



MFEM: High-order Finite Element Algorithms for Next-Generation Exascale Simulations



LLNL-TR-2017208

R&D CHALLENGE

Developing MFEM as a scalable simulation technology that can robustly serve multiple LLNL mission codes required:

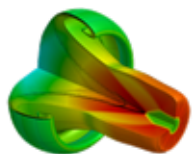
- Pushing the boundaries of research in high performance computing (HPC) and numerical methods for PDEs.
- Sustained close collaboration among researchers in multiple LLNL directorates
- Co-design between algorithm developers and application scientists targeting evolving HPC architectures
- External collaborations facilitated by open-source scientific software

APPROACH

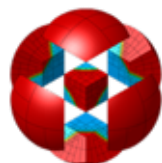
- Researched new high-order finite element algorithms that can both produce better results + scale better on modern systems
- Worked closely with scientists in WCI/SD to demonstrate simulation and HPC benefits on key classes of mission-relevant problems
- Developed state-of-the-art algorithms for high-order meshing, discretizations and solvers driven by application needs
- Advanced GPU kernels for performance at scale, developed as part of the effort in the Exascale Computing Project (ECP)
- Delivered the R&D into reusable open-source software library to enable modularity and facilitate external collaboration

IMPACT & BENEFIT

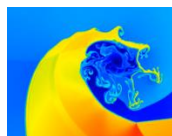
- Helped establish LLNL as a worldwide leader in finite element research for HPC
- LDRD research resulted in the next-gen BLAST code in WCI/SD, enabled other LLNL next-gen efforts, e.g. SMITH and LiDo in ENG
- Broad community adoption (100K+ downloads per year) with many external collaborators
- Supported by ASC, Office of Science, WFO, under SciDAC, Base, HPC4, SBIR, Earthshots.
- Performed largest finite element simulation to date, 55.5 trillion unknowns on 43,520 GPUs of El Capitan, earning 2025 ACM Gordon Bell Prize
- Continues to drive innovation as a main thrust in the new DMC SI for differentiable simulations



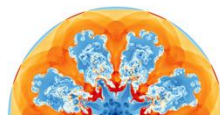
LDRD project starts investigating new finite element approaches for Lagrangian Hydrodynamics



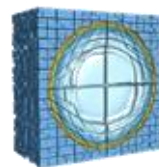
Version 1.0 of the MFEM library, developed to aid in the LDRD research, released as open-source



LDRD builds on MFEM to apply high-order methods to ALE problems at LLNL



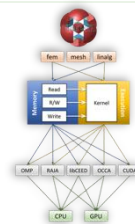
SHOCX strategic initiative focuses on multi-physics applications. Results in the MFEM-based next-gen BLAST code in WCI/SD.



Added powerful and easy-to-use adaptive mesh refinement capabilities



CEED center starts developing high-order algorithms for exascale in MFEM



Initial GPU support added in mfem-4.0



Gordon Bell Prize for tsunami simulation on El Capitan with MFEM



DMC strategic initiative starts to enable differentiable multi-physics codes based on MFEM



2009



2010



2012



2014



2015



2017



2019



2025



2026