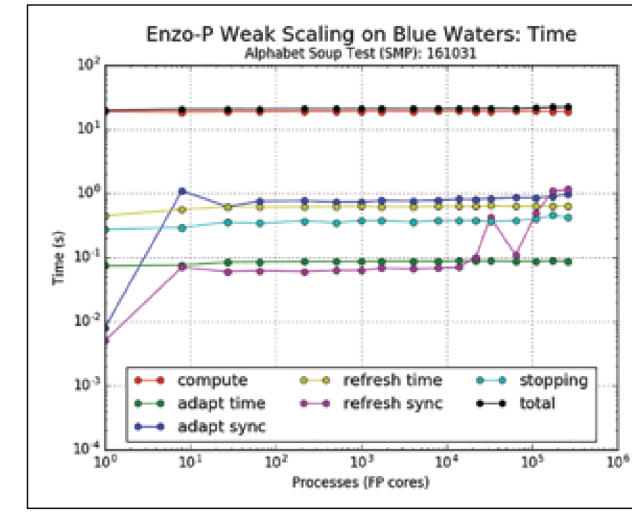

Figure 2: Weak scaling results for Enzo-P/Cello on the Alphabet Soup AMR hydrodynamics test problem. Plotted are components of the execution time per timestep per core versus floating point core count. The red line is time spent doing compressible hydrodynamics. The black line is total time including AMR and Charm++ overhead functions (other colored lines.)

RESULTS & IMPACT

We have achieved ideal weak scaling to 262,000 cores on a hydrodynamic AMR test problem we call "Alphabet Soup" involving an array of blastwaves driven by high-pressure regions in the shape of letters of the alphabet. Each core is assigned a blastwave in the N × N × N array, where N ranges from 1 to 64. The problem is evolved with AMR until the blastwaves interact. We measure parallel efficiency for both memory and execution speed, finding 100% for the former and 85% for the latter at 262,000 cores. The largest problem evolved 1.7 trillion cells representing over 52 million Cartesian blocks of 32^3 cells arranged in a 64^3 array of octrees each with four levels of AMR refinement.

Weak and strong parallel scaling tests of a cosmology test problem including dark matter particles, adiabatic gas dynamics, and self-gravity on uniform meshes as large as $4{,}096^3$ and 110,000 cores have been performed with excellent results. We are currently repeating these tests with AMR turned on, but those results were not ready in time for this report.

The significance of this work is that it provides a path to exascale for the entire Enzo community, which numbers over 100 active developers and users. The technical approach is highly innovative as well, leveraging prior developments in parallel AMR algorithms (Forest-of-Octrees) and task-based dynamic execution with Charm++.

WHY BLUE WATERS

The scale of the system and our ability to get large scaling tests approaching full system size to execute quickly and reliably accelerated our code development substantially.