



A Tale of Two Solvers: Vortices in MFEM and OpenFOAM Fluid Flow Simulations

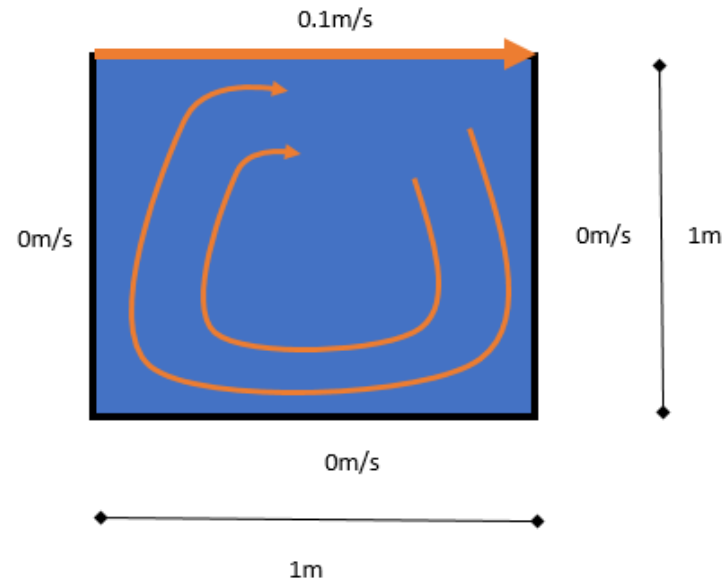
Justin Crum and Craig Gross
Computing/DSSI

Vic Castillo, Andrew Gillette, Josh Levine, Yamen Mubarka, Brian Yoxall





Lid driven cavity



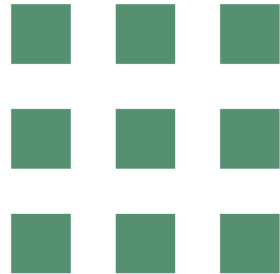
$$\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} = -\nabla p + \nabla^2 \mathbf{u} \quad \text{inside the cavity,}$$
$$\nabla \cdot \mathbf{u} = 0$$
$$\mathbf{u} = \begin{cases} (Re, 0) & \text{on the lid} \\ 0 & \text{on the other walls} \end{cases}$$



OpenFOAM and MFEM

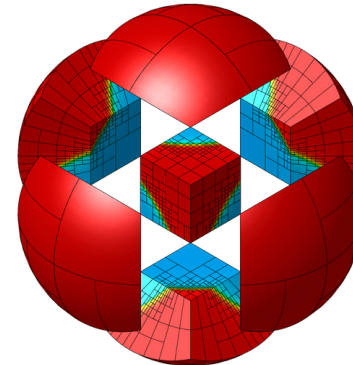
- OpenFOAM

- Open source CFD library
- Meshing capabilities
- `simpleFoam` solver
- openfoam.org



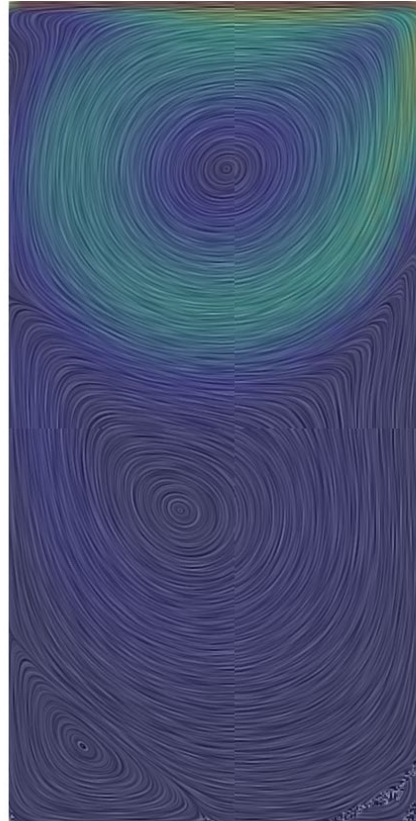
- MFEM

- Finite element method
- Higher order solutions
- Navier-Stokes miniapp
- MFEM.org



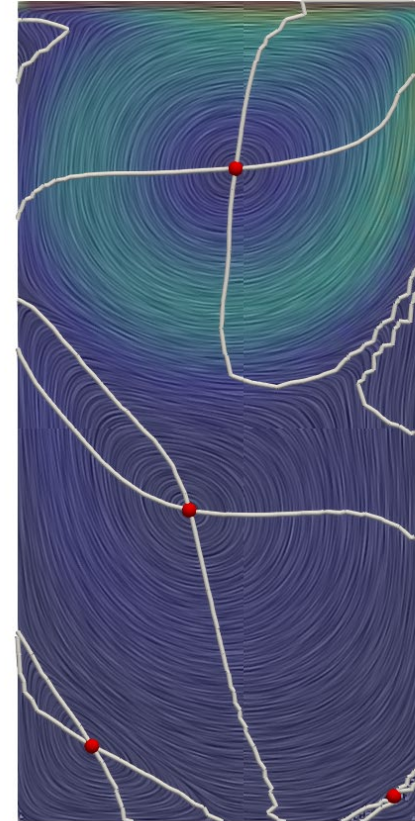


Vortices



Streamlines in a typical steady-state flow

- Vortices are regions of rotational motion
- White lines trace locations of no velocity in horizontal or vertical directions
- Red dots represent vortices



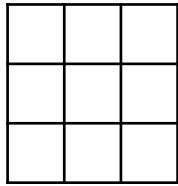
Visualization of vortex detection algorithm

Experiment design with Merlin



Merlin

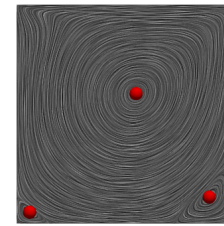
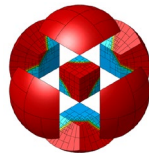
<https://github.com/LLNL/merlin>



Mesh



Solve



(Some solutions for
various geometries)



Vortex
detection



Results

Aspect ratio	Viscosity									
	1.00E-03	9.11E-04	8.22E-04	7.33E-04	6.44E-04	5.56E-04	4.67E-04	3.78E-04	2.89E-04	2.00E-04
1.00	3	3	3	3	3	3	3	3	3	3
1.14	3	3	3	3	3	3	3	3	3	X
1.29	3	3	3	3	3	4	4	3	4	4
1.43	3	4	3	3	3	4	4	4	4	4
1.57	4	4	4	4	4	4	4	4	4	4
1.71	4	4	4	4	4	4	4	4	4	X
1.86	4	4	4	4	4	4	4	4	4	X
2.00	4	4	4	4	4	4	4	4	4	X
2.14	4	4	4	4	4	4	4	4	4	X
2.29	4	4	4	4	4	4	4	4	4	X
2.43	4	4	4	4	4	4	4	4	4	X
2.57	4	4	4	4	4	4	4	4	4	X
2.71	4	4	4	4	4	4	5	5	5	X
2.86	4	4	5	5	5	5	5	5	5	X
3.00	5	5	5	5	5	5	5	5	5	X
	100	110	122	136	155	180	214	265	346	500
Reynolds number										

MFEM (low resolution)

Aspect ratio	Viscosity									
	1.00E-03	9.11E-04	8.22E-04	7.33E-04	6.44E-04	5.56E-04	4.67E-04	3.78E-04	2.89E-04	2.00E-04
1.00	3	3	3	3	3	3	3	3	3	3
1.14	3	3	3	3	3	3	3	3	3	3
1.29	3	3	3	3	3	3	3	3	3	3
1.43	3	3	3	2	3	3	2	2	2	3
1.57	3	2	2	2	2	3	3	3	4	4
1.71	2	3	3	3	4	4	4	4	4	4
1.86	4	4	4	4	4	4	4	4	4	4
2.00	4	4	4	4	4	4	4	4	4	4
2.14	4	4	4	4	4	4	4	4	4	4
2.29	4	4	4	4	4	4	4	4	4	4
2.43	4	4	4	4	4	4	4	4	4	4
2.57	4	4	4	4	4	4	4	4	4	4
2.71	4	4	4	4	4	4	4	5	4	3
2.86	4	4	4	4	5	3	3	3	3	5
3.00	4	3	3	3	3	4	5	5	5	5
	100	110	122	136	155	180	214	265	346	500
Reynolds number										

OpenFOAM (low resolution)

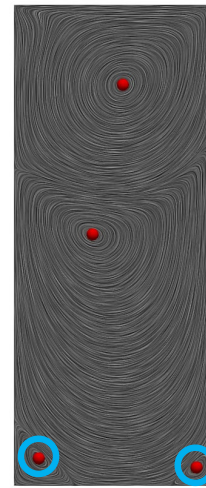
Aspect ratio	Viscosity									
	1.00E-03	9.11E-04	8.22E-04	7.33E-04	6.44E-04	5.56E-04	4.67E-04	3.78E-04	2.89E-04	2.00E-04
1.00	3	4	3	3	3	4	4	4	4	4
1.14	3	4	4	4	4	4	4	4	4	4
1.29	4	4	4	5	4	4	5	4	4	4
1.43	4	5	5	4	4	4	4	4	4	4
1.57	4	4	4	4	4	4	4	4	4	4
1.71	4	4	4	4	4	4	4	4	4	4
1.86	4	4	4	4	4	4	4	4	4	4
2.00	4	4	4	4	4	4	4	4	4	4
2.14	4	4	4	4	4	4	4	4	4	5
2.29	4	4	4	4	4	4	4	4	4	4
2.43	4	4	4	4	4	4	4	4	5	6
2.57	4	5	5	4	4	6	6	6	6	6
2.71	6	6	6	6	6	6	6	6	5	5
2.86	6	6	6	6	6	5	5	5	5	5
3.00	6	5	5	5	5	5	5	5	5	5
	100	110	122	136	155	180	214	265	346	500
Reynolds number										

OpenFOAM (high resolution)

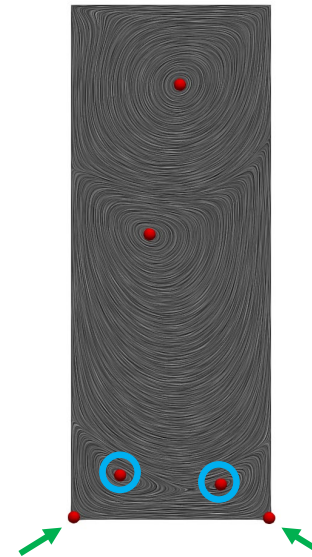


Conclusion and Future Work

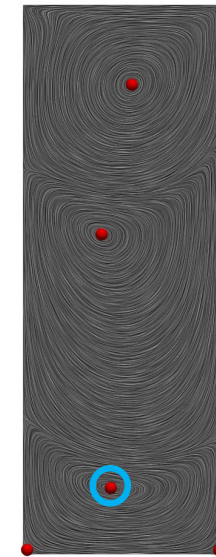
- Conclusions
 - Vortices
 - Challenges
 - MFEM
 - OpenFOAM
- Future work
 - Machine Learning
 - Vortices
 - Big Navier-Stokes data set
 - Complex Geometries
 - Improved Merlin Workflows



4 vortices



6 vortices



5 vortices



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