DE LA RECHERCHE À L'INDUSTRIE

A VOF EXTENSION TO LIVE BETTER WITH FILAMENTS AND FRAGMENTS IN MULTIMATERIAL SIMULATIONS

MULTIMAT 2013 | Christophe Fochesato[1], Raphaël Loubère[2], Renaud Motte[1], Jean Ovadia[3]

[1]CEA, DAM, DIF, F-91297 Arpajon, France

[2]Institut de Mathématiques de Toulouse, CNRS, Université de Toulouse

[3]Retired fellow from CEA, CESTA, F-33114 Le Barp, France

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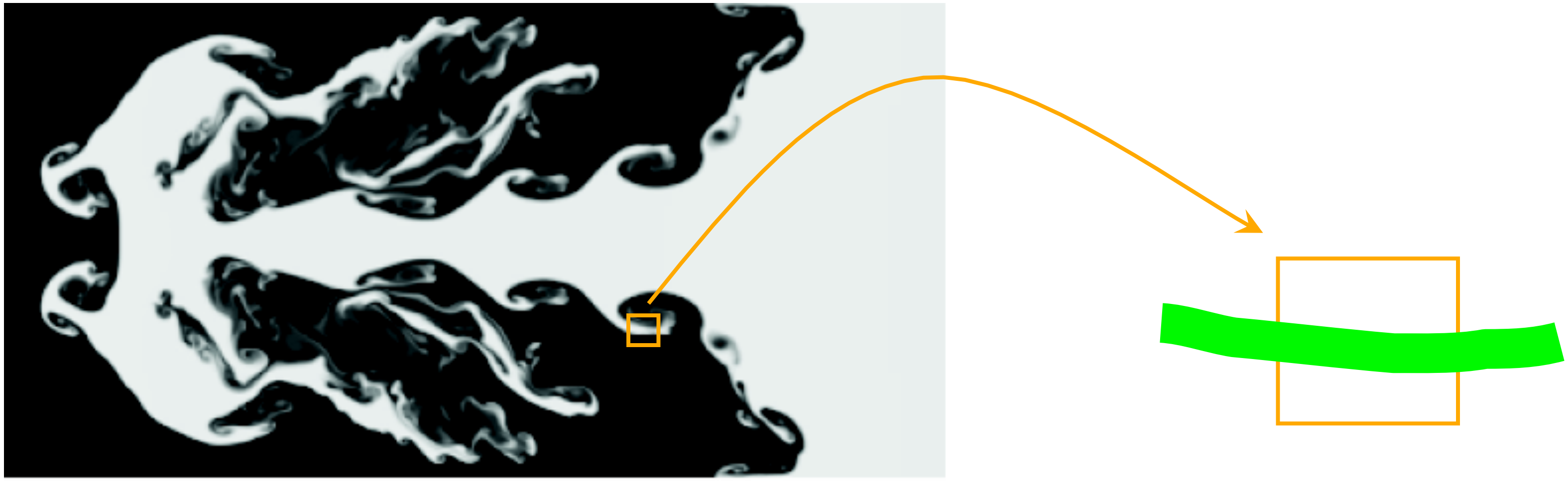
Outline

I – The context

- Bi-fluids hydrodynamical flows with interfaces
- VoF interface reconstruction
- Maximum possible resolution is not always sufficient

  → structures size < mesh cell size

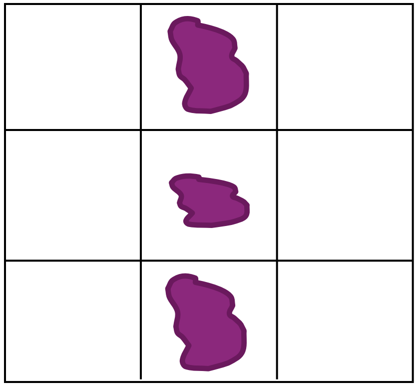


I – The question

- Usual VoF methods use only one interface per mixed cell, typically a straight line (PLIC)
  - → numerical surface tension
  - → generation of flotsam

- Youngs' normal can be irrelevant: ~0 because of almost symmetrical volume fractions on the stencil

- Reconstruction is coarse whereas there is enough information to do better with the same 9-cells stencil

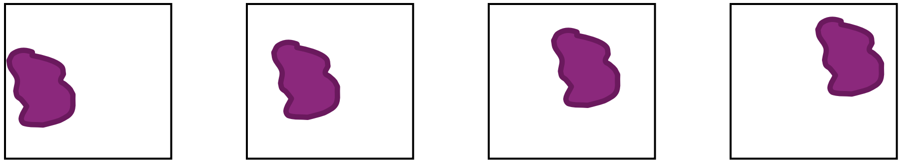


- Can we design a VOF/PLIC method more « filament friendly » ?

II – Key principles or the « Three Commandments » of a filament friendly method

- be able to represent staticly a filament… more degrees of freedom than PLIC are needed

- be able to follow dynamically a filament inside the cell… a lagrangian tracer is required



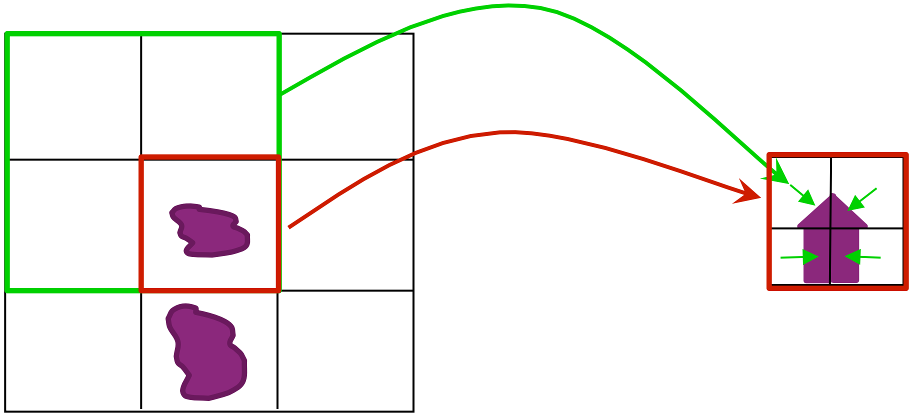
- let the situation occur ! Youngs/PLIC arranges things so that filaments are not appearing…

II – Design requirements for coarse representation interface methods like PLIC

- Detect a filament/fragment situation in mixed cell
- Subdivide the cell
- Distribute the fluid into the subzones
- Reconstruct in each subzone
- Update some information to determine how the small structure is evolving across the mixed cell

II – The idea at the origin of the method: subgradients

- The idea is to compute subgradients from a local stencil associated with each corner (2x2 cells for instance) in order to reconstruct one interface per subzone, with normals given by these subgradients



- Method does not contain more physics
- Another geometrical choice
  - → with less numerical surface tension
  - → avoiding to use irrelevant normal information
- Localized algorithm in the code: no change in the numerical scheme

→ other volume fraction fluxes given by the interface reconstruction method

II – The proposed method

- Detect a filament/fragment situation in mixed cell by analysis of the 3x3 stencil

- Choose a center of subdivision which brings information about the location of the filament/fragment in the cell: an estimation of the centroid in the cell

- Subdivide the cell regularly from this center

- Distribute uniformly the fluid into the subzones

- Reconstruct with PLIC algorithm in each subzone (normals given by 2x2 stencil)

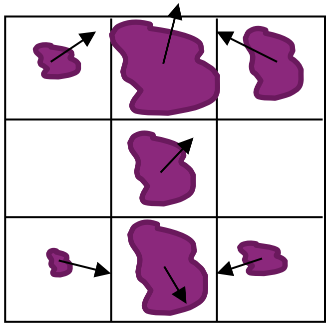
- Compute and advect centroids of each reconstructed piece of fluid

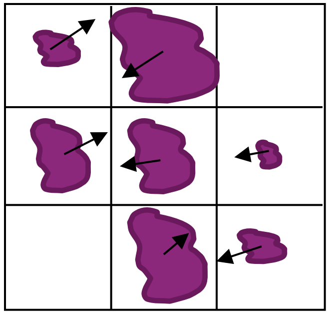
The method is an adaptive one-level refinement interface technique based on PLIC, adapted to thin structures like filaments and fragments.
→ we will say ASPLIC (Adaptive Subdivision with PLIC) in the following

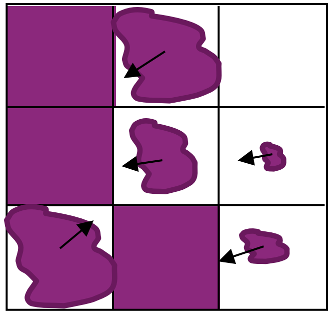
II – Detection of concerned cells

- Computation of a volume fraction gradient per cell to get a cell normal « as usual »
- The cell is marked

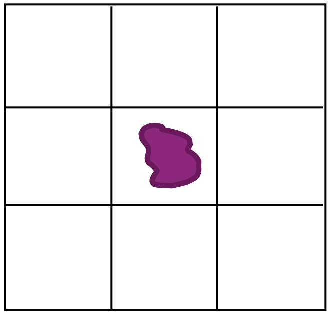
→ if neighboring normals are different enough: angle threshold

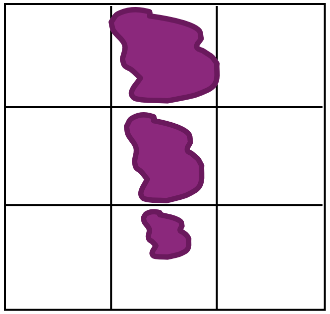






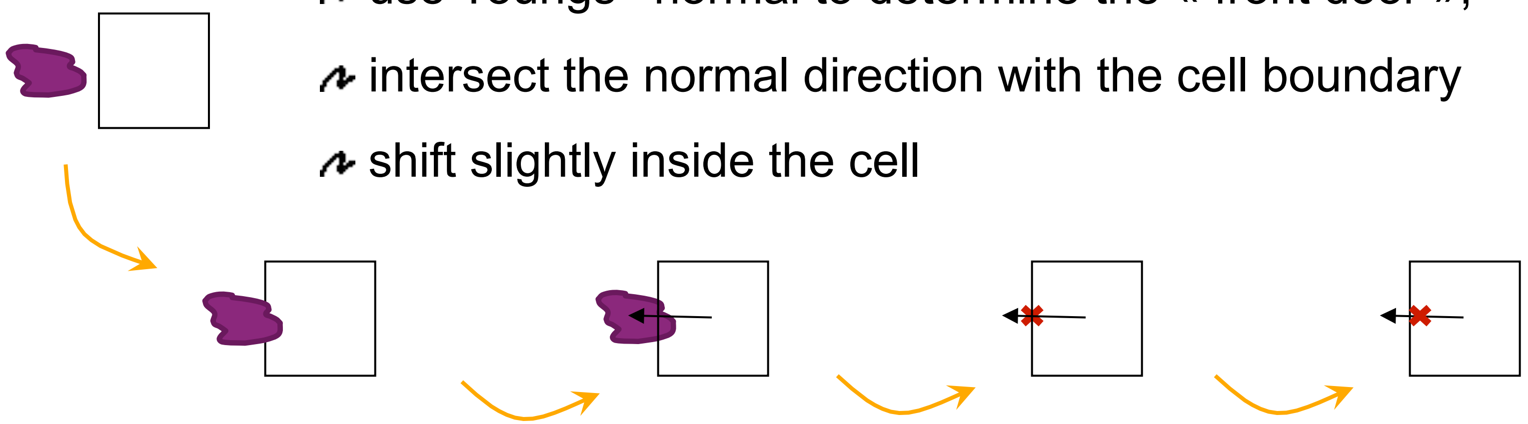
→ if the fluid passes through the cell



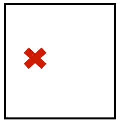


II – Estimation of centroids

- If the fluid is coming in the cell → no centroid information
  - use Youngs' normal to determine the « front door »,
  - intersect the normal direction with the cell boundary
  - shift slightly inside the cell



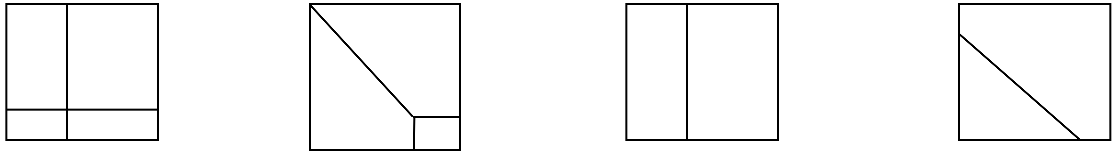
- else
  - use the advected centroids from the previous step or init



II – Determination of subzones

- the center of the subdivision is given by the estimated centroid in the cell

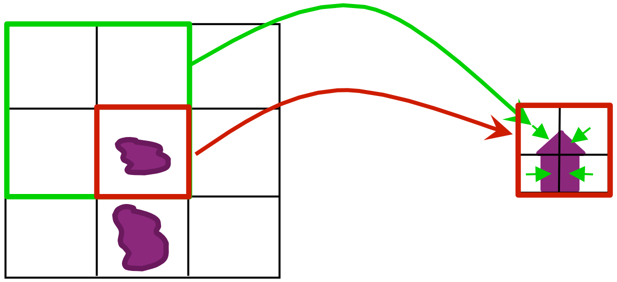
- attempts to specify more elaborate subdivisions to detect particular configurations : vertical filament, diagonal, …



for now, results are better with only a subdivision in 4 subzones

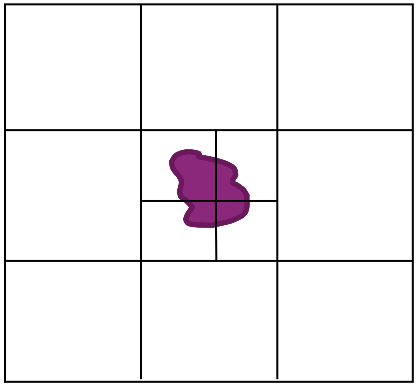
- the subdivision in 4 subzones consists in cutting vertically and horizontally the cell from the center

- for each subzone, we associate a corner subgradient, calculated on a 2x2 stencil



II – Distribution of the volume of fluid

➢ In priority, fill in uniformly



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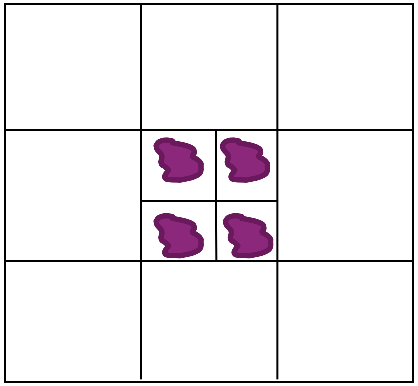
- In priority, fill in uniformly



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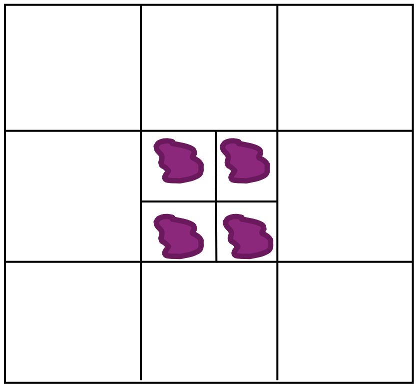
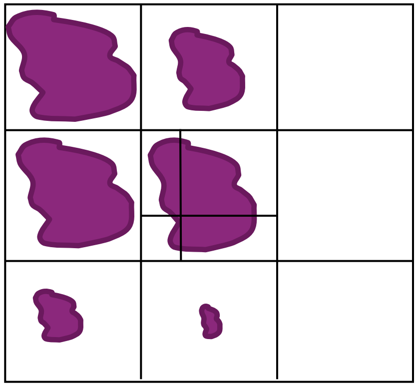


- If more volume of fluid than volume of the subzone
  - distribute proportionally to the presence of the fluid in the stencil



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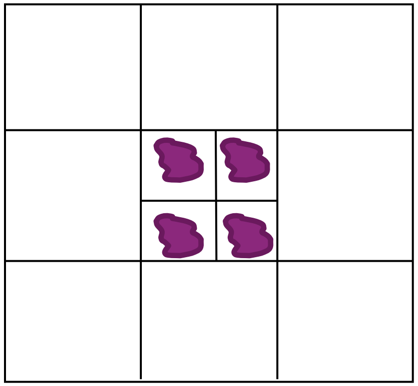

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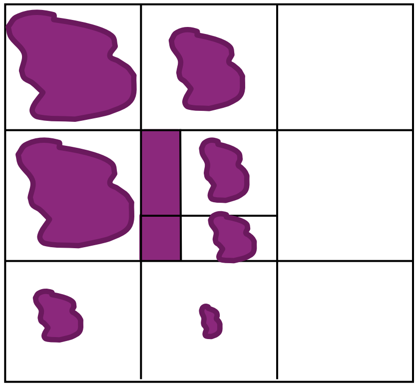
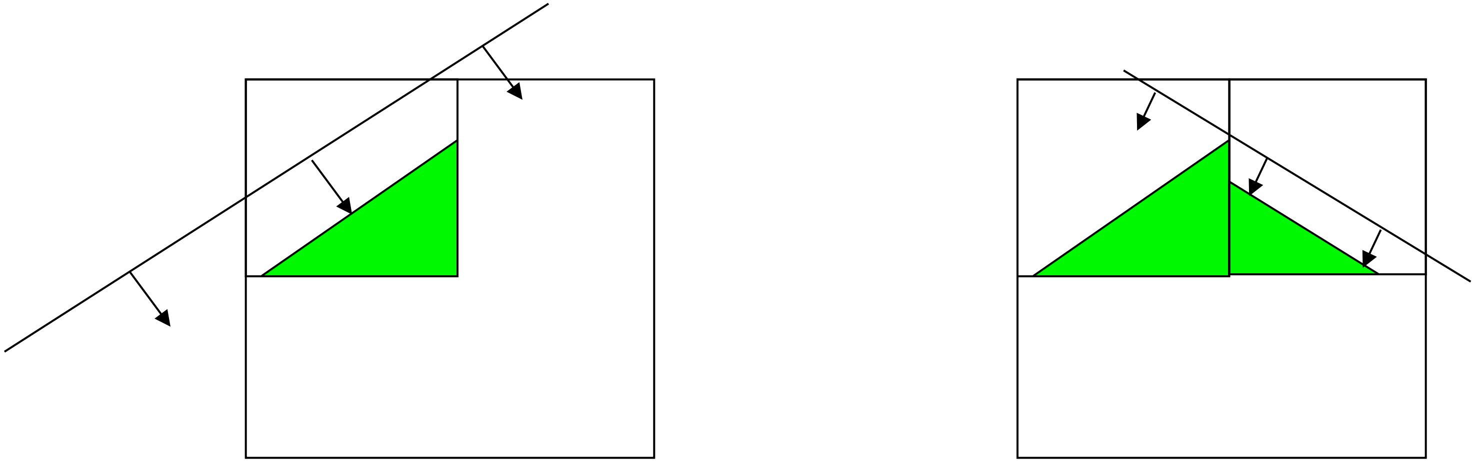


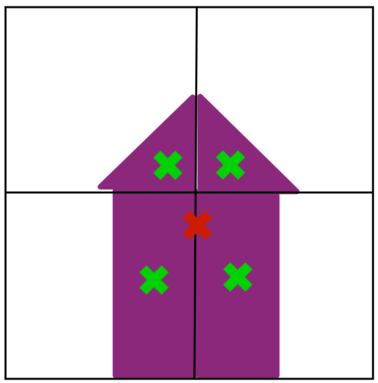
II – Reconstruction of interfaces

- PLIC per subzone

→ Youngs' algorithm



II – Computation of centroid and advection



- Compute the centroid for reconstructed cell

  - mean of centroid of each subzone

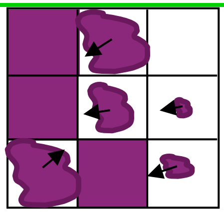
  → could be improved by computing the centroid of non convex polygons

- Advect the relative location of the centroid in the cell

Linear interpolation of the velocity field

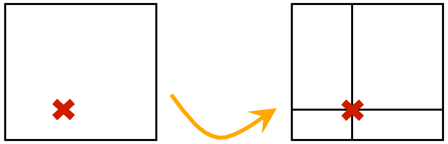
II – Sum up of the method from the design requirements

- Detect a filament/fragment situation in mixed cell



angle criterium

- Subdivide the cell

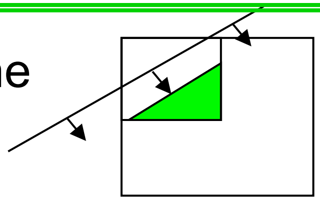


regular subdivision from estimated centroid

- Distribute the fluid into the subzones

uniformly

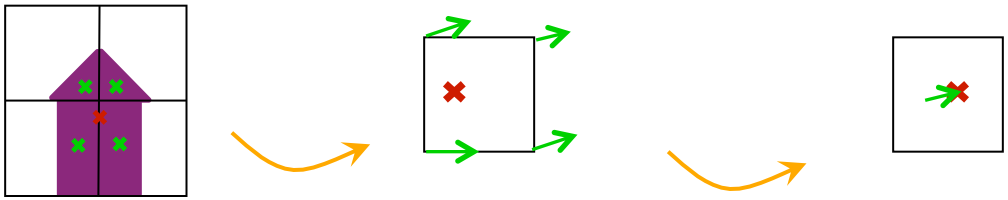
- Reconstruct in each subzone



PLIC

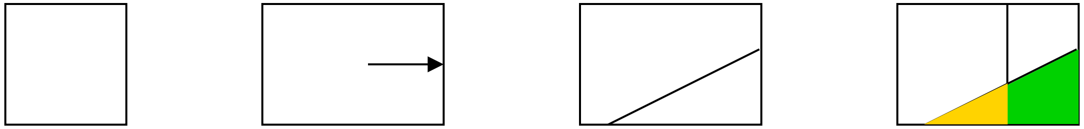
- Update some information to determine how the small structure is evolving across the mixed cell

approximate centroid



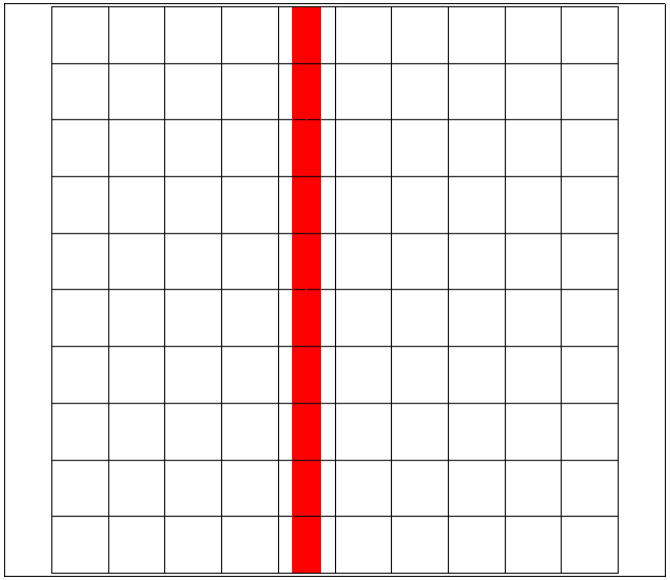
III – Code used for the tests

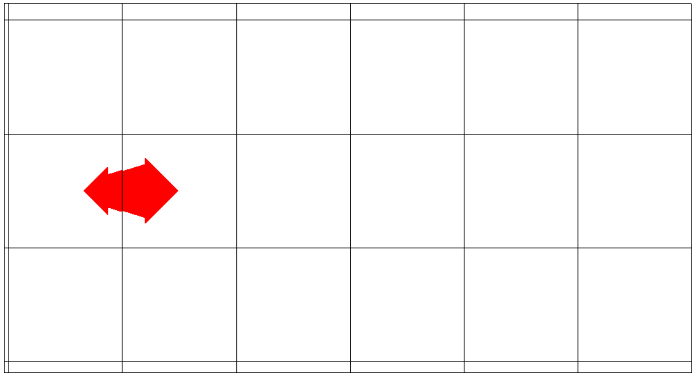
- Eulerian code, Cartesian grid
- Gradients computation with Youngs' Finite Difference formula
- Subgradients computation with Finite Difference formula
- Lagrange+remap scheme with direction splitted remapping
  - → interface reconstruction on 1D-stretched cells for each direction
  - → exact intersection of transfer volume of the cell with reconstructed interface gives transfer volume for the fluid

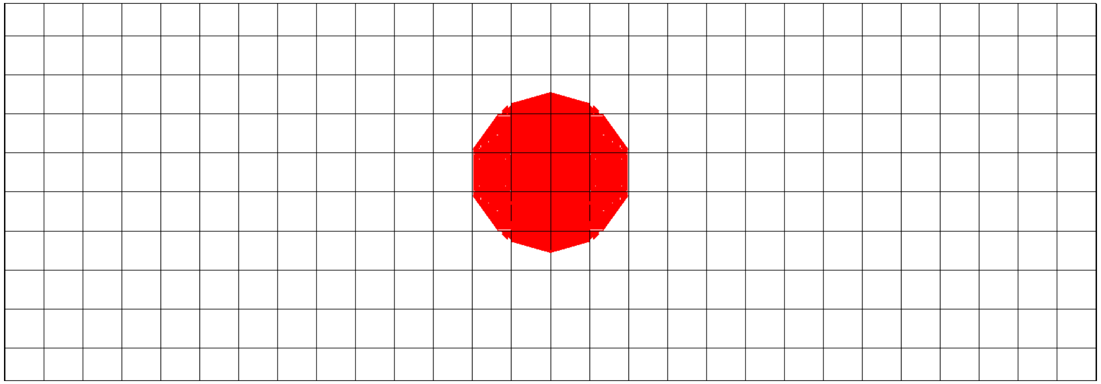


First advection tests

- 1D movement, aligned with the grid, is OK
- An isolated fragment can travel through the mesh
- A shape of fluid can be stretched until a filament appear

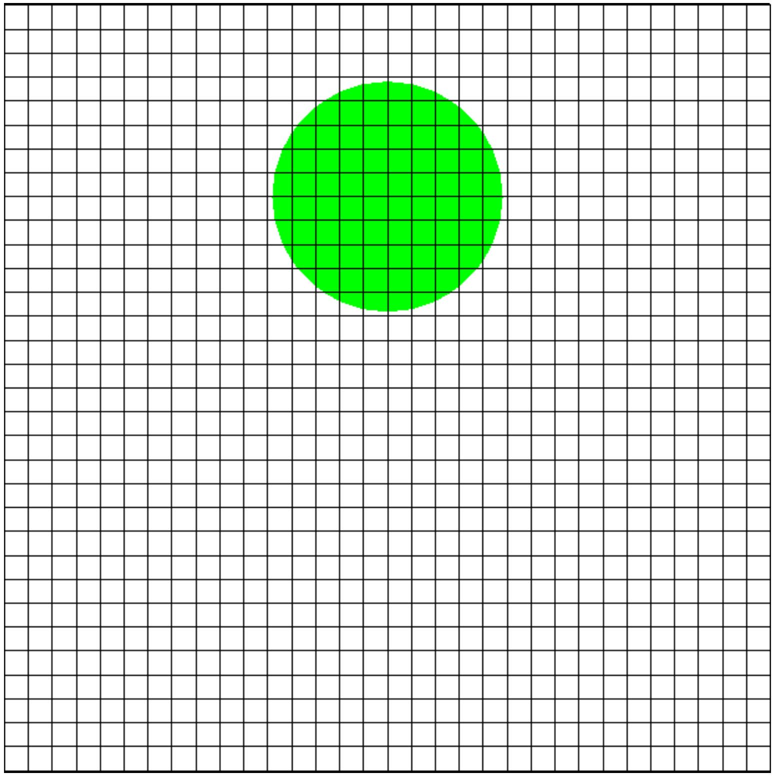






Numerical results: Rider & Kothe's vortex

- Rider & Kothe's vortex stretching of a droplet and reverse flow
- Maximum stretching at t=T/2
- The droplet goes back to its initial location at t=T, it should have recovered its round shape
- Mesh 32x32
- Constant time step at 1.e-3



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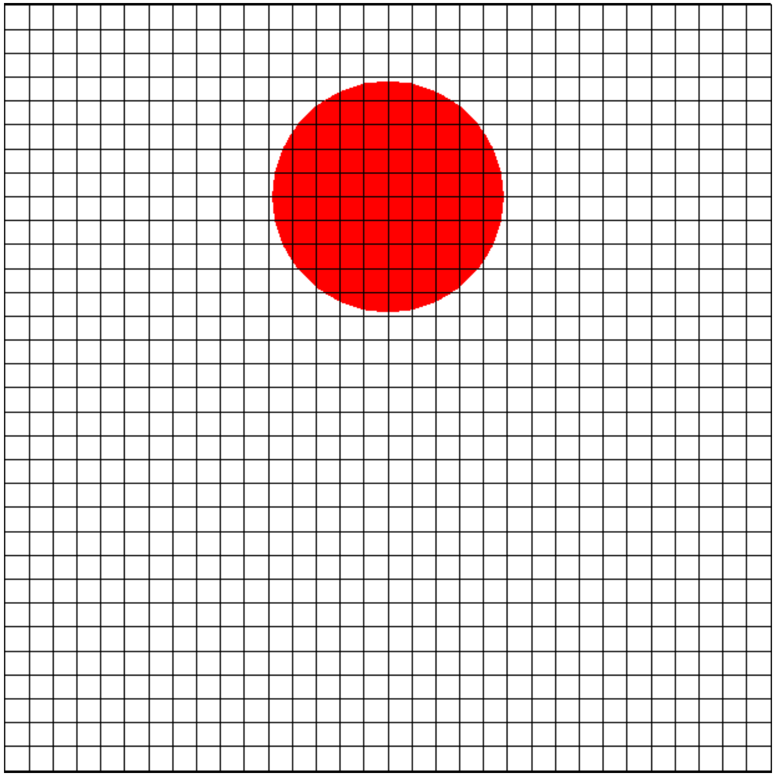
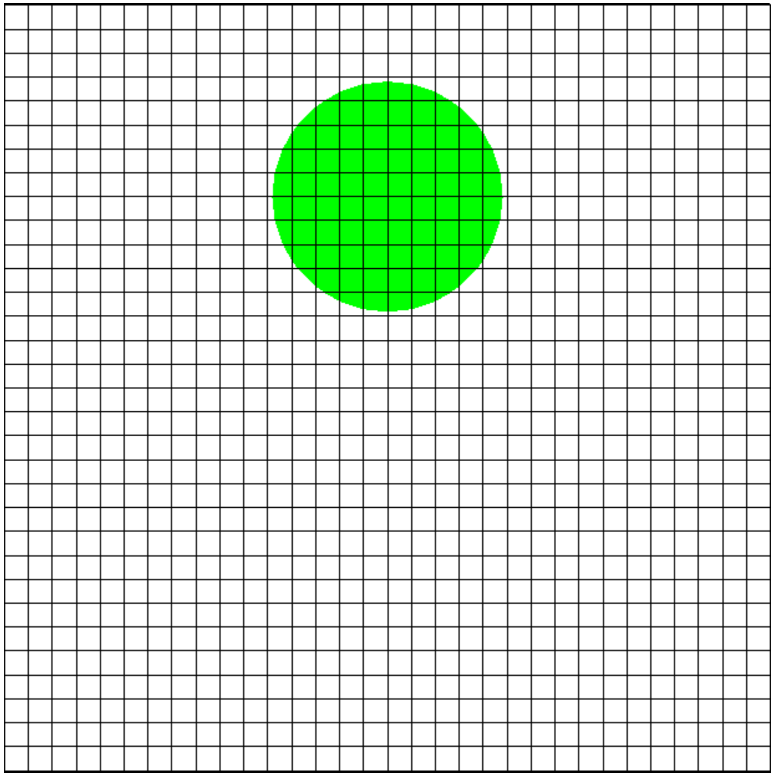
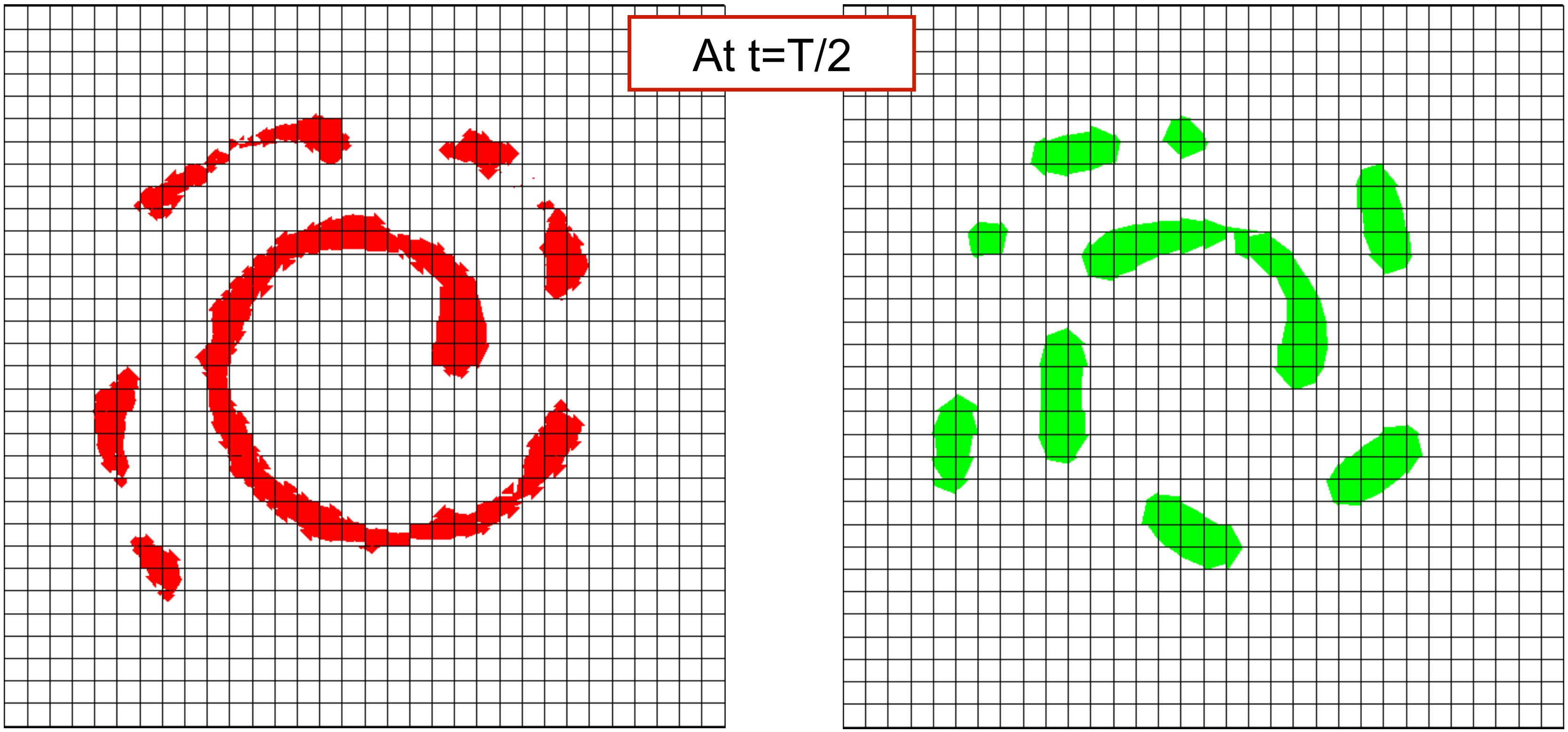




ASPLIC has a good behavior for this dynamics, fragmentation is delayed

As known, Youngs/PLIC reconstruction early leads to blobby flows for this coarse mesh

Numerical results: Rider & Kothe's vortex



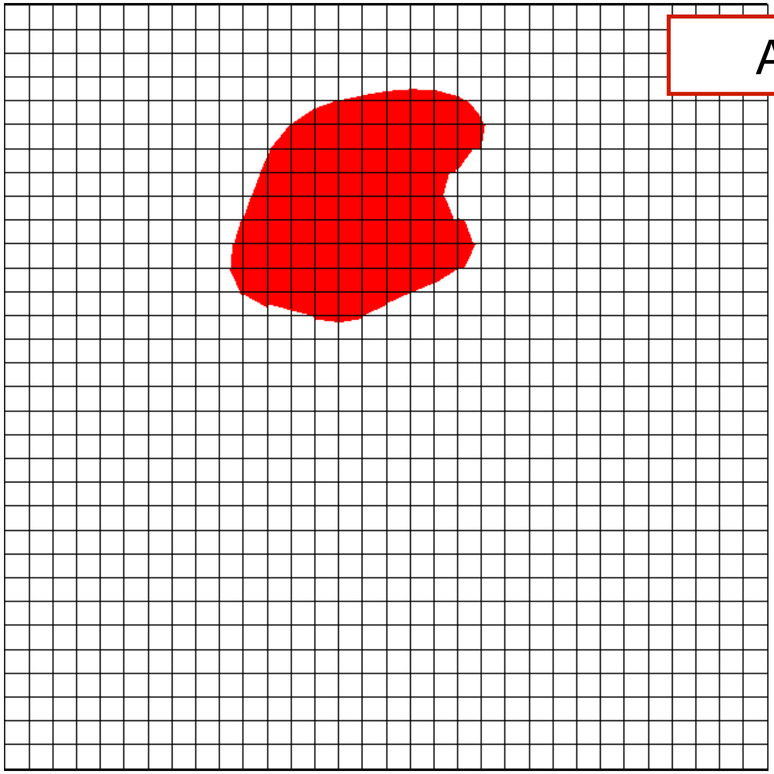
At maximum stretching, the filament is better preserved with ASPLIC

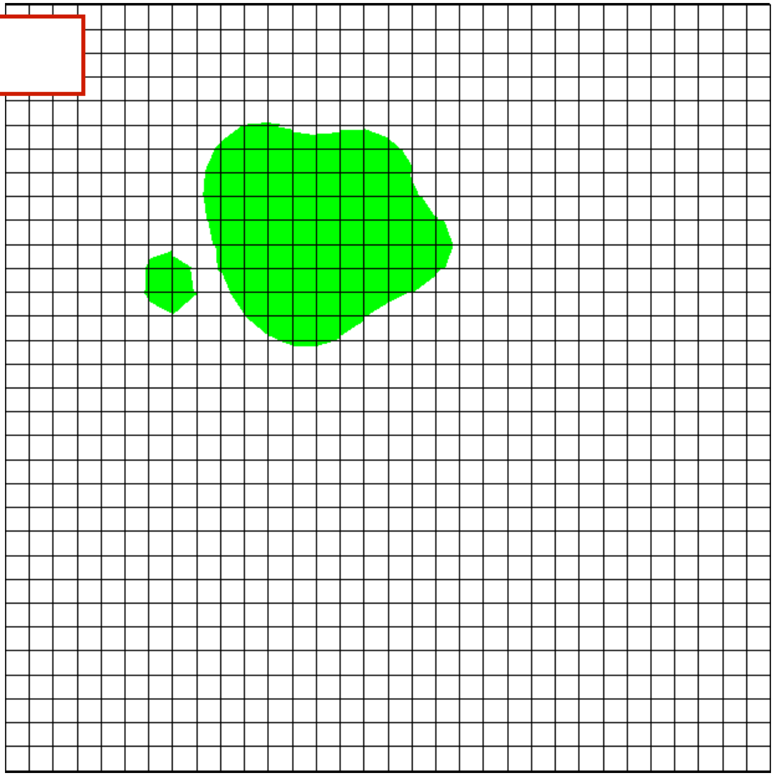
Continuity is not improved

Youngs' reconstruction early leads to blobby flows

Numerical results: Rider & Kothe's vortex

At t=T



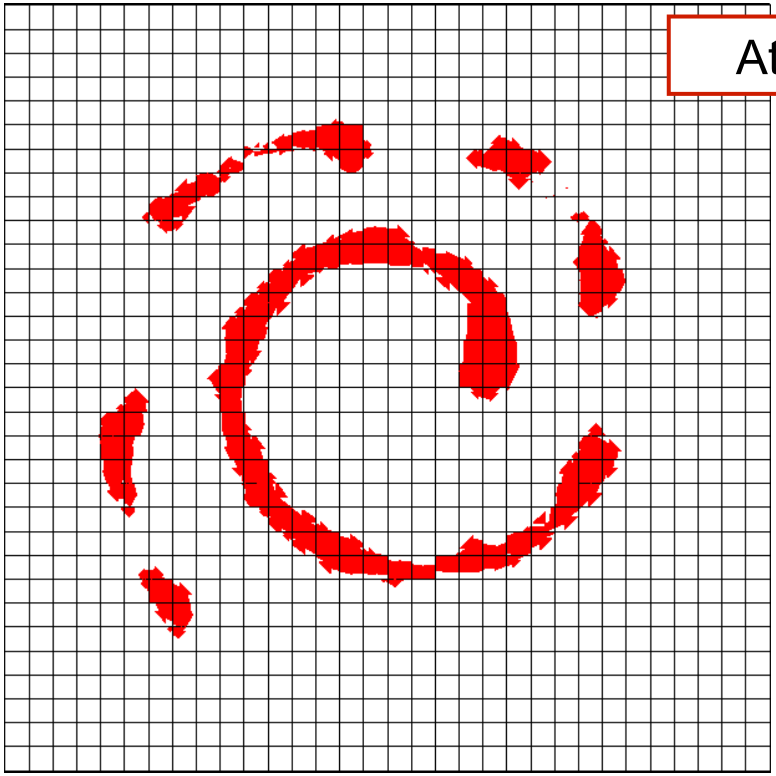


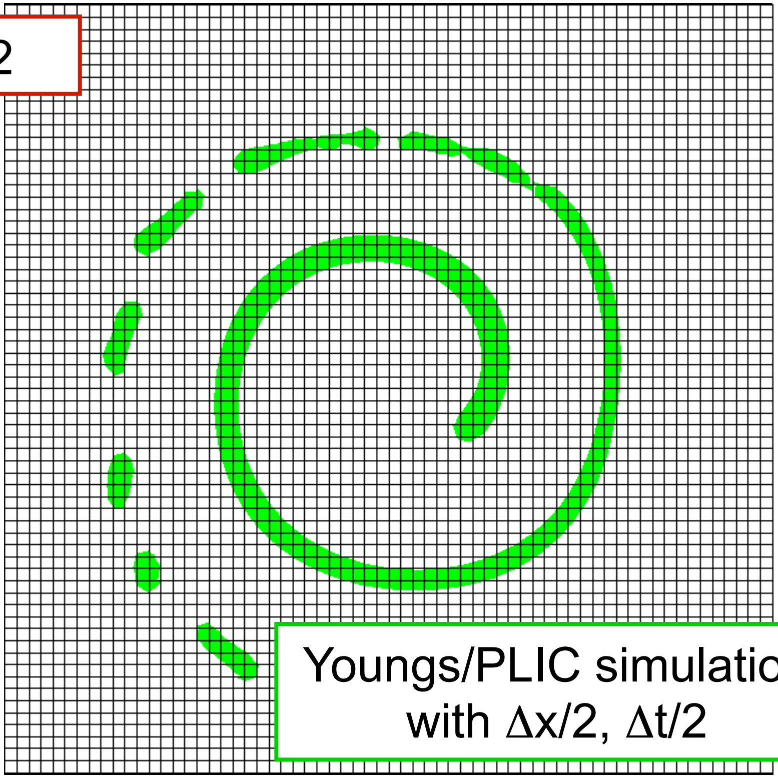
Final shape of the droplet with ASPLIC is compact

Youngs/PLIC reconstruction is not compact

Numerical results: Rider & Kothe's vortex

At t=T/2



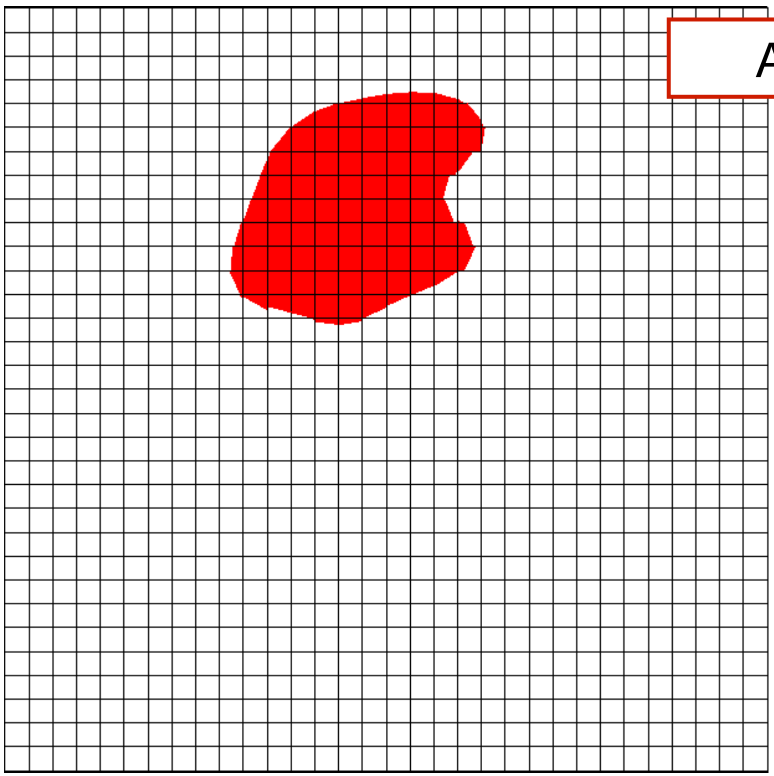


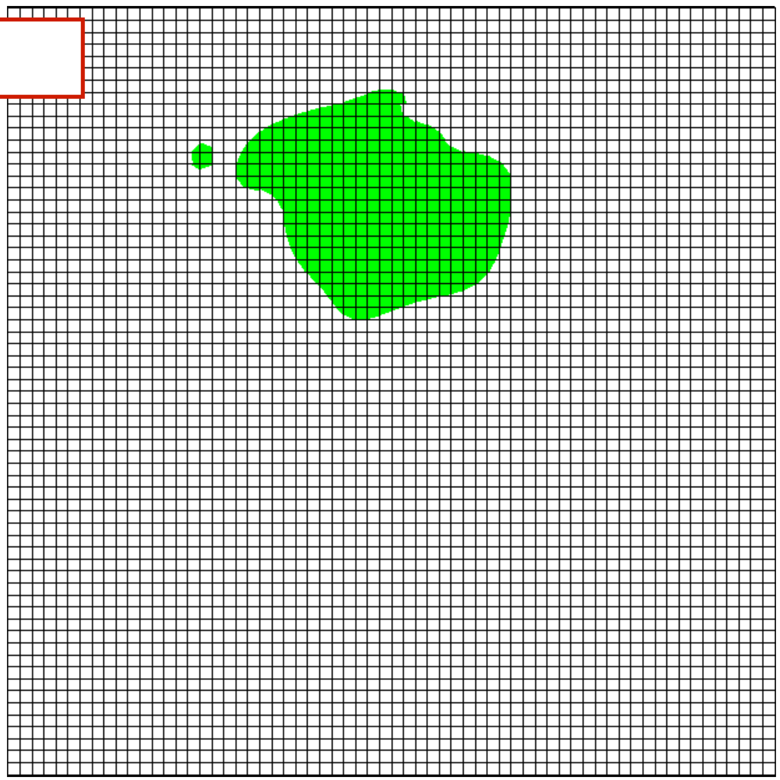
Youngs/PLIC simulation with $\Delta x/2$, $\Delta t/2$

Refined Youngs/PLIC reconstruction preserves longer the filament, but expensive computation

Numerical results: Rider & Kothe’s vortex

At t=T





Refined Youngs/PLIC reconstruction still is not compact

Numerical results: Rider & Kothe's vortex

- Comparison of computational times

Method	Time
Youngs/PLIC	30 s
ASPLIC	35 s
Youngs/PLIC refined	3 min 30 s

Quite cheap method

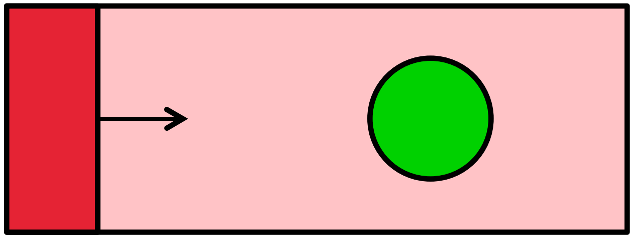
- Variation of the detection parameter, the angle between neighboring cell gradients

Results are similar with angle $\pi/8$, $\pi/4$ or $\pi/3$

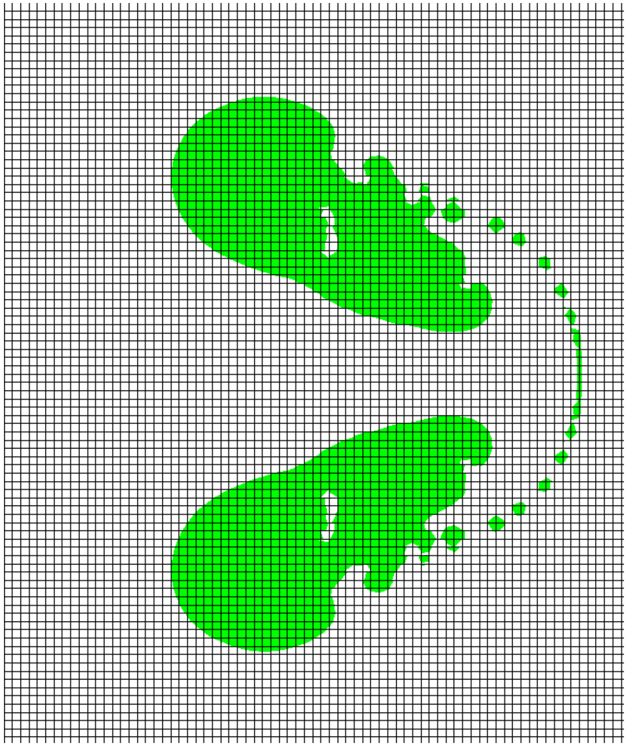
Greater angles (attempts with $\pi/2$ and $3\pi/4$) does not preserve as well the filament

Quite insensitive to the detection parameter angle, chosen $\pi/3$ in next results

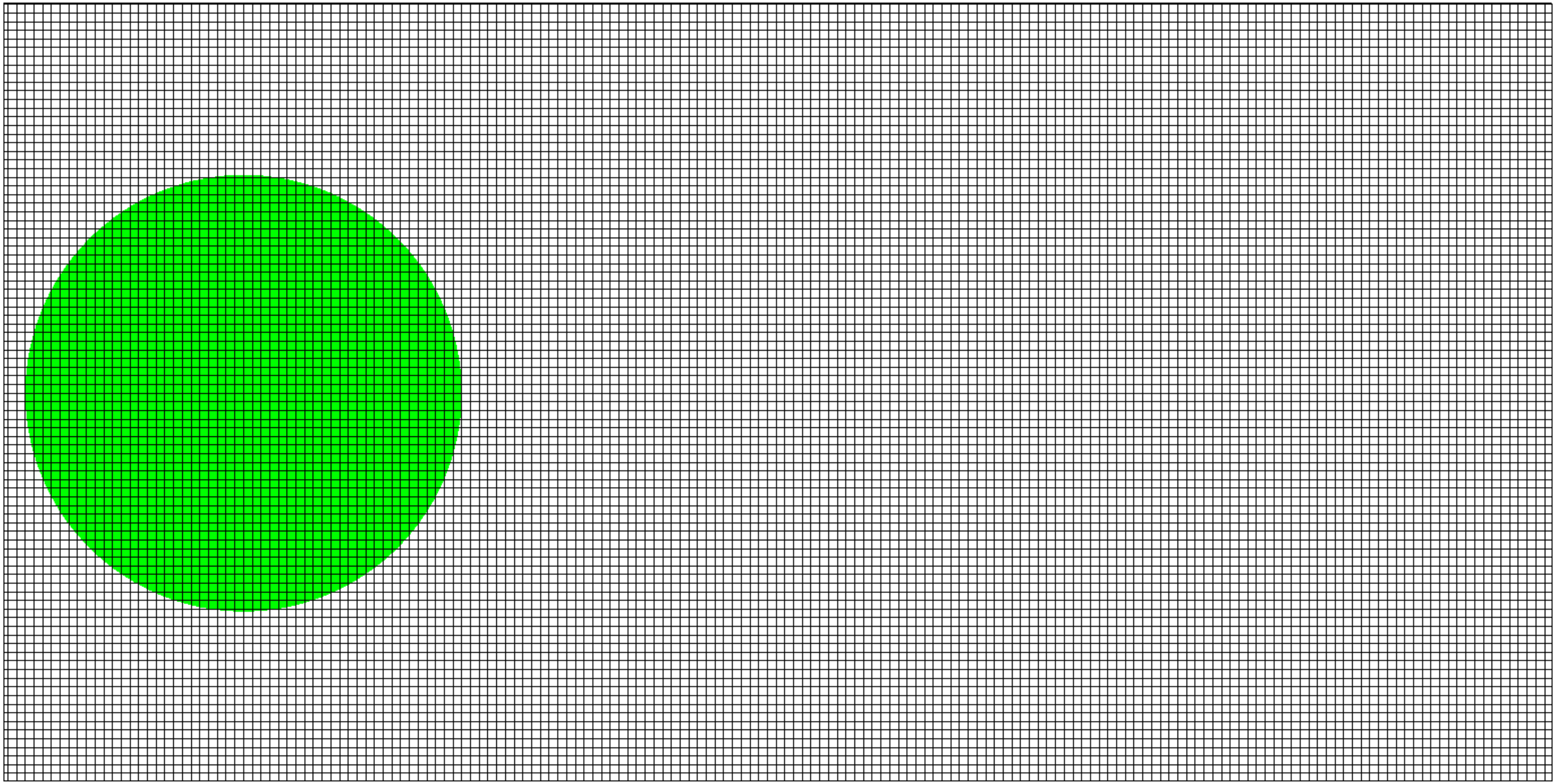
Numerical results: Haas & Sturtevant’s Shock-Bubble



- Haas & Sturtevant’s experiment of the interaction between a shock wave in air and Helium bubble
- A filament occurs at the back of the bubble
- The filament interacts with the reflective shock
- Mesh 334x90
- CFL=0.4

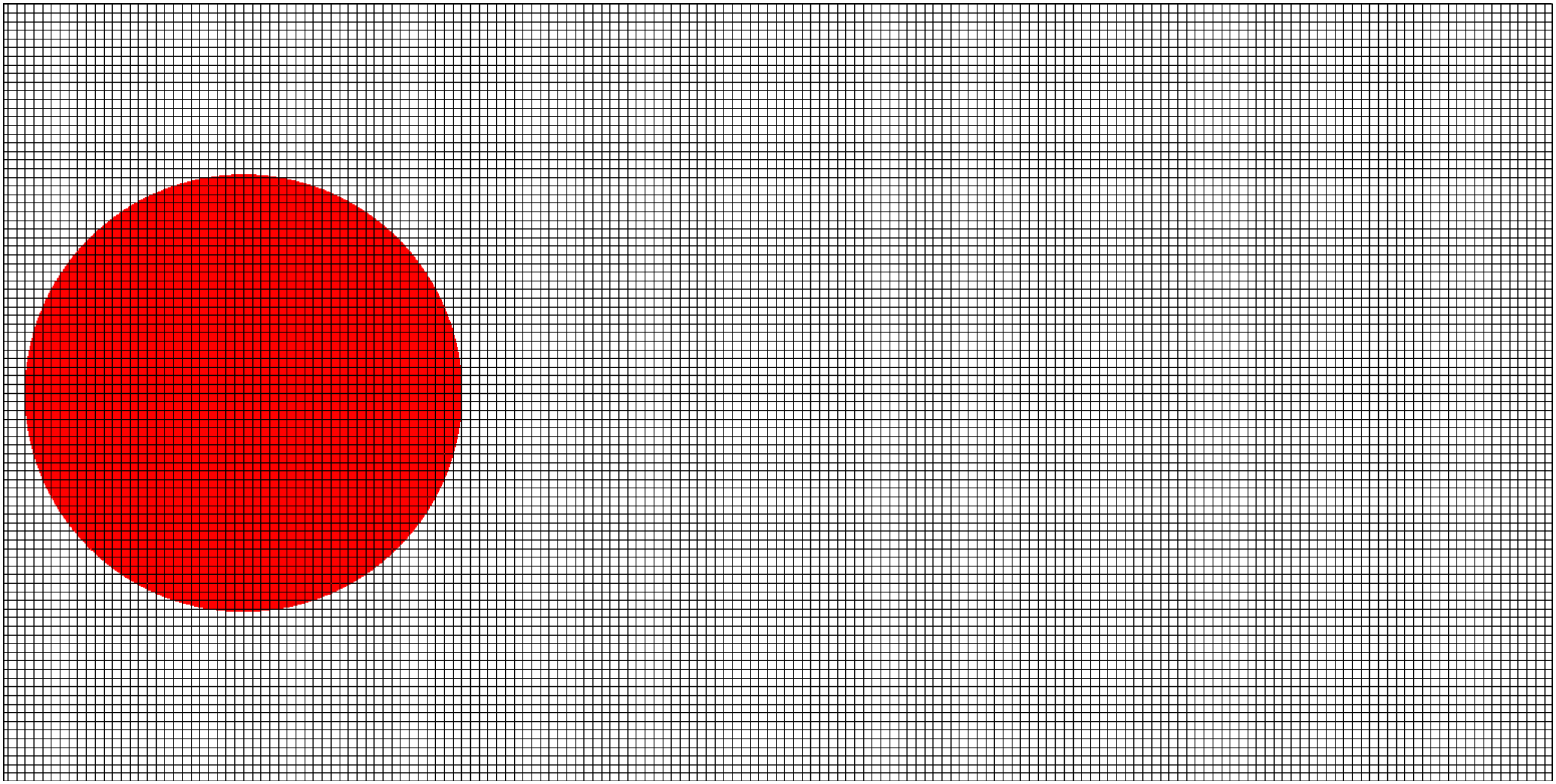


Numerical results: Haas & Sturtevant’s Shock-Bubble



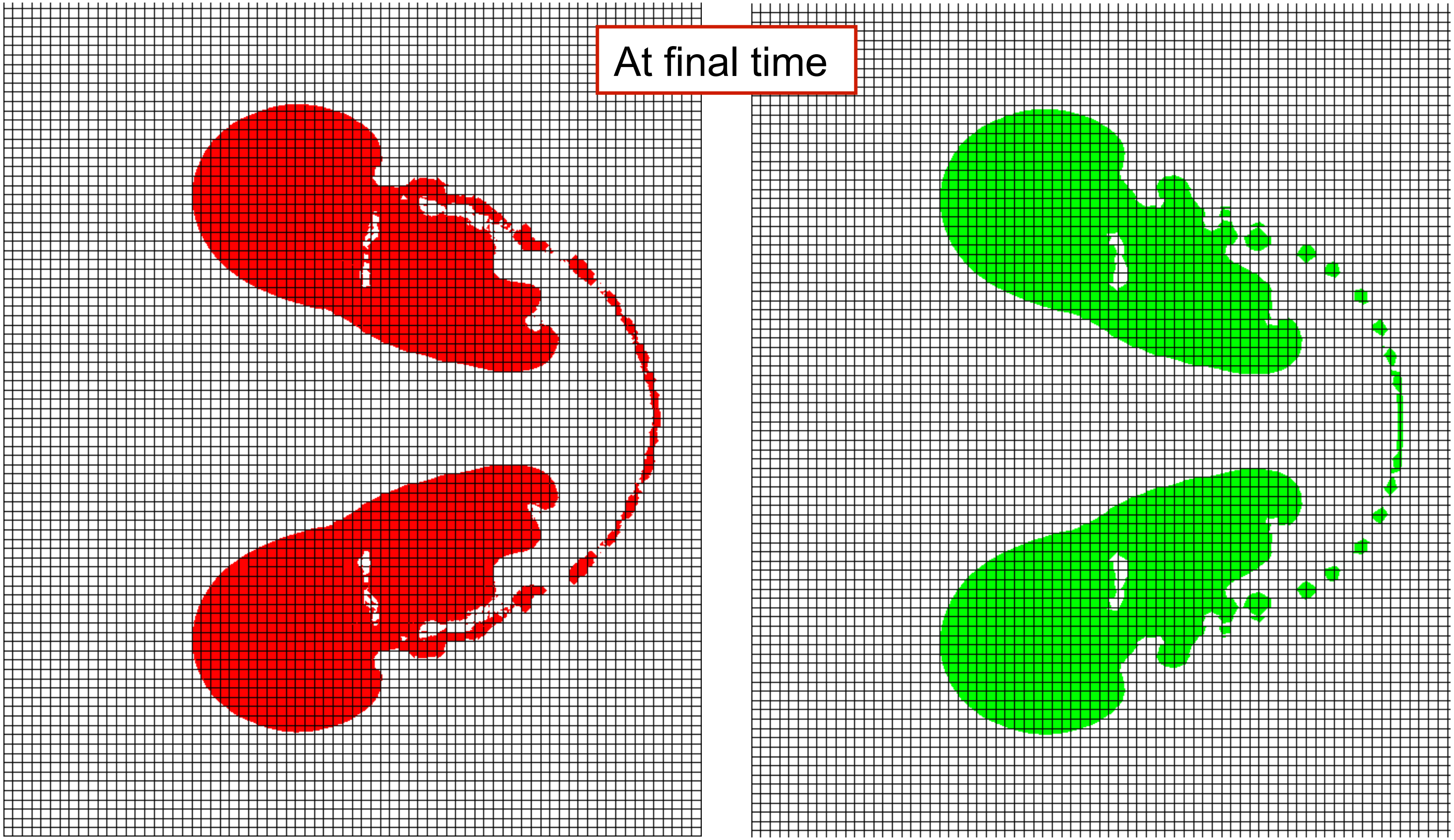
simulation with Youngs/PLIC reconstruction

Numerical results: Haas & Sturtevant’s Shock-Bubble



simulation with ASPLIC reconstruction

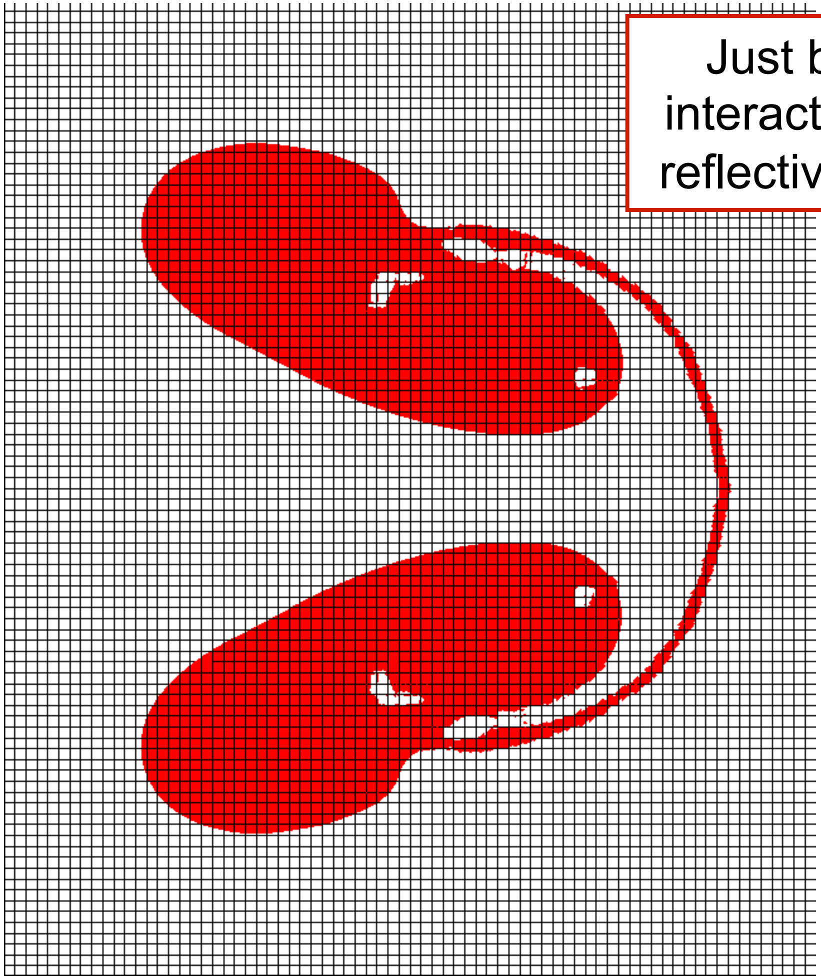
Numerical results: Haas & Sturtevant’s Shock-Bubble

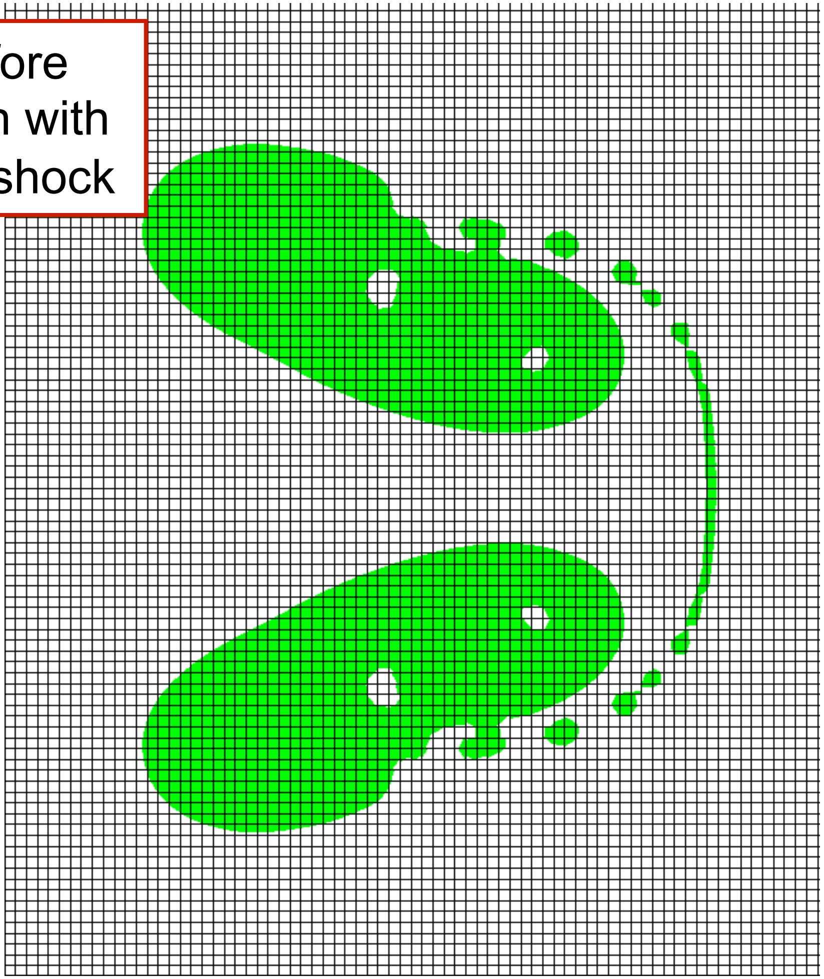


Global behavior is similar
Symmetry, even not exactly, is well preserved
Filament is better preserved

Youngs/PLIC is more fragmented

Numerical results: Haas & Sturtevant’s Shock-Bubble





Just before interaction with reflective shock

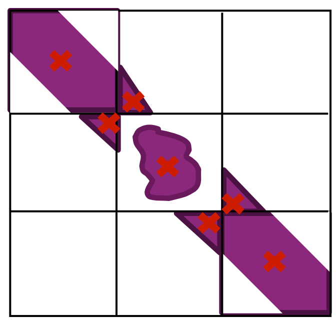
Filament is entirely preserved with ASPLIC

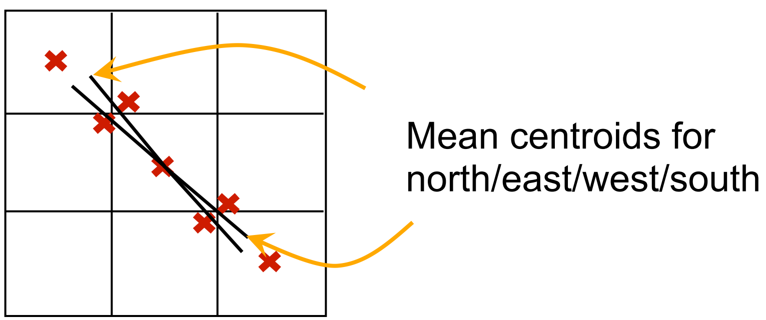
Youngs/PLIC is fragmented

Perspectives for ASPLIC

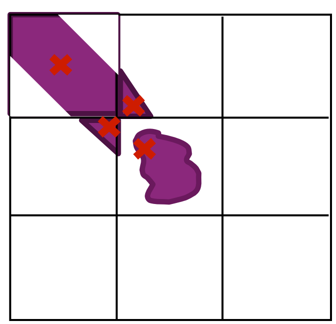
- A natural extension for ASPLIC: Adaptive Subdivision in Polygons (ASPPLIC)
- Pre-requisite: a polygonal PLIC algorithm is available
- Subdivide the cell in 4 subzones from the center as before

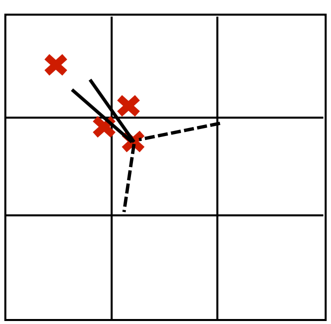
  → but not a regular cutting: follow the line linking neighbor centroids





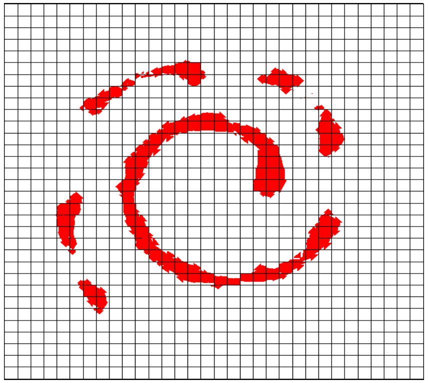
- If less than 4 subzones, complete with a subdivision « regular in angle »

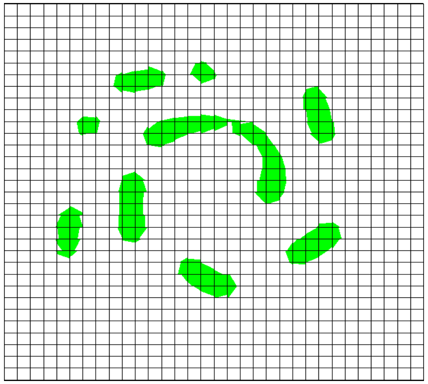




Conclusion (1)

- A subgradient method to compute VoF/PLIC interfaces in subzones has been proposed, based on an Adaptive Subdivision with PLIC (ASPLIC)
- Not a subgrid physical model: method as geometrical as original VoF with the same volume fraction field information
- Not a visualization tool: continuity of the interface is not ensured
- Quite cheap geometrical flux method improving Youngs/PLIC for hydrodynamical flows involving thin interface structures





Conclusion (2)

- Most of the steps of the method may be improved or optimized: detection filter, choice of the subgradients, of the subdivision, of the centroids, …

- A richer adaptive subdivision is possible yet (if polygonal PLIC is available): an Adaptive Subdivision in Polygons (ASPPLIC) rather than rectangular subzones
  - ✓ Implementation in progress
  - ✓ Should improve static representations, continuity of interfaces and we hope fluxes still more accurate

- AS(P)PLIC formalism may not be restricted to filaments but used for other « boring details » such as triple points
  - ✓ The center of subdivision = point separating subzones with only 2 fluids per subzone, given by analysis of the presence in the stencil

- Extension to 3D is immediate, as well as extension to unstructured mesh

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