ESFR Pull Request - My suggestion for the review

March 30, 2022

This short document outlines a flow that I suggestion for reviewing the pull request.

1 Unsteady Tests

Since the ESFR PR was mainly for unsteady tests, a good starting point are the files:
src/testing/advection_explicit_periodic.cpp
src/testing/burgers_stability.cpp
src/testing/convection_diffusion_explicit_periodic.cpp
and euler split form taylor green

They all have the flow of

(a) Setup poly degree and mesh size depending on whether it's an energy test or OOA test

(b) setup the grid (linear or curvilinear)

(c) set the timestep

(d) Interpolate the Initial condition (note for curvilinear the dealii interpolate function doesn't work optimally so in curvilinear I hard coded it).

(e) Setup DG

(f) solve: if energy→ compute energy and conservation at the given time, else (if not energy ie OOA) then solve and compute error

2 DG Initialize

Since the initialization of DG happens before the solve at 1.(e), I suggest looking at it getting setup before DG strong.

When constructed, it constructs operators. For the rest of the DG initialization, it only needs the operators→ mass-type matrices. I'd suggest jumping to the construction of the mass matrices to see how it builds the mass matrix whether it's DG, FR, or a weight-adjusted FR. Note that this requires a computation of the determinant of the Jacobian. I'd suggest first familiarizing with the assembly of the mass matrices before looking into the metric indices.

For now that's all you should look at in dg.cpp

2. Explicit solver

Since we solve, jump to the ode_solver and see that the modifications are to allow a switch between whether it's an energy test or not, and added rk4.

3. DG loop

So now we need to solve the RHS. This is when we return to DG and look at the modification in the cell loop. The main changes are the 1D periodic setup (which is verified) and the calls for the explicit.

I'd also suggest now looking at the allocate auxiliary.

4. Operators with DG Strong - Volume

Now that we need to solve a RHS, I would strongly advice that you review operators in parallel with DG strong. Start with DG strong volume term explicit, and you will see at the start we need the metric cofactor. So look at how the metric dofs are re-indexed, then jump to operators metric operators. Here you'll see the construction of the cofactor matrix and determinant of the Jacobian for both volume and surface. Not a bad idea to then go to operators unit tests and look at the series of GCL tests and metric derivative test to get a feel for the metric dependent terms.

After, we now need volume operators, like interpolation and projection operators. So, jump to the operators, volume operators and see the structure etc of it.

Once there's a grip on the volume operators, we see that the source term is now dependent on the current time since unsteady. This is where all the physics changes come into play.

After that, we arrive at the divergence of the flux. Note that the metric gradient splitting was done at the construction of the operator, so we use it for the 2-pt flux.

4. Operators with DG Strong - Face

Now, go to the assemble face term explicit, and you'll see a lot of small details about what is being interpolated/constructed from where, what is physical, what is reference etc. This follows the same flow from our curvilinear paper's DG section. This is a good time to now go into the face operators and see how they're constructed to interpolate to certain points. The main thing to remember in this section is this equation from our curvilinear paper:

$$\begin{aligned}\int_{\mathbf{\Omega}_r} \chi_i(\boldsymbol{\xi}^r) J_m^{\Omega} \boldsymbol{\chi}(\boldsymbol{\xi}^r) \frac{d}{dt} \hat{\boldsymbol{u}}_m(t)^T d\mathbf{\Omega}_r + \frac{1}{2}\int_{\mathbf{\Omega}_r} \chi_i(\boldsymbol{\xi}^r)\left(\sum_{j=1}^{N_p} \nabla^r \chi_j(\boldsymbol{\xi}^r)\cdot \hat{\boldsymbol{f}}^r_{m,j}(t)\right) d\mathbf{\Omega}_r \\ + \frac{1}{2}\int_{\mathbf{\Omega}_r} \chi_i(\boldsymbol{\xi}^r)\left(\sum_{j=1}^{N_p}\left(\nabla^r \chi_j(\boldsymbol{\xi}^r)\boldsymbol{C}_m^T\right)\cdot \hat{\boldsymbol{f}}_{m,j}(t)\right) d\mathbf{\Omega}_r \\ + \int_{\mathbf{\Gamma}_r} \chi_i(\boldsymbol{\xi}^r)^T \left[\hat{\boldsymbol{n}}^r \boldsymbol{C}_m^T \cdot (\boldsymbol{f}_m^* - \frac{1}{2}\boldsymbol{f}_m) - \hat{\boldsymbol{n}}^r \cdot \frac{1}{2}\boldsymbol{\chi}(\boldsymbol{\xi}^r)\hat{\boldsymbol{f}}_m^r(t)^T\right] d\mathbf{\Gamma}_r = 0,\ \forall i = 1,\ldots,N_p,\end{aligned} \tag{1}$$

where we need the physical normal dot the numerical flux and flux evaluated on the face, and (the last term) we need the reference normal dot the interpolation of the reference flux in the volume interpolated to the face.

Then, for other split forms, currently with if else statements we do the splitting between the flux evaluated at the face and the interpolation of the volume flux to the face. This leads to the other physics changes of the surface splitting.

This is also a good time to go through the numerical fluxes and see that some were added to conserve energy/entropy.

5. Auxiliary
Lastly, then go through the auxiliary and see how it mimics the primary.