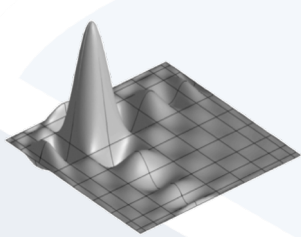
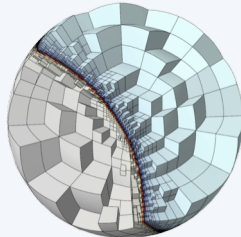


Next-gen discretizations

- PDE-based simulations on unstructured grids
- High-order and spectral finite elements
 - ✓ any order space on any order mesh
 - ✓ curved meshes,
 - ✓ unstructured AMR
 - ✓ matrix-free methods
 - ✓ optimized low-order support



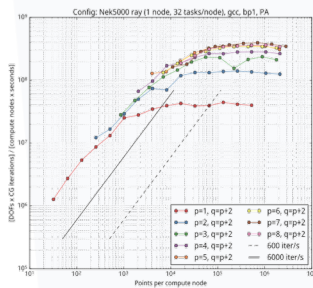
10th order basis function



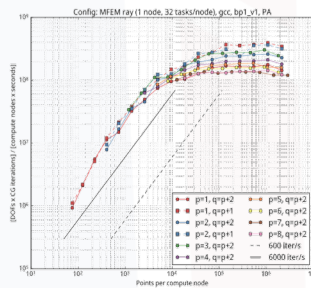
non-conforming AMR, 2nd order mesh

Why high-order?

- Better HPC
 - ✓ multiple levels of parallelism
 - ✓ inter-device parallel sparse linear algebra
 - ✓ on-device dense linear algebra
 - ✓ tensor product form → batched tensor contractions



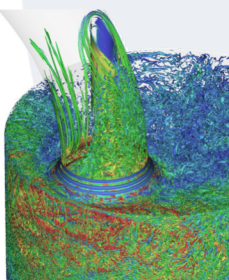
(a) Nek5000



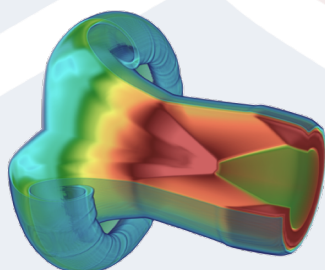
(b) MFEM

Performance vs. local size for various orders (p) on BP1

- Better science
 - ✓ ExaSMRs, MARBL – CEED’s “first wave” apps
 - ✓ ACME, Urban, ExaWind, GEOS, ExaAM, ...
 - ✓ interested in working with new applications!



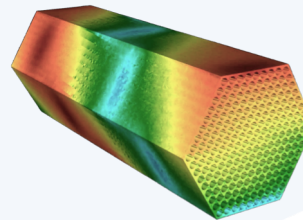
6th order DNS turbulence (Nek)



2nd order compressible shock hydro (MFEM)

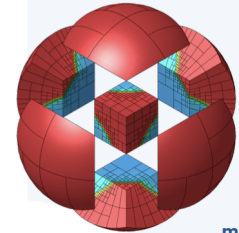
How can we help?

- CEED discretization libraries
 - ✓ based on MFEM and Nek5000
 - ✓ better exploit the hardware → significant performance gains



nek5000.mcs.anl.gov

High-performance spectral elements

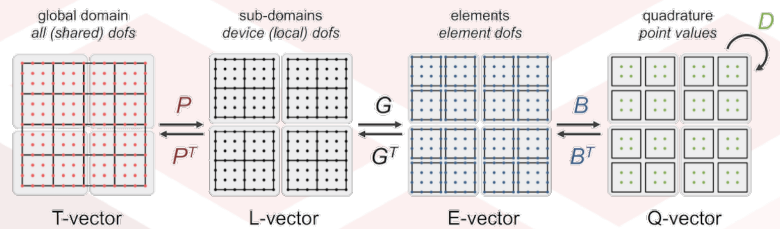


mfem.org

Scalable high-order finite elements

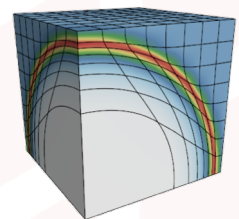
- **new** libCEED
 - ✓ new high-order API library for efficient operator evaluation
 - ✓ low-level algebraic “format” → widely applicable
 - ✓ multiple frontends and backends (CPU, GPU, ...)

$$A = P^T G^T B^T D B G P$$



Finite element operator decomposition

- Miniapps
 - ✓ Nekbone, **new** Laghos
 - ✓ CORAL-2, ECP, ASC proxies
 - ✓ NekCEM ceedling, HPGMG, ...



Sedov blast in Laghos

- Benchmarks
 - ✓ bake-off problems: BP1-BP4
 - ✓ high-order community benchmarks

- High-order simulation ecosystem
 - ✓ high-order meshing & optimization [PUMI](http://pumi.score.rpi.edu/pumi)
 - ✓ high-order physics (shock capturing, LES, monotonicity, ...)
 - ✓ scalable “matrix-free” solvers [hypre](http://hypre.org), [PETSc](http://petsc.org)
 - ✓ high-order visualization [visit](http://visit.ornl.gov), [ASCENT](http://ascend.ornl.gov), [VTK](http://vtk.org)
 - ✓ dense linear algebra on GPUs, etc. [MAGMA](http://magma.ics.utk.edu/magma)
 - ✓ lightweight performance portability [libocca](http://libocca.org)

- More information and downloads
 - ✓ CEED project website: <http://ceed.exascaleproject.org>
 - ✓ CEED code repositories: <https://github.com/CEED>