LA-UR-12-24130

Approved for public release; distribution is unlimited.

Title:	Moment of Fluid Interface Reconstruction with Filaments
Author(s):	Jemison, Matthew B.
Intended for:	Presentation of work to fellow students for university seminars Report

Moment of Fluid Interface Reconstruction with Filaments

Matthew Jemison
Mentor: Dr. Mikhail Shashkov

Department of Applied and Computational Mathematics
Florida State Univeristy
Tallahassee, Florida

August 15, 2012

Moment of Fluid Method (MOF) Interface Reconstruction

- A moving system made up of multiple fluids (e.g. air and water) may be defined by an evolving interface with a changing topology.
- MOF uses a piecewise linear interface reconstruction to numerically model deforming boundaries [2].
- Given a volume fraction V and reference centroid $\mathbf{x}$ for a material in cell Ω, we seek to find an interface Γ that exactly captures V and minimizes error in $\mathbf{x}$.
- This differs from Volume of Fluid methods.

Moment of Fluid Method (MOF) Interface Reconstruction

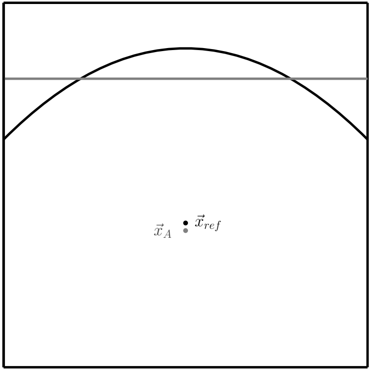


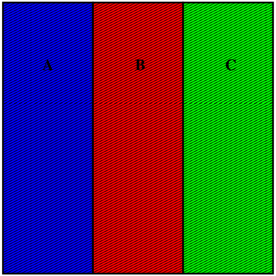
Figure: Given a curved interface, we can exactly capture volume, but will have error in the centroid.

- Define an interface Γ as follows. Vector $\hat{n}$ is the normal vector of the interface, $\mathbf{x}_i$ is the cell centroid.

$$\Gamma = \hat{n} \cdot (\mathbf{x} - \mathbf{x}_i) + b$$

Multimaterial Moment of Fluid

- In a cell where three fluids meet (e.g. air, water, & oil), it is necessary to define multiple interfaces [1].
- Use nested dissection.
- How do we know where to start?



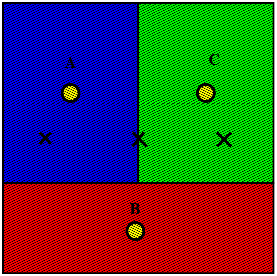


Figure: An incorrect dissection ordering (starting with B) will lead to improper interface reconstruction (right). True centroid is shown as an 'X,' computed centroid is a yellow circle.

Moment of Fluid vs. Filaments

- Define a filament as a structure that divides a cell into three distinct regions.
- A filament cannot be accurately represented using MOF without mesh refinement.
- What will MOF do?

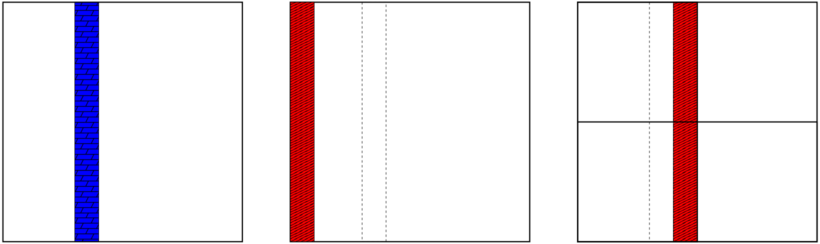


Figure: The true interface is defined on the left. The center and right images show MOF reconstructions for varying grid refinements, with the true solution in dotted lines.

Filament Goals

- Model a filament using two interfaces rather than one, similar to the multimaterial method.
- In the case of a filament with no curvature, accuracy should be limited only by errors in advection and the tolerance of the volume error.
- Either material should be able to form a filament.
- Filament techniques should be compatible with other MOF functionality (multistage advection, Adaptive Mesh Refinement).

Advection

- An unsplit advection strategy is used. Velocity is projected to cell corners. Backtracing is used to find the departure region for the target cell.

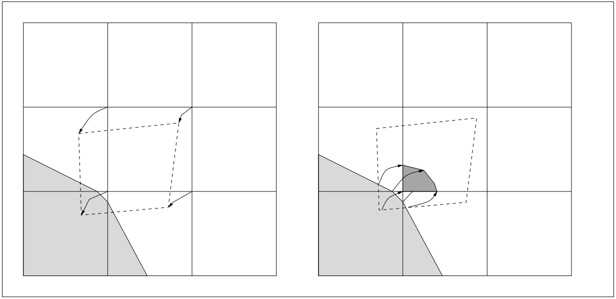


Figure: Example of advection backtracing with forward mapping.

Basic Conglomeration Algorithm

- Intersection of backward velocity sweep with mesh and interface yields a set of polygons. Detect disconnected groups.
- Allow at most two conglomerates of each material type. Attach all others in a 'reasonable' way and introduce fictitious material ID's
- Perform reconstruction.

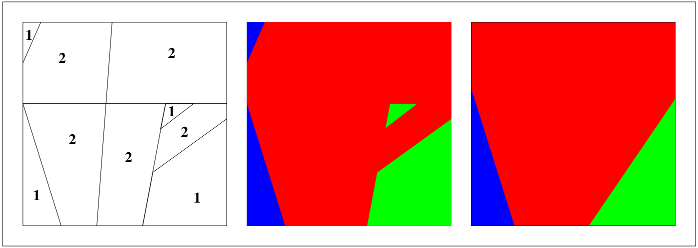


Figure: Example of a material configuration with the corresponding grouping and interface reconstructions.

Error Calculation

- A common error metric for deforming interface problems is the symmetric difference error.

$$E_{SD} = |(\Omega_E \cup \Omega_C)/(\Omega_E \cap \Omega_C)|$$

- Values Ω_E and Ω_C represent the calculated and exact material configuration.

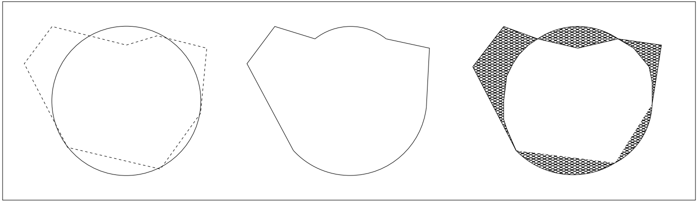


Figure: Left: Exact solution (solid) and computed solution (dotted). Center: Exact $\cup$ Computed. Right: (Exact $\cup$ Computed)/(Exact $\cap$ Computed)

Long Period Deforming Vortex: Final Time

- Velocity is defined by the stream function, with $T = 8$. Velocities $u = -\Psi_y$, $v = \Psi_x$ [3].
$$\Psi(x, y, t) = \frac{1}{\pi} \sin^2(\pi x) \sin^2(\pi y) \cos\left(\frac{\pi t}{T}\right)$$
- A circle of radius R=0.15 is initialized at the center of the $[0, 1]^2$ domain.

Error: Full Reversal

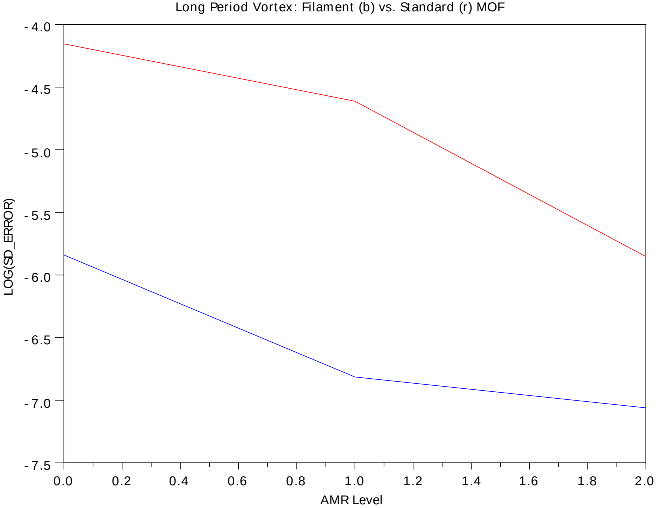


Figure: Log plot of error for Filament MOF (blue) and Standard MOF (red) at final time T=8. Initial mesh resolution is 32^2.

Long Period Deforming Vortex: Maximum Deformation

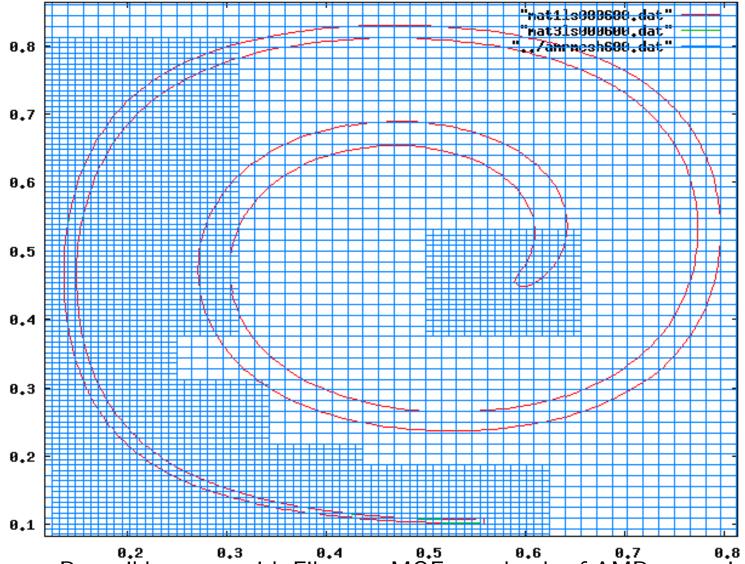


Figure: Reversible vortex with Filament MOF, two levels of AMR at maximum deformation time T=4. Initial mesh resolution is 32^2.

Long Period Deforming Vortex: Maximum Deformation

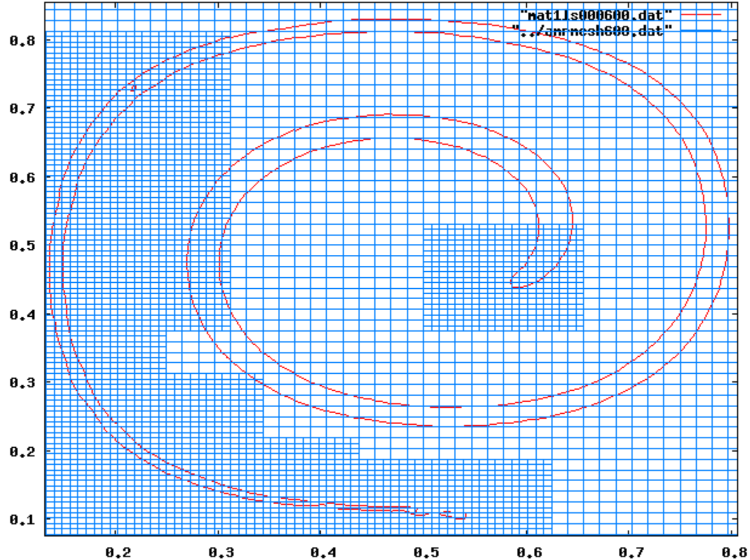


Figure: Reversible vortex with Standard MOF, two levels of AMR at maximum deformation time T=4. Initial mesh resolution is 32^2.

Long Period Deforming Vortex: Maximum Deformation

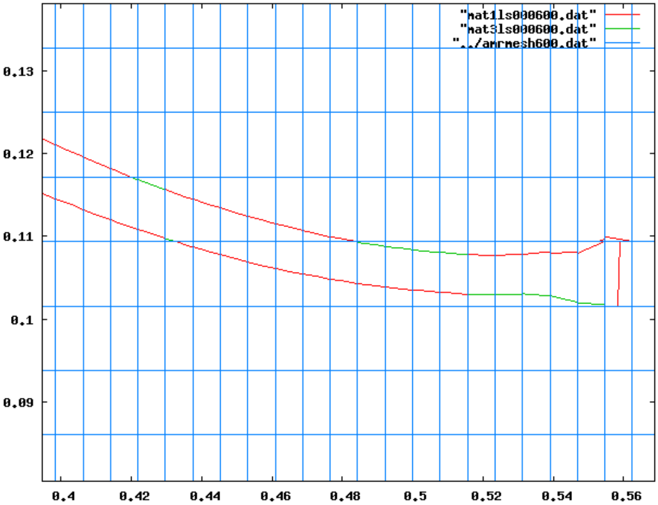


Figure: Reversible vortex with Filament MOF, two levels of AMR at maximum deformation time T=4. Emphasis on the tail. Initial mesh resolution is 32^2.

Long Period Deforming Vortex: Maximum Deformation

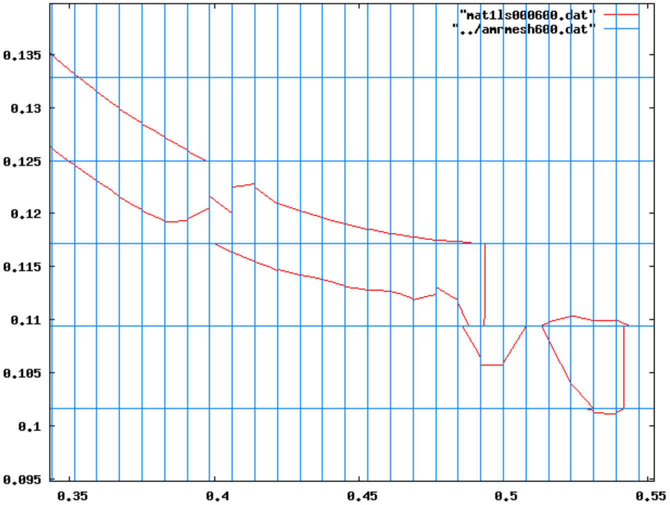


Figure: Reversible vortex with Standard MOF, two levels of AMR at maximum deformation time T=4. Emphasis on the tail. Initial mesh resolution is 32^2.

Long Period Deforming Vortex: Final Time

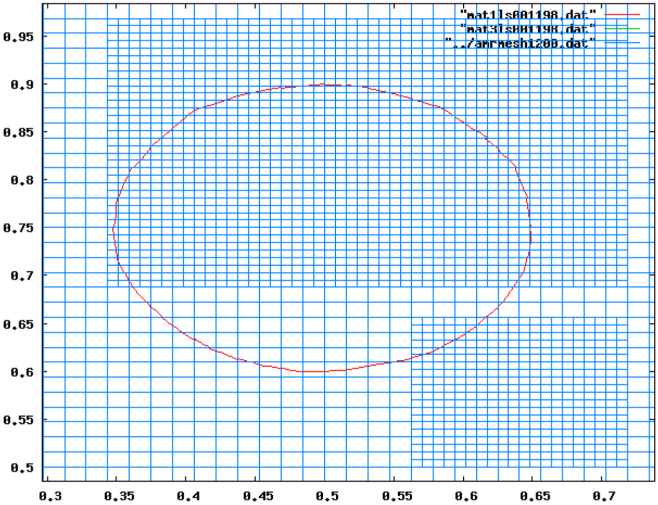


Figure: Reversible vortex with Filament MOF, two levels of AMR at final time T=8. Initial mesh resolution is 32^2.

Long Period Deforming Vortex: Final Time

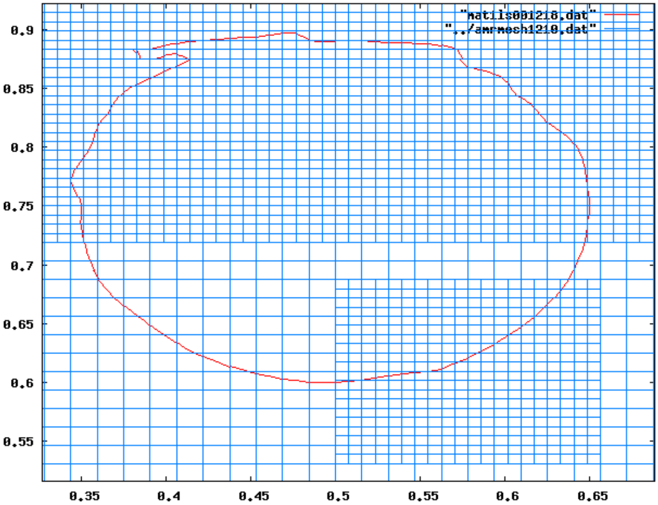


Figure: Reversible vortex with Standard MOF, two levels of AMR at final time T=8. Initial mesh resolution is 32^2.

Conclusions & Future Work

- It is possible to use multimaterial MOF to model filaments.
- Filaments provide gains in accuracy for little extra investment in time (5-15%).
- Prevents breakup of thin structures in reconstruction
- When to use filaments rather than standard MOF?
- 3D?
- True physics simulations?

References

H. Ahn and M. Shashkov.
Multi-material interface reconstruction on generalized polyhedral meshes.
J. Comput. Phys., 226(2):2096–2132, 2007.

V. Dyadechko and M. Shashkov.
Moment-of-fluid interface reconstruction.
Technical Report LA-UR 07-1537, Los Alamos National Laboratory, 2007.

W. Rider and D. Kothe.
Reconstructing volume tracking.
J. Comput. Phys., 141:112–152, 1998.

Acknowledgements

Thank you to mentor Dr. Mikahil Shashkov for his direction for the project and motivation when problems arose; collaborator Dr. Mark Sussman for his technical advice; partner Andrew Winters for many fruitful discussions; program coordinator Dr. Scott Runnels for organizing the LANL Computational Physics Summer Workshop; LANL for this valuable opportunity; and everyone who listens to this talk.