libCEED: an open-source library for efficient high-order operator evaluations

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CEED
EXASCALE DISCRETIZATIONS

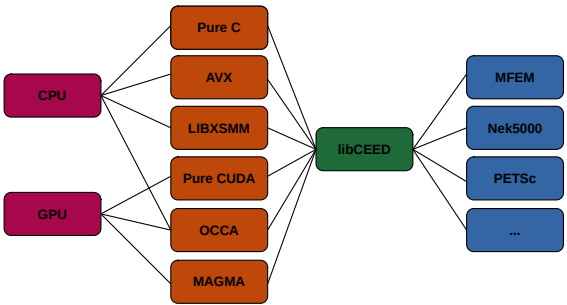
ECP
EXASCALE COMPUTING PROJECT

libCEED

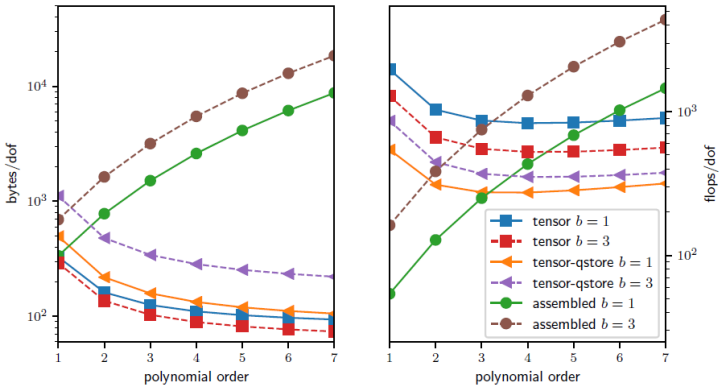
What is the point of having a **Ferrari**, if you drive it stuck in second gear?

- libCEED is a low-level API for achieving high-performance scientific computing on different architectures

- libCEED supports run-time selection of implementations tuned for a variety of computational device types (e.g., CPUs, GPUs, etc).
- Single source code can call multiple backends



Motivation: Why matrix-free? And why high-order?



Flops per dof (right) and memory bandwith (left) to apply a Jacobian matrix, obtained from discretizations of a b-variable PDE system. Assembled matrix vs matrix-free (exploits the tensor product structure by either storing at q-points or computing on the fly)

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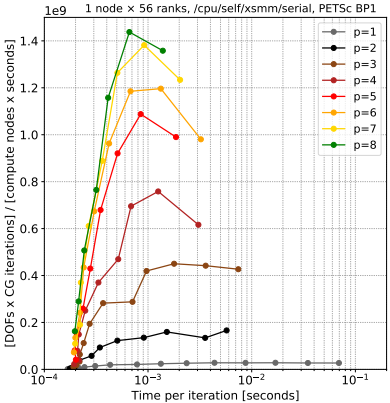
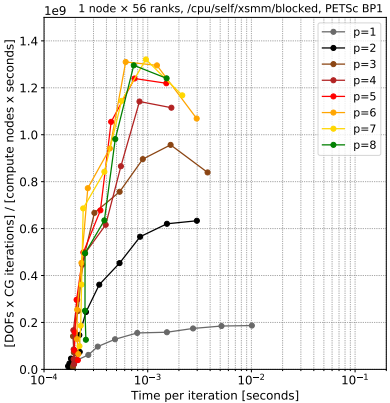
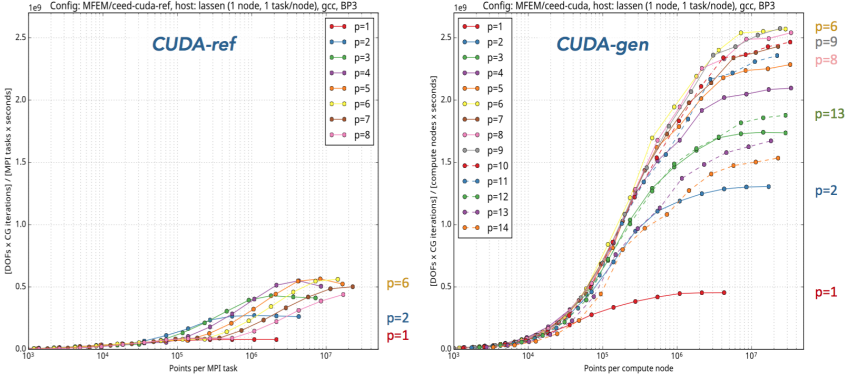
CPU Performance





GPU Performance



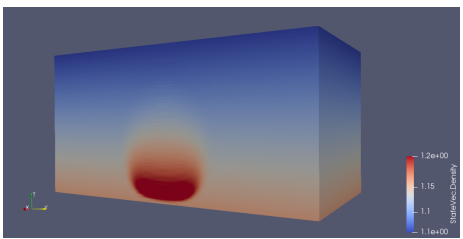
CFD Application Example

libCEED is not just for toy problems.
Compressible Navier-Stokes equations in conservative form:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \mathbf{U} = 0\,, \tag{1a}$$

$$\frac{\partial \mathbf{U}}{\partial t} + \nabla \cdot \left(\frac{\mathbf{U} \otimes \mathbf{U}}{\rho} + P\mathbf{I}_3 \right) + \rho g \mathbf{k} = \nabla \cdot \boldsymbol{\sigma}\,, \tag{1b}$$

$$\frac{\partial E}{\partial t} + \nabla \cdot \left(\frac{(E + P)\mathbf{U}}{\rho} \right) = \nabla \cdot (\mathbf{u} \cdot \boldsymbol{\sigma} + k \nabla T)\,, \tag{1c}$$



A fast and efficient Navier-Stokes solver.
Polynomial order of spectral elements:
$p = 10$
Computational domain:
$[0, 6000] \times [0, 6000] \times [0, 3000]$ m
Elem. Resolution: 500 m

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Conclusions and Outlook

- We developed an open-source, light-weight, versatile mathematical library: libCEED, which targets high-order finite/spectral element discretizations
- We allow run-time selection of specialized implementations for CPUs, GPUs, etc
- Single-source code for different backends
- Demonstrated performance on CPUs & GPUs
- Demonstrated the usage and capabilities of libCEED with examples in CFD

Work in progress:

- Deployment of a Python interface for our C library
- Ongoing development of shallow-water equations solver on the cubed-sphere grid

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