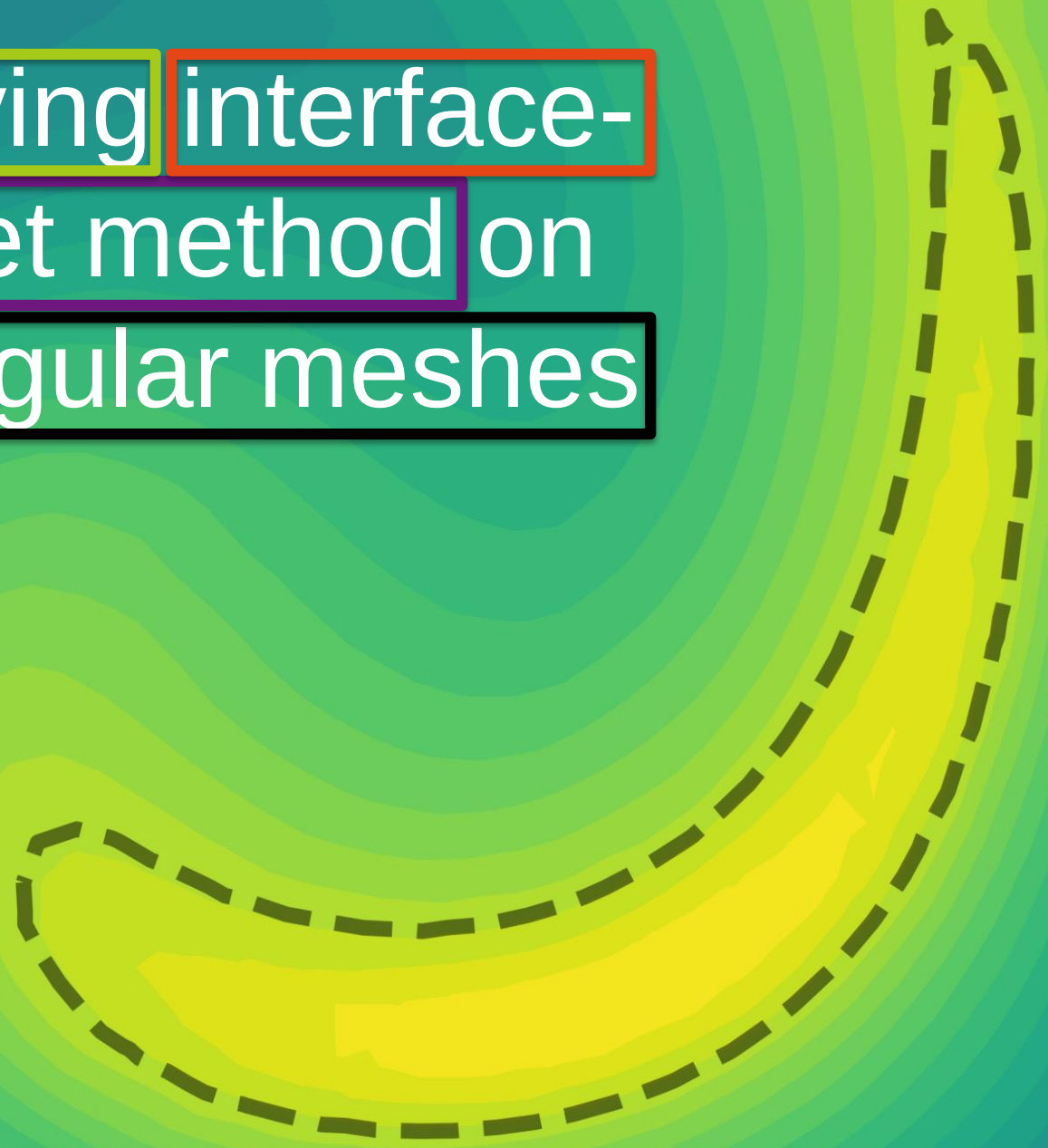
A volume-conserving interface-correction level-set method on unstructured triangular meshes

Arthur Kerst



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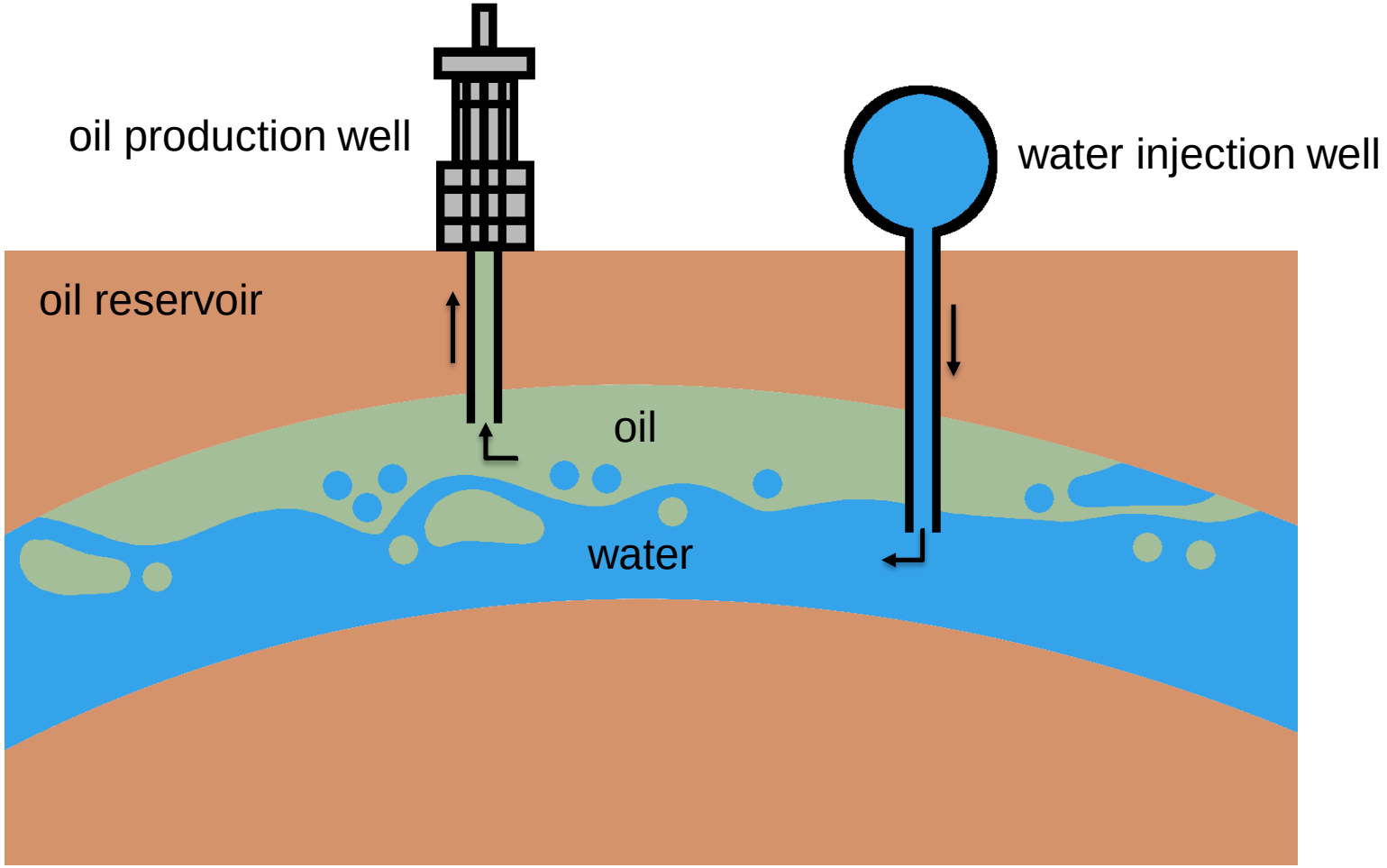
Two-phase flows: examples

- I: coal and gas-fired power stations
- II:



Two-phase flows

- Fundamental tools in many industrial applications and natural processes
- Far more challenging than single phase flow
- Accurately modelling the interface and demanding volume conservation

level-set method

Goal of project

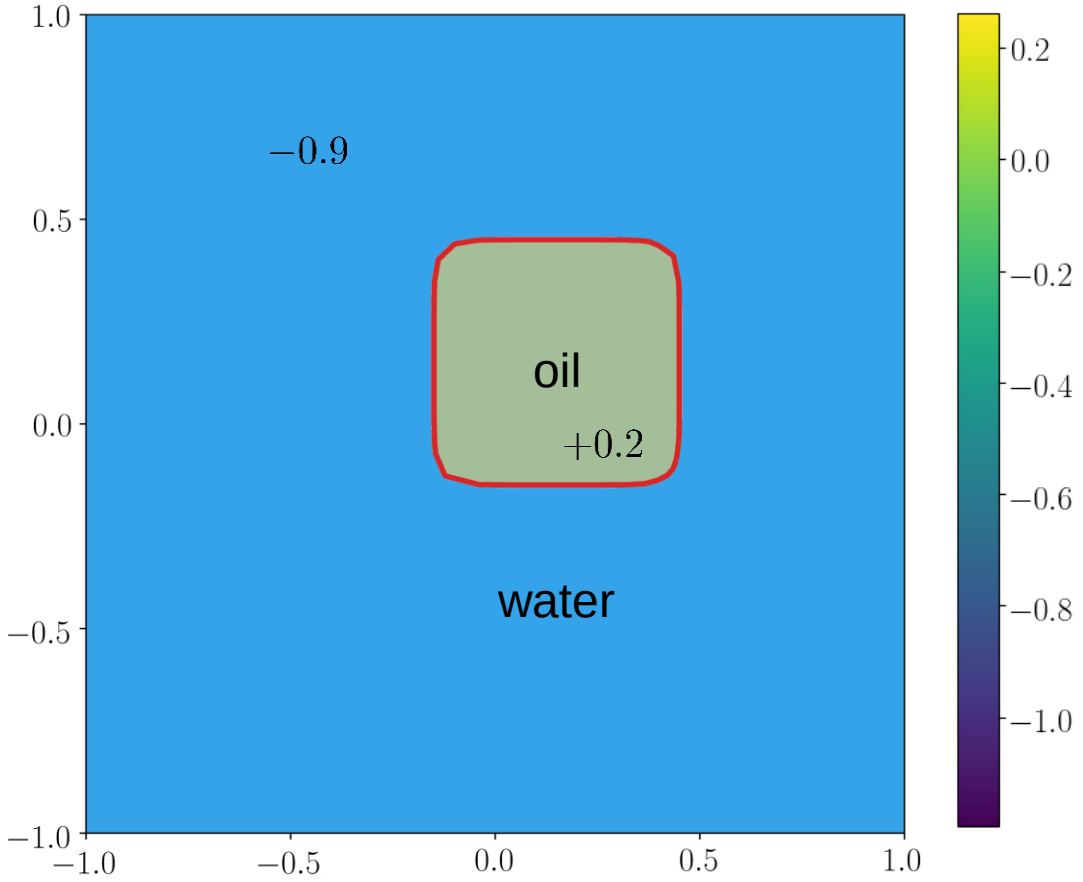
Goal: *develop a level-set method that…*

- conserves volume
- has a continuous description of the interface
- tracks interface accurately
- is able to handle unstructured triangular meshes

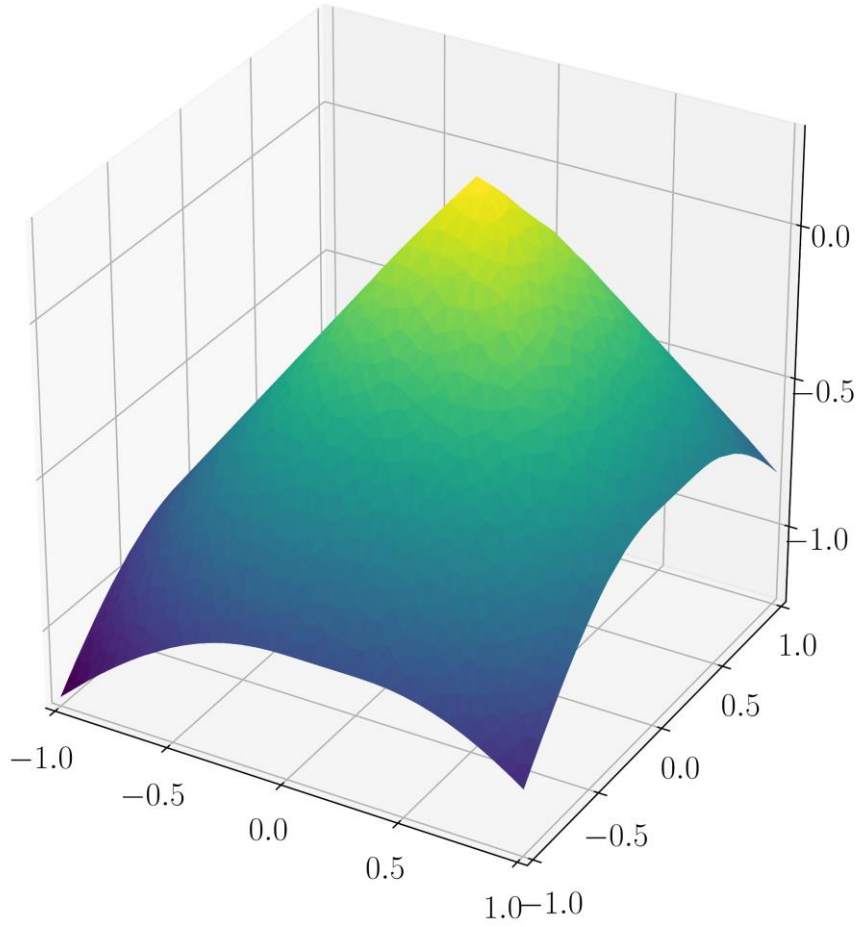
Level-set method

$\phi(\mathbf{x}, t) :=$ level-set field

$\phi(\mathbf{x}, 0) =$ signed-distance function



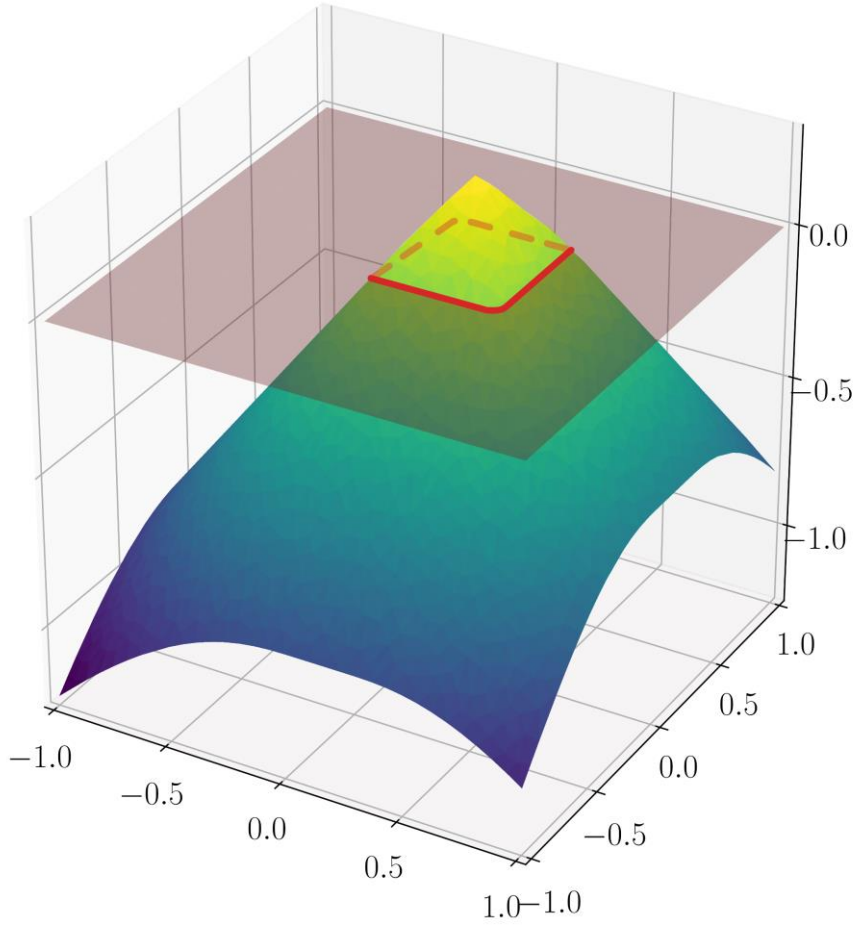
2D



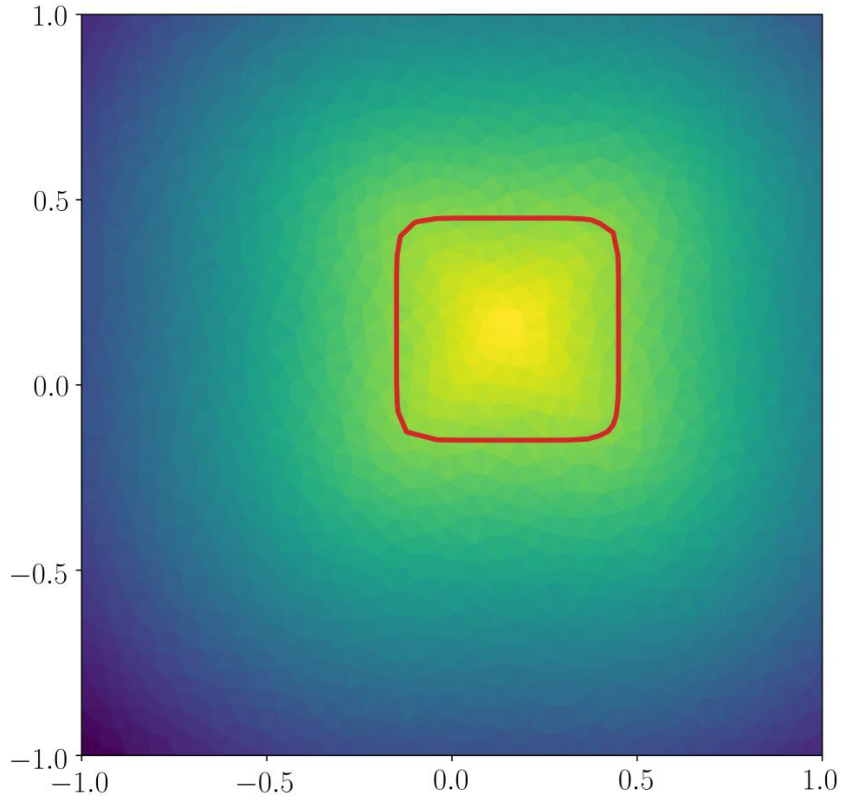
3D

Level-set method

Advection: transport of a substance by flow



3D



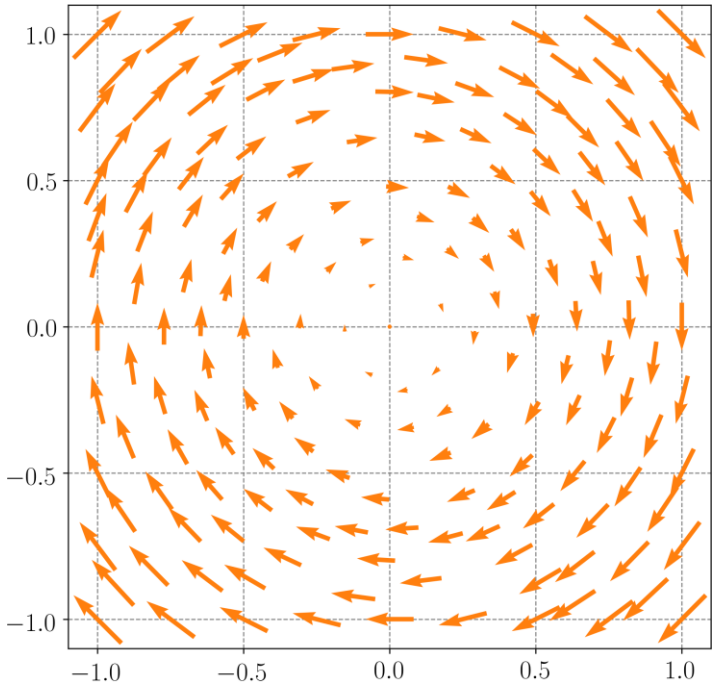
2D

Level-set method

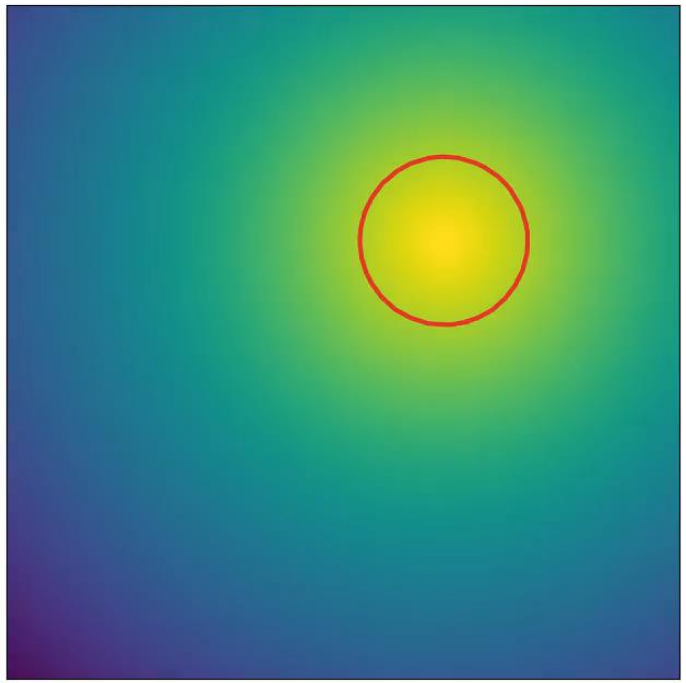
Advection: transport of a substance by flow

$$\frac{\partial \phi}{\partial t} + \mathbf{u} \cdot \nabla \phi = 0$$

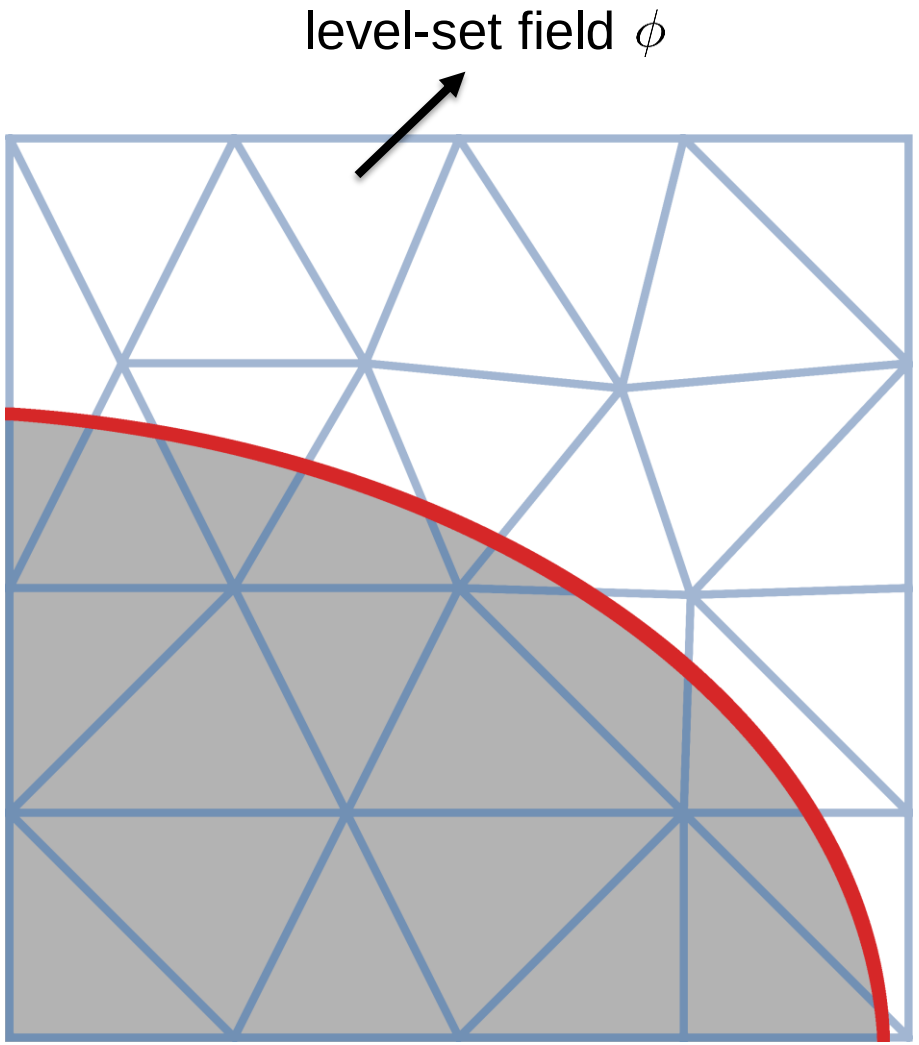
velocity field $\mathbf{u}$



level-set field ϕ

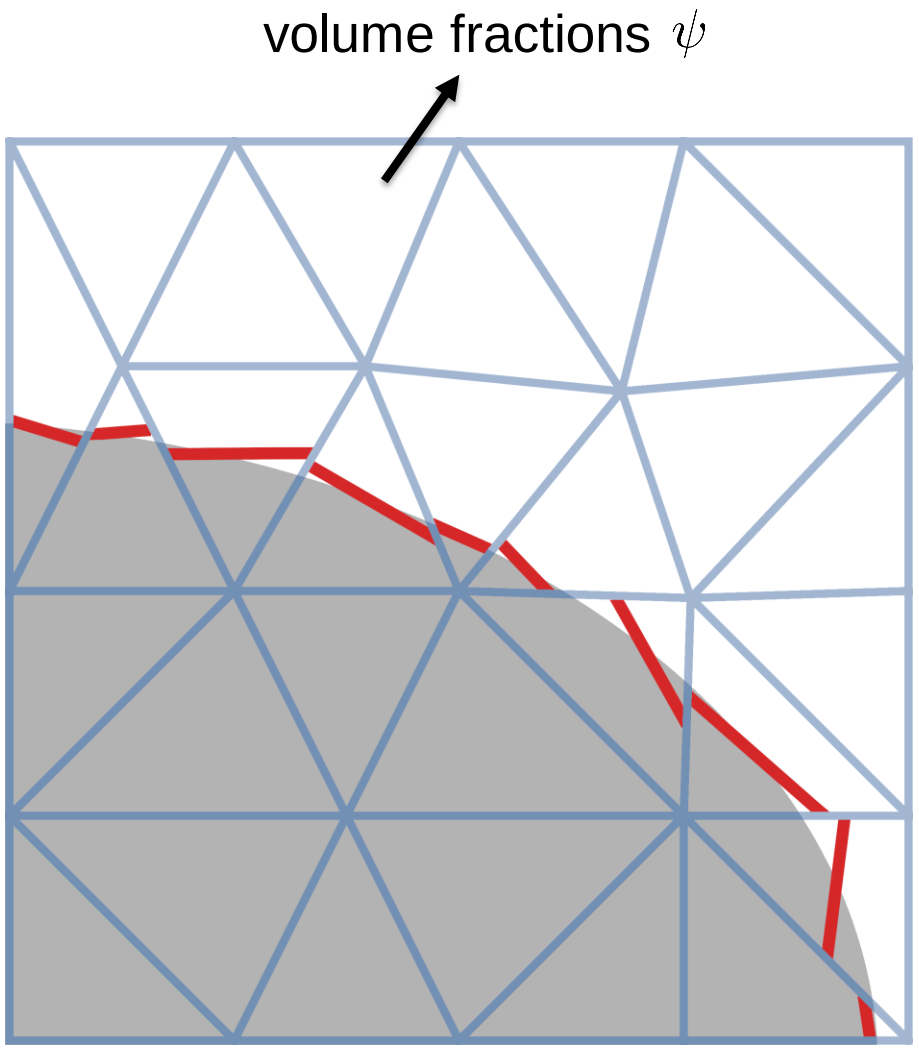


Level-set method



- Advantage
  - Continuous interface
- Disadvantage
  - Not volume conserving

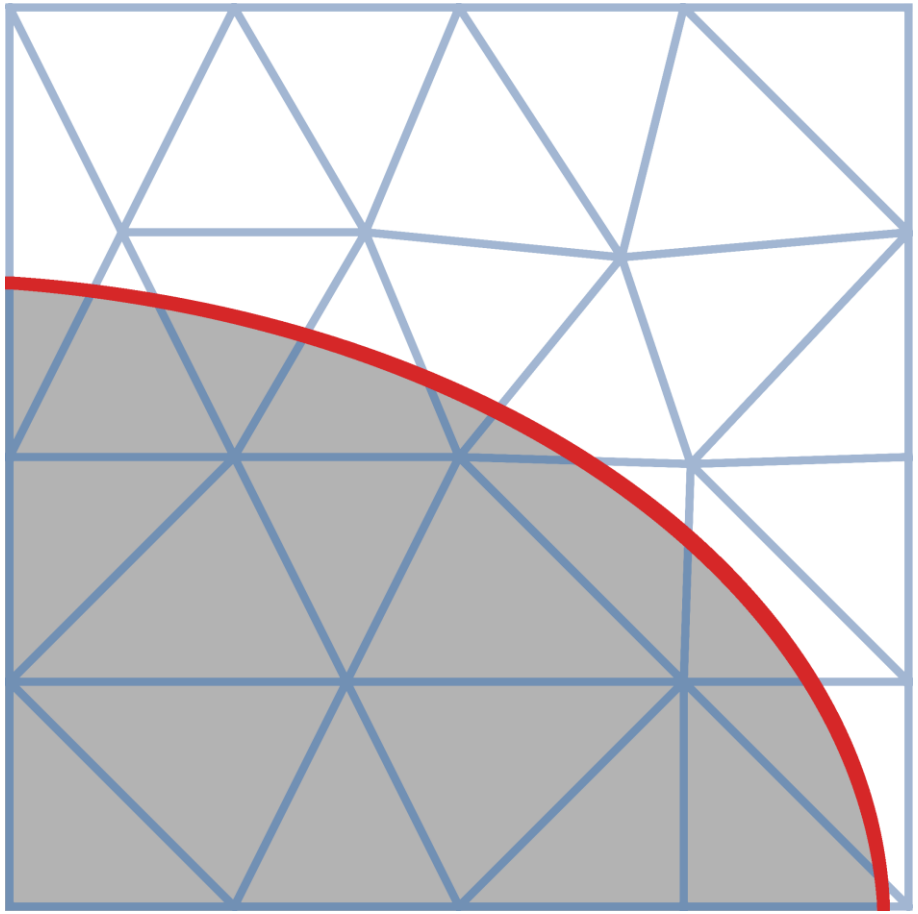
Volume-of-fluid method



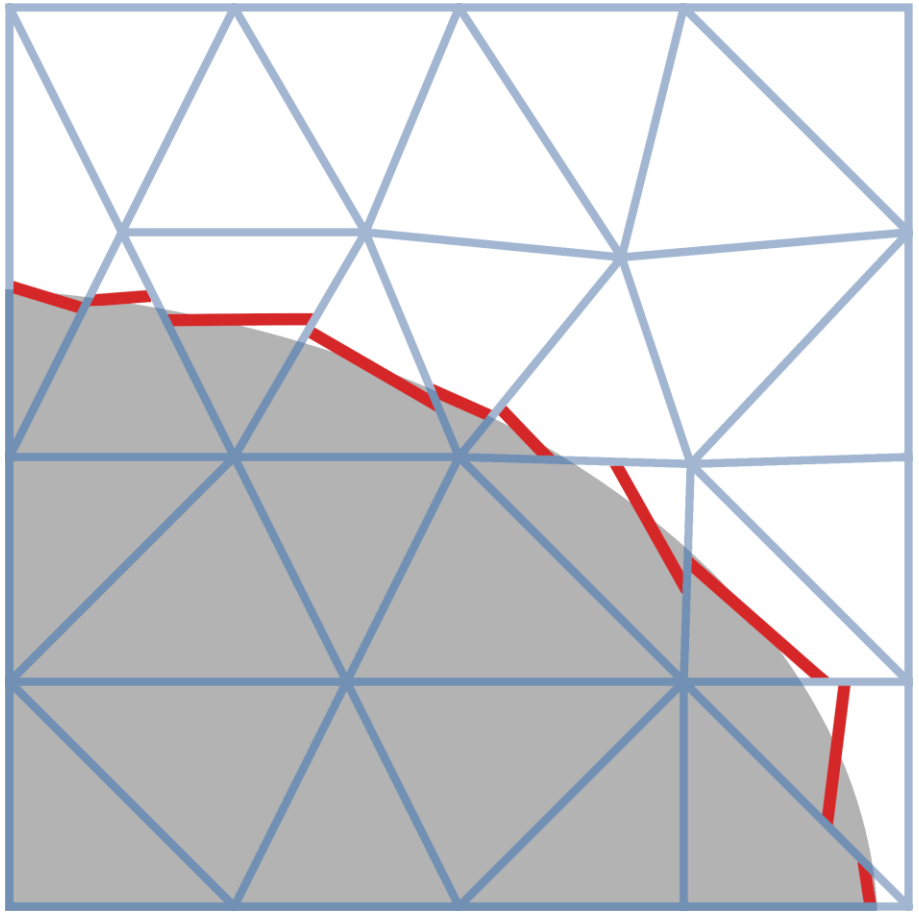
- Advantage
  - Volume conservation
- Disadvantage
  - Discontinuous interface

Level-set method vs. volume-of-fluid method

continuous ✓



volume-conserving ✓

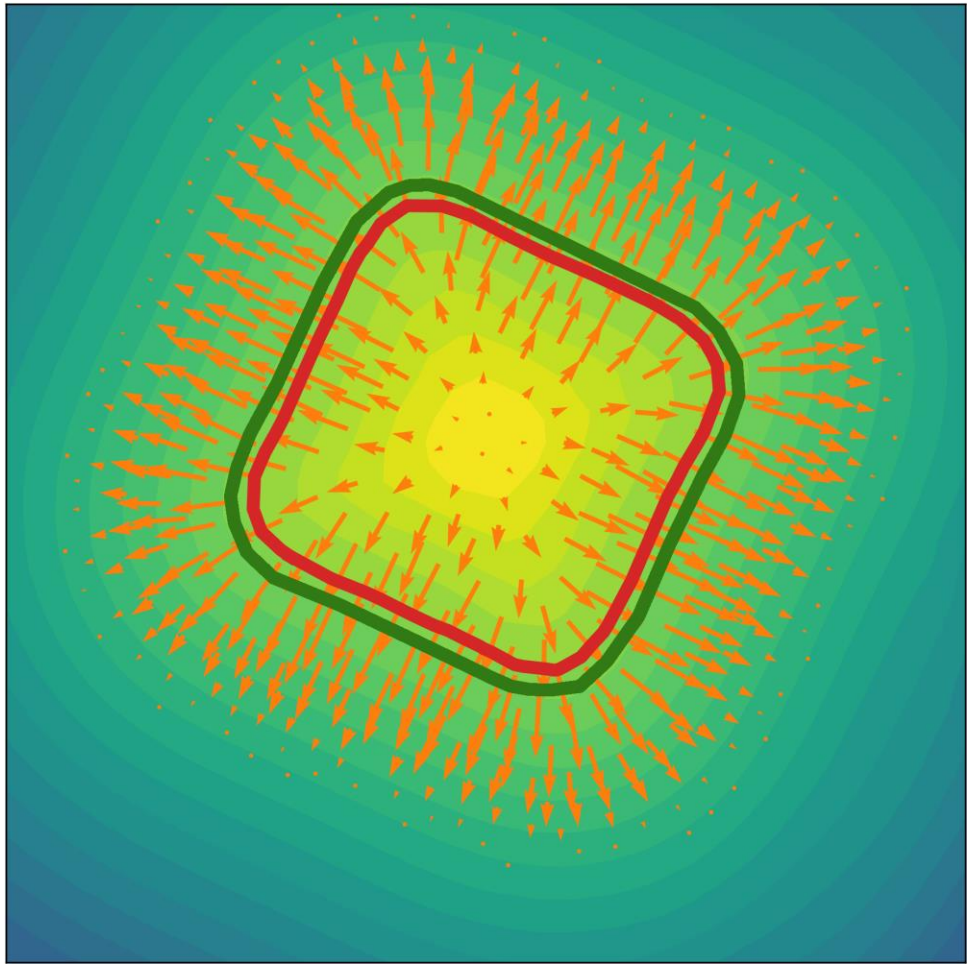


Improvements to the level-set method

- Hybrid methods
- Volume correction methods

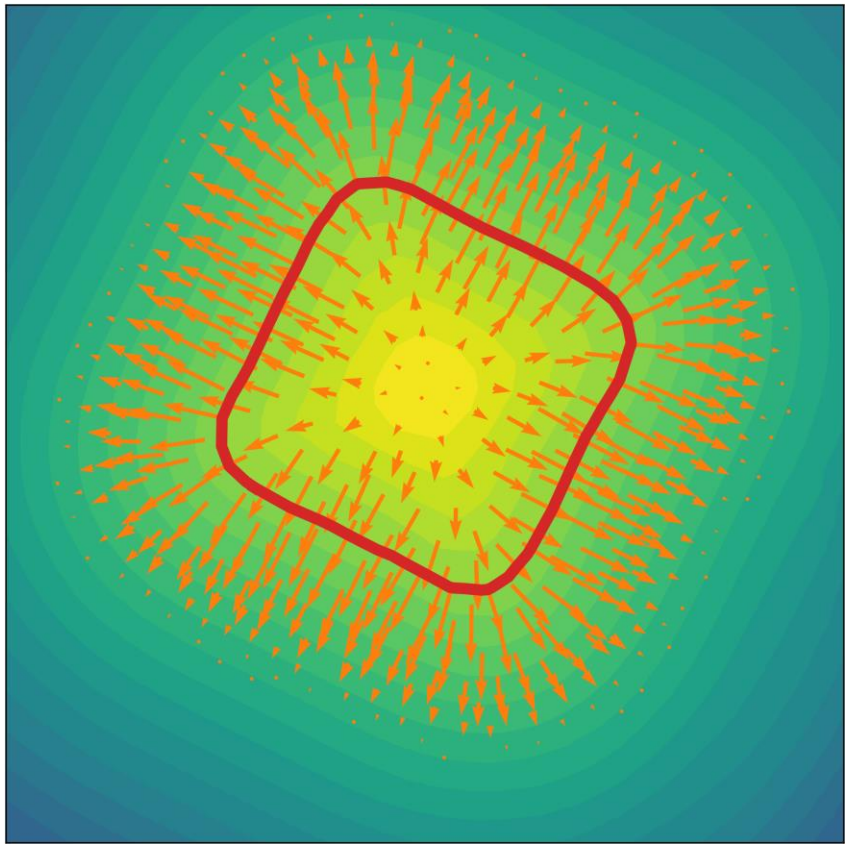
Interface-correction level-set (ICLS) method

- Velocity field from gradient of level-set field
- Scaling based on volume loss/gain
- Advection with correction-velocity

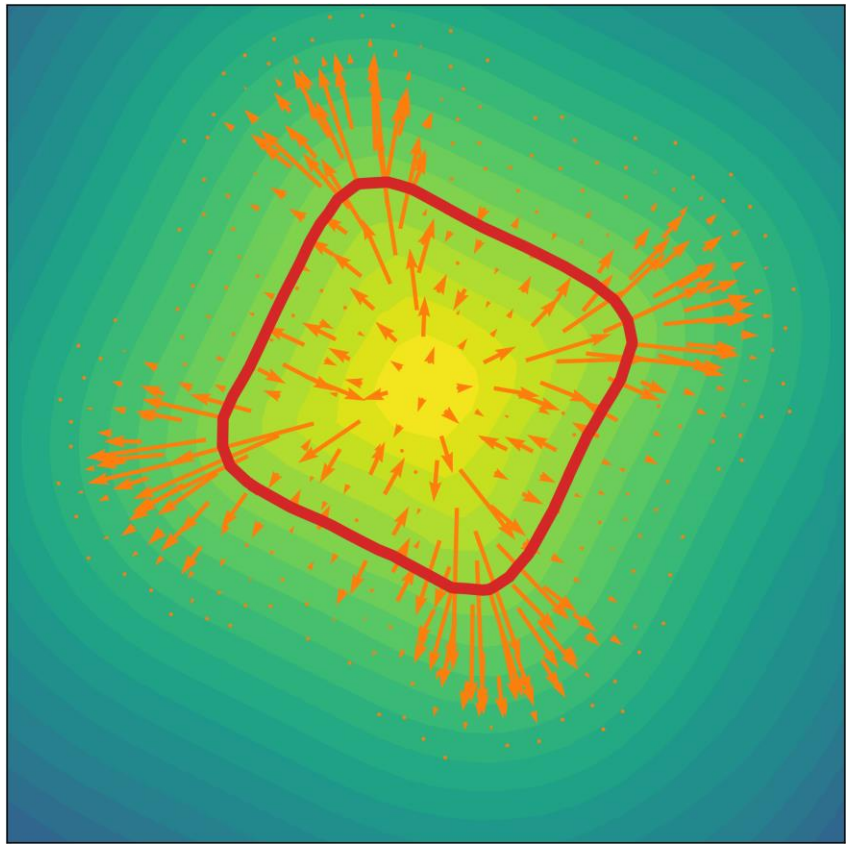


Construction of correction-velocity

- ICLS method uses a speed function



uniform speed function

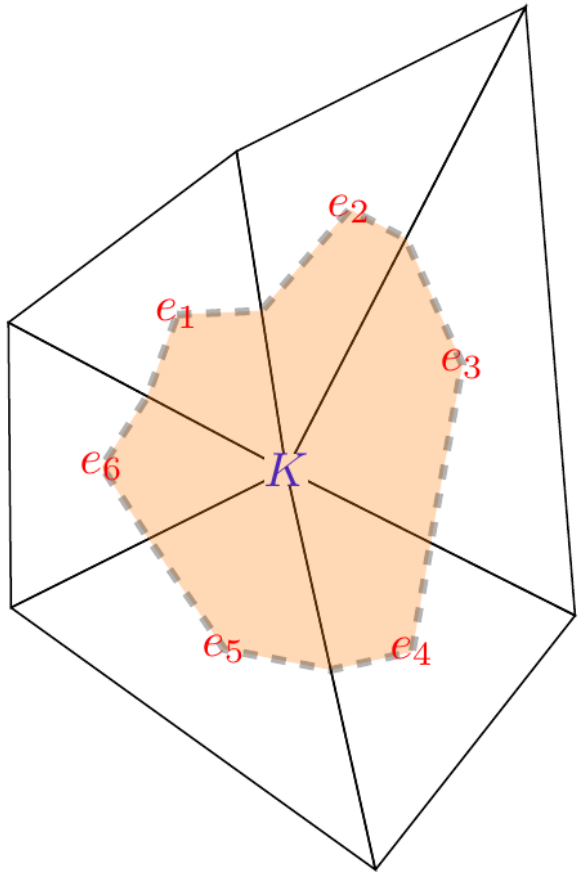


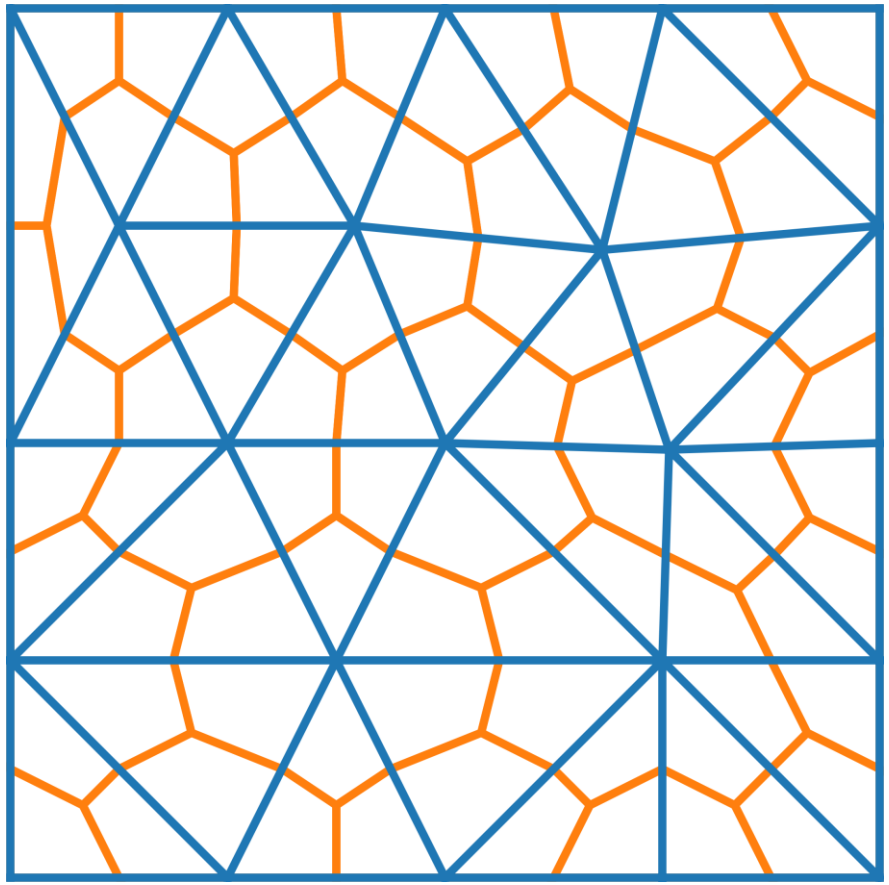
curvature-dependent speed function

Developed method in this thesis

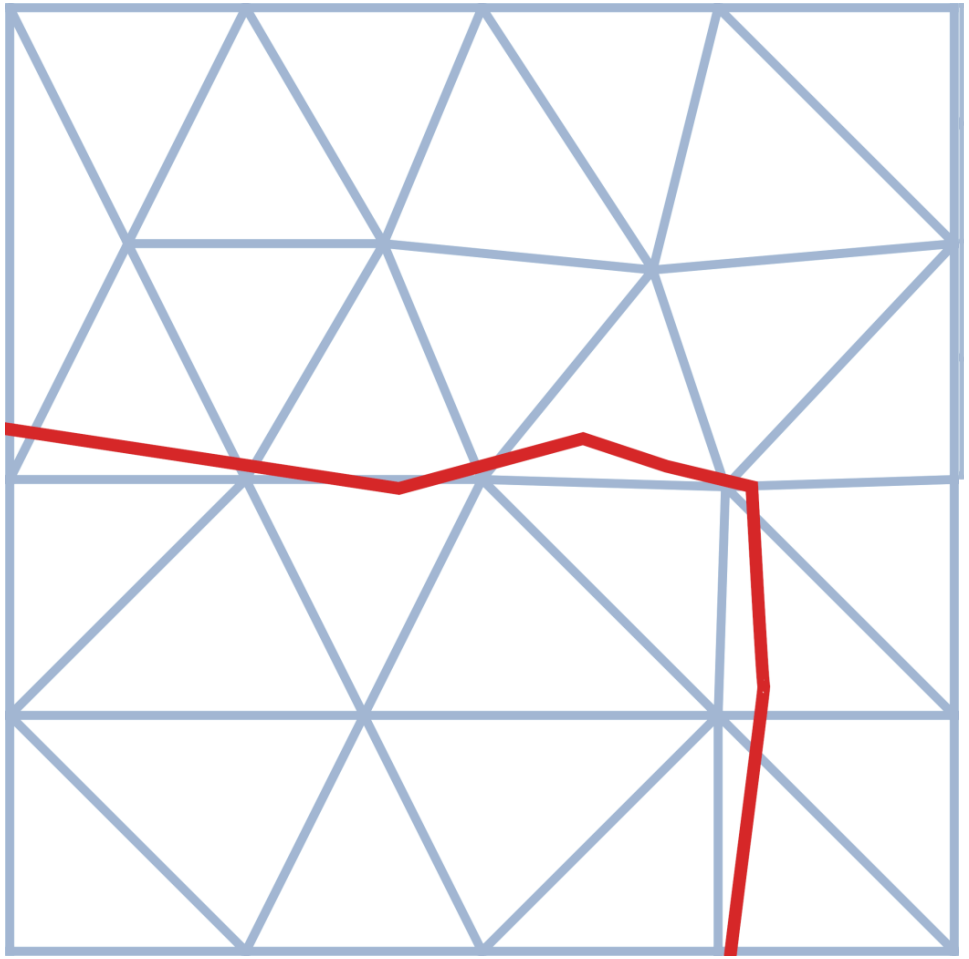
- Volume-of-fluid-based local interface-correction level-set method (VOF-LICLS)
- Uses correction-velocity
- Combination with volume-of-fluid (VOF) method
- Aims to restore volume locally

Dual mesh construction



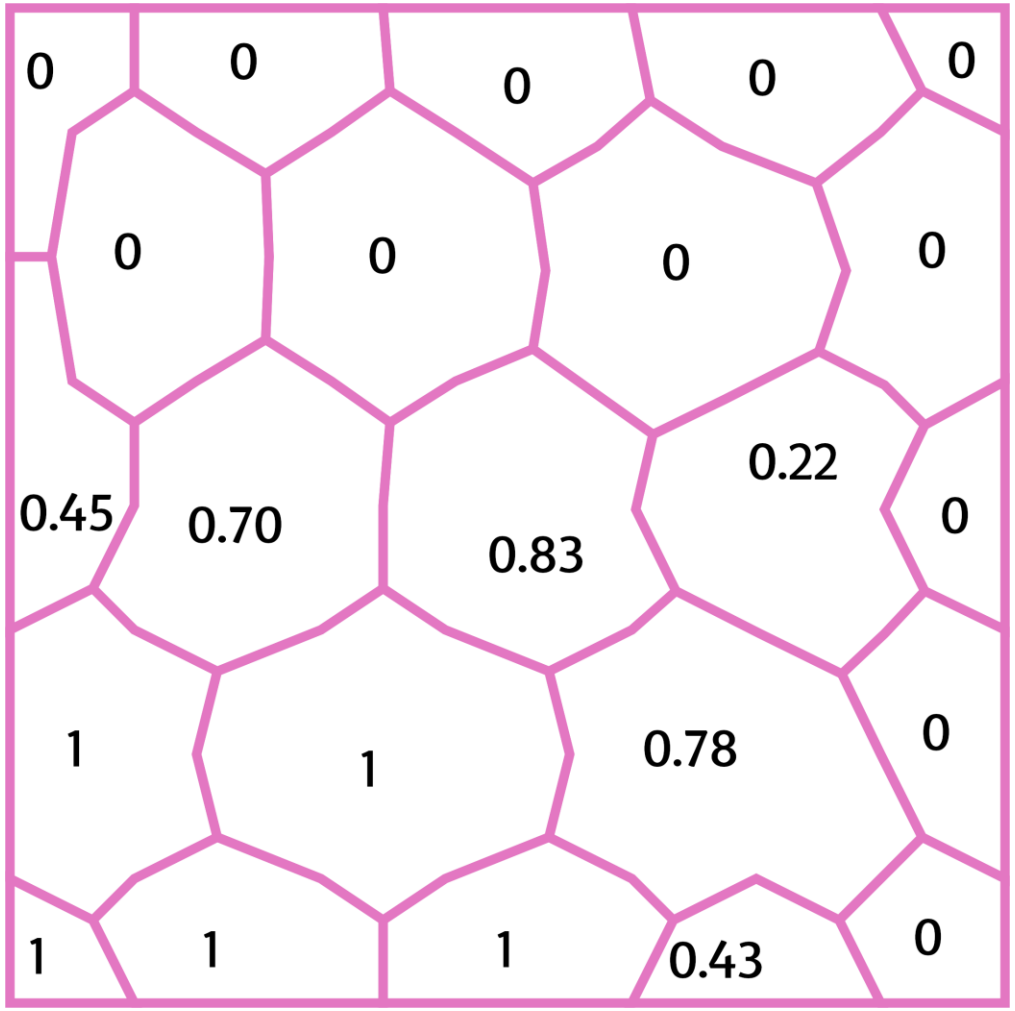


Construction of correction-velocity



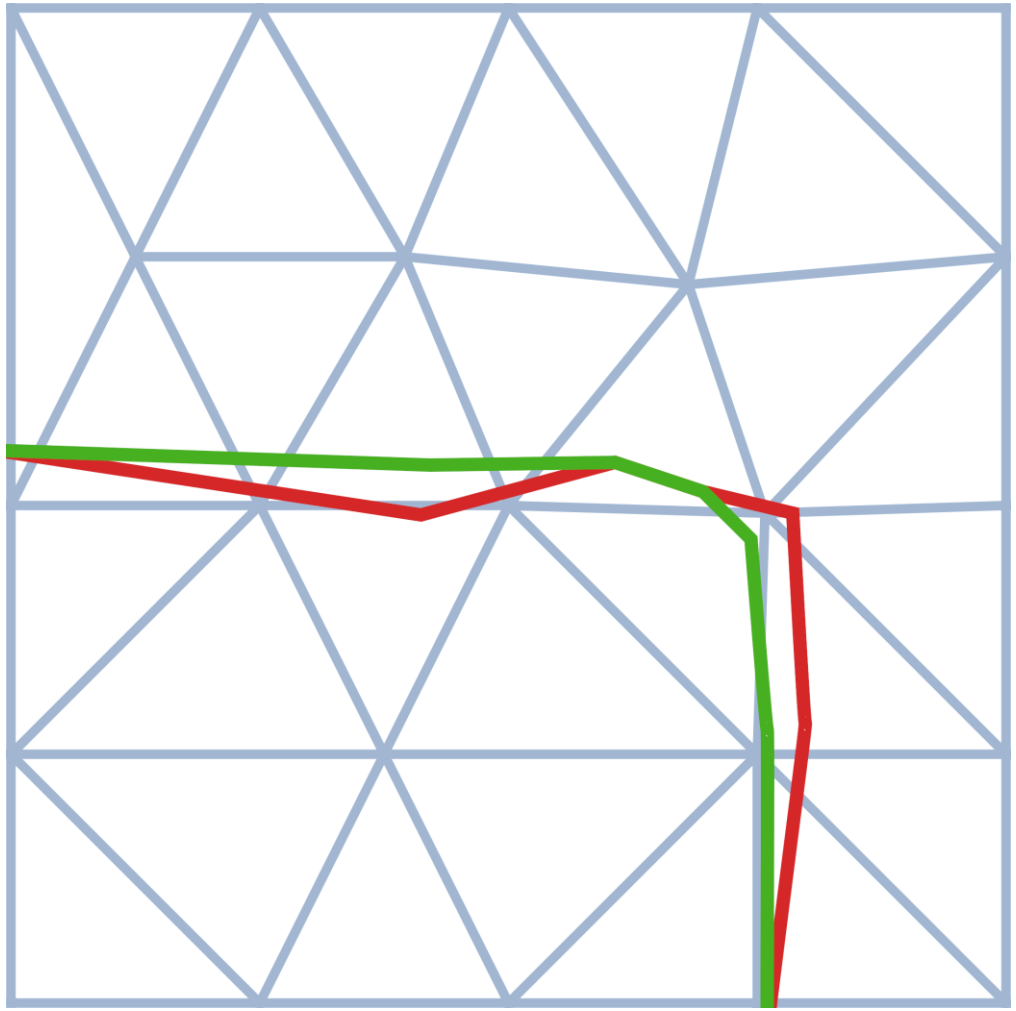
Construction of correction-velocity

VOF -> **correct** volume fractions



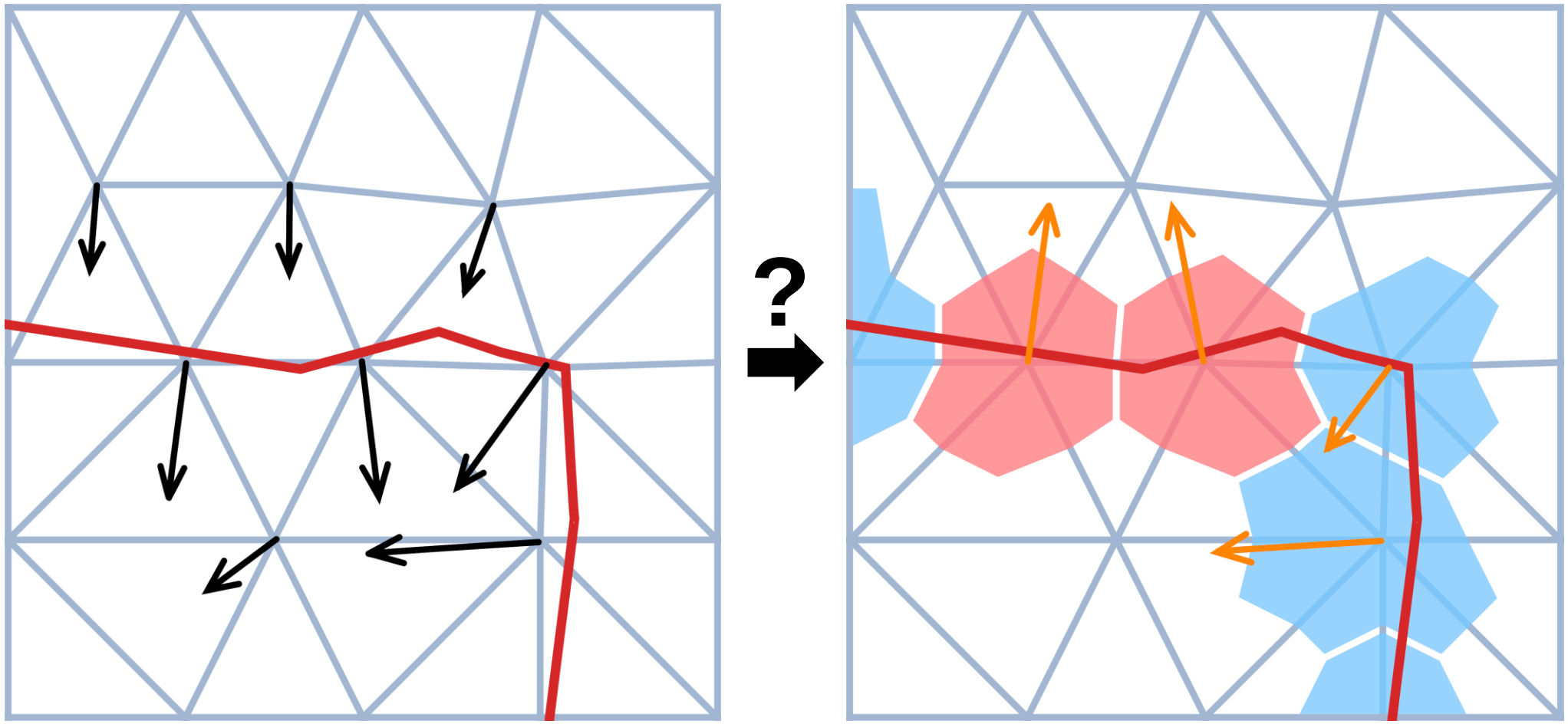
Advected volume fraction field

LS -> **incorrect** volume fractions



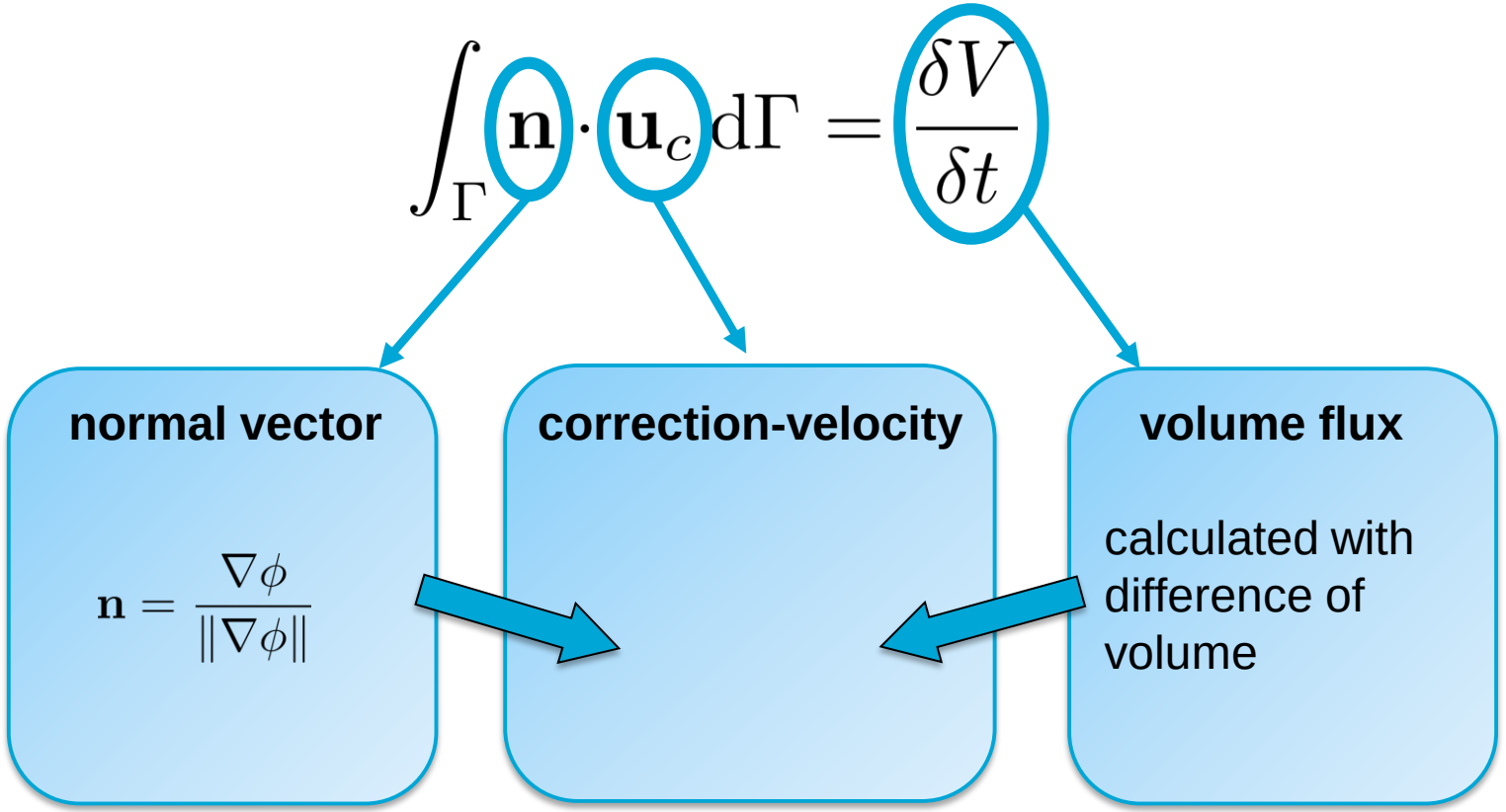
Difference volume fraction fields

Construction of correction-velocity



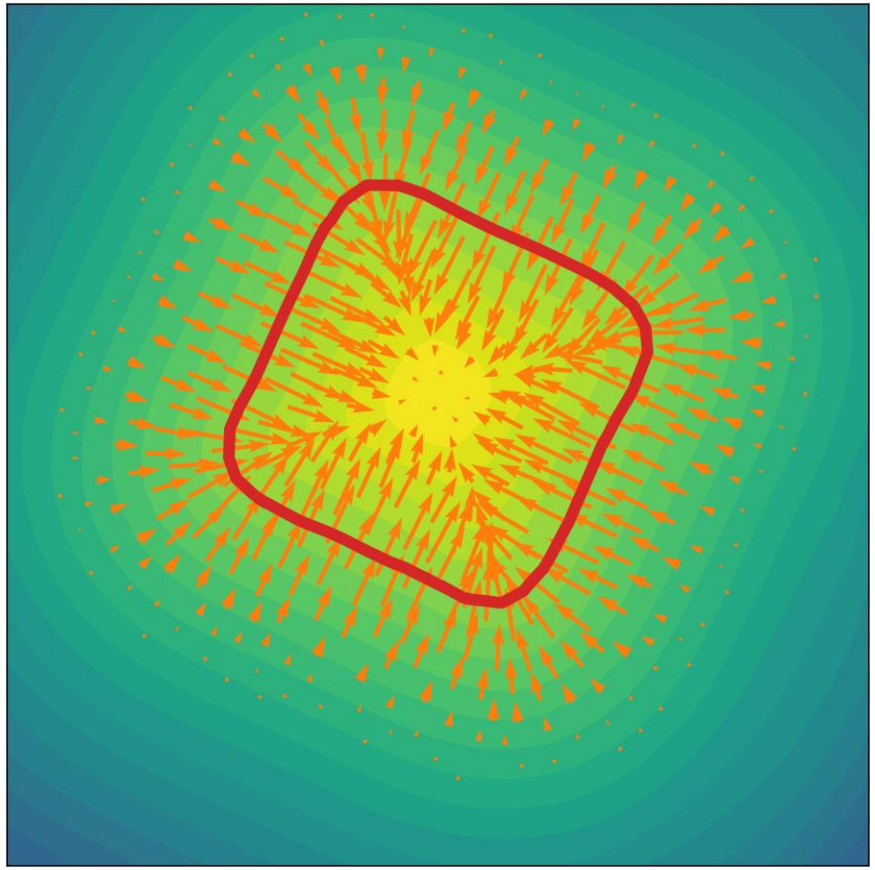
Construction of correction-velocity

- The rate of change in volume must correspond to the total flux of the fluid out of the boundary of the region.



Construction of correction-velocity

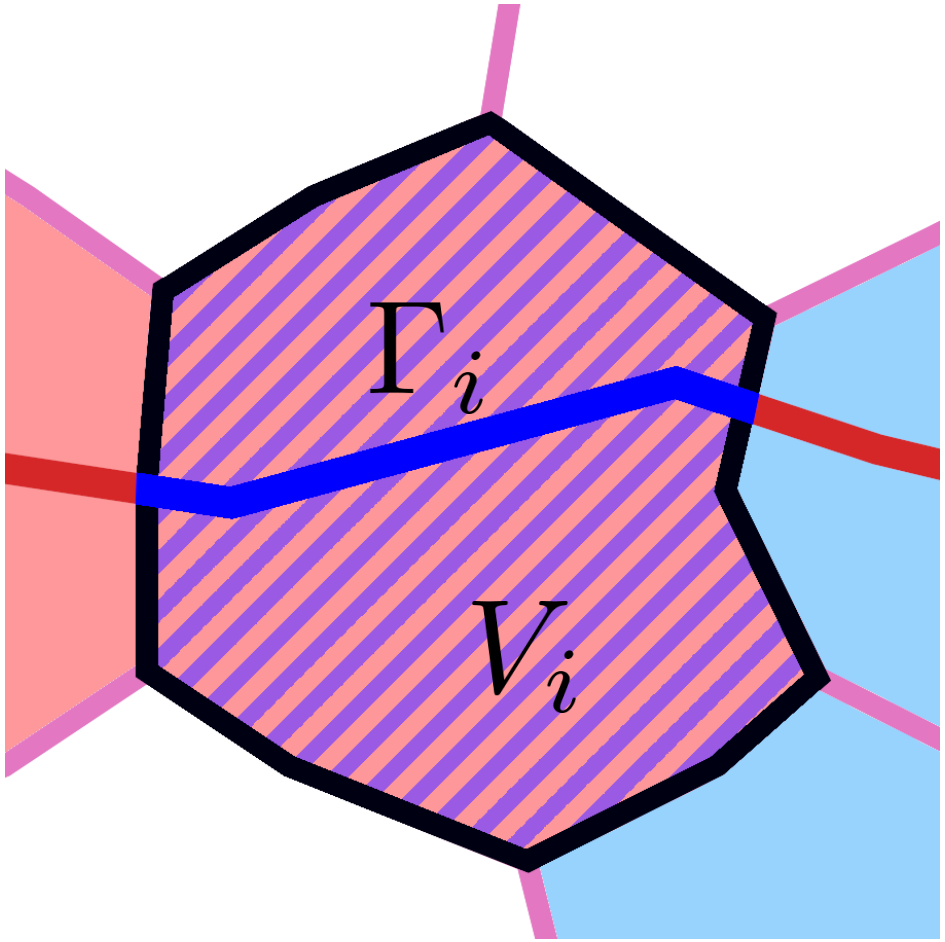
- ICLS: global volume conservation



$$\int_{\Gamma} \mathbf{n} \cdot \mathbf{u}_c \, \mathrm{d}\Gamma = \frac{\delta V_{\mathrm{total}}}{\delta t}$$

Velocity is pointed inward or outward

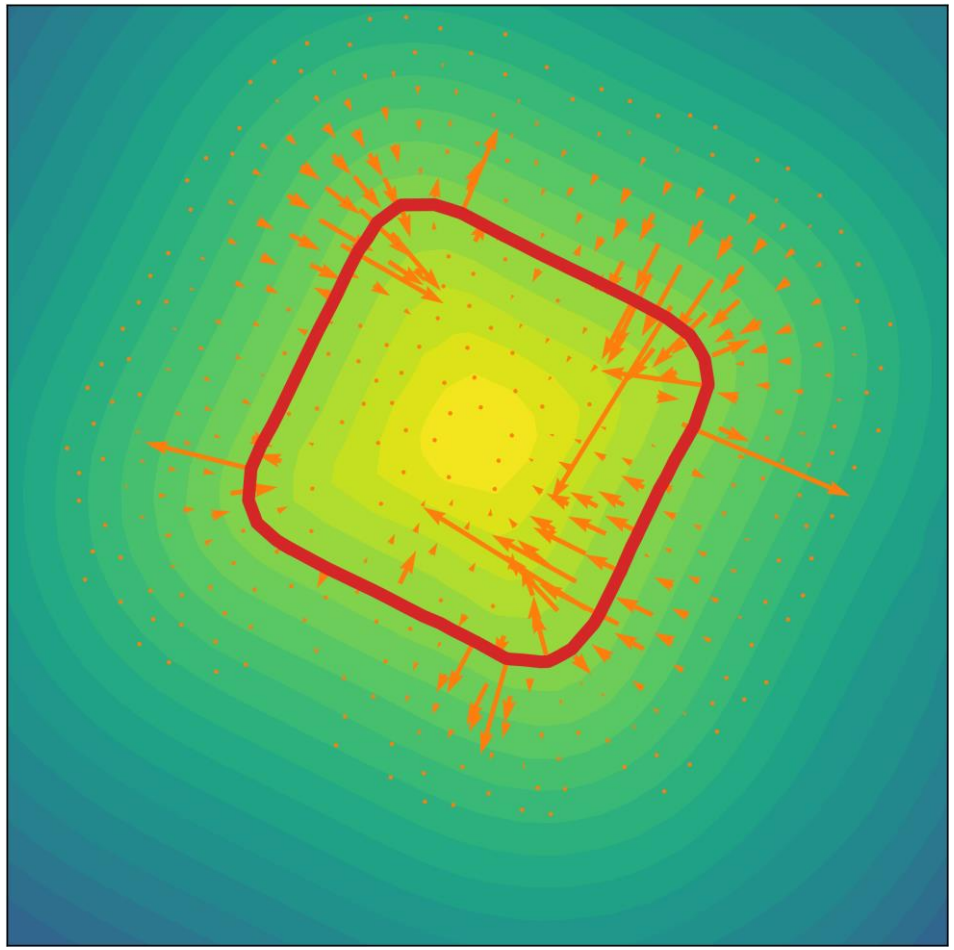
Construction of correction-velocity

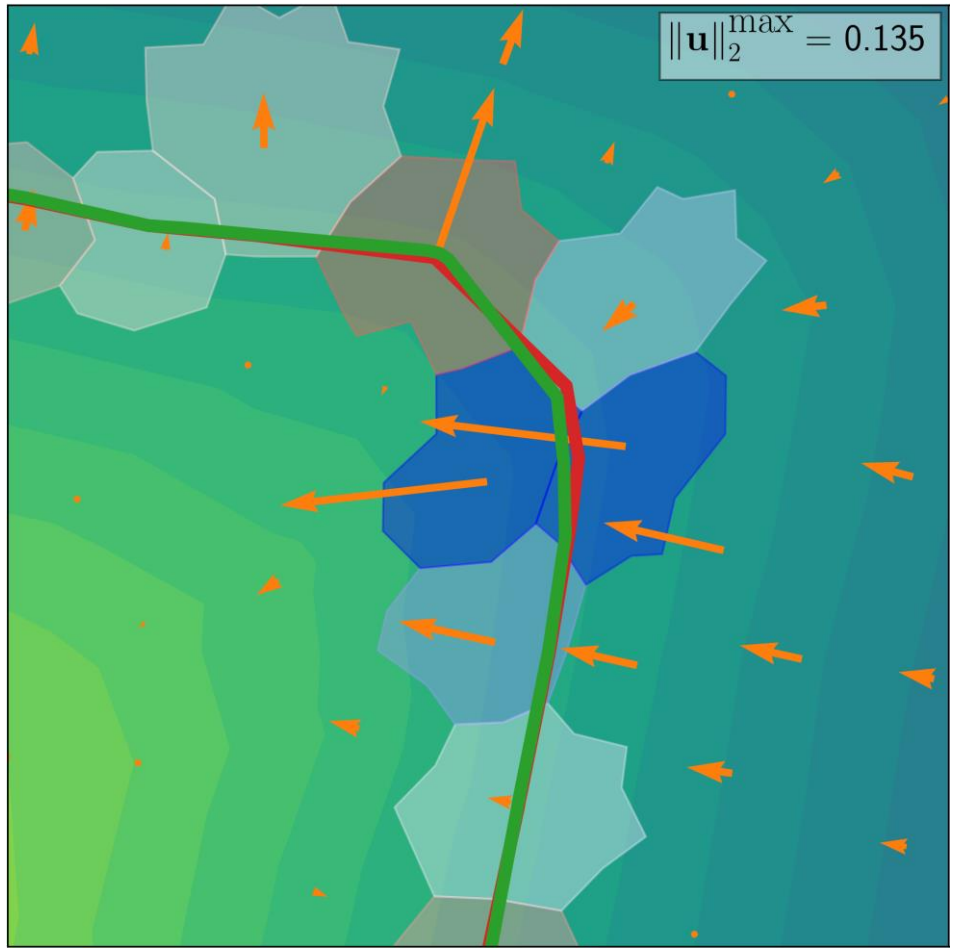


$$\int_{\Gamma_i} \mathbf{n} \cdot \mathbf{u}_c \, \mathrm{d}\Gamma = \frac{\delta V_i}{\delta t}$$

$$\implies (\mathbf{u}_c)_i = \dots$$

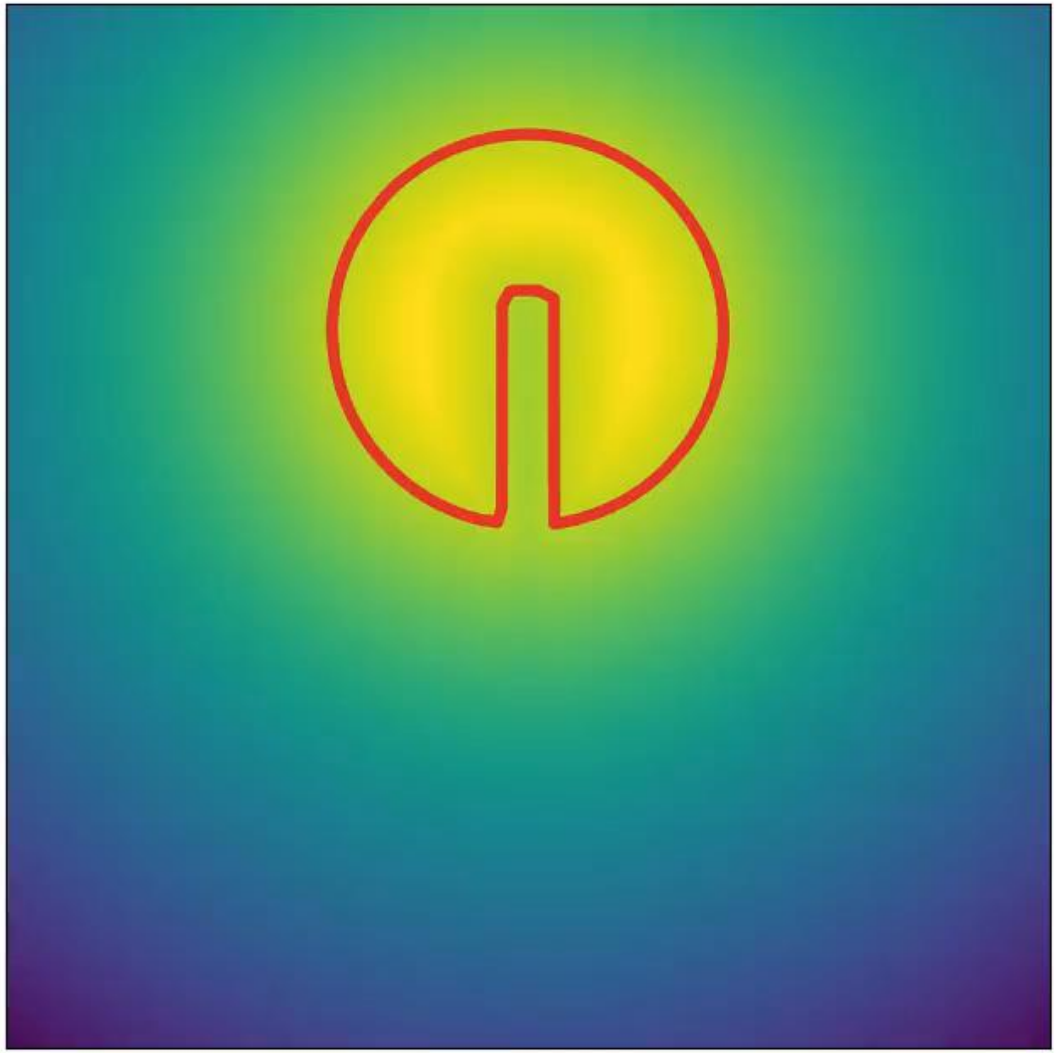
Advection with correction-velocity





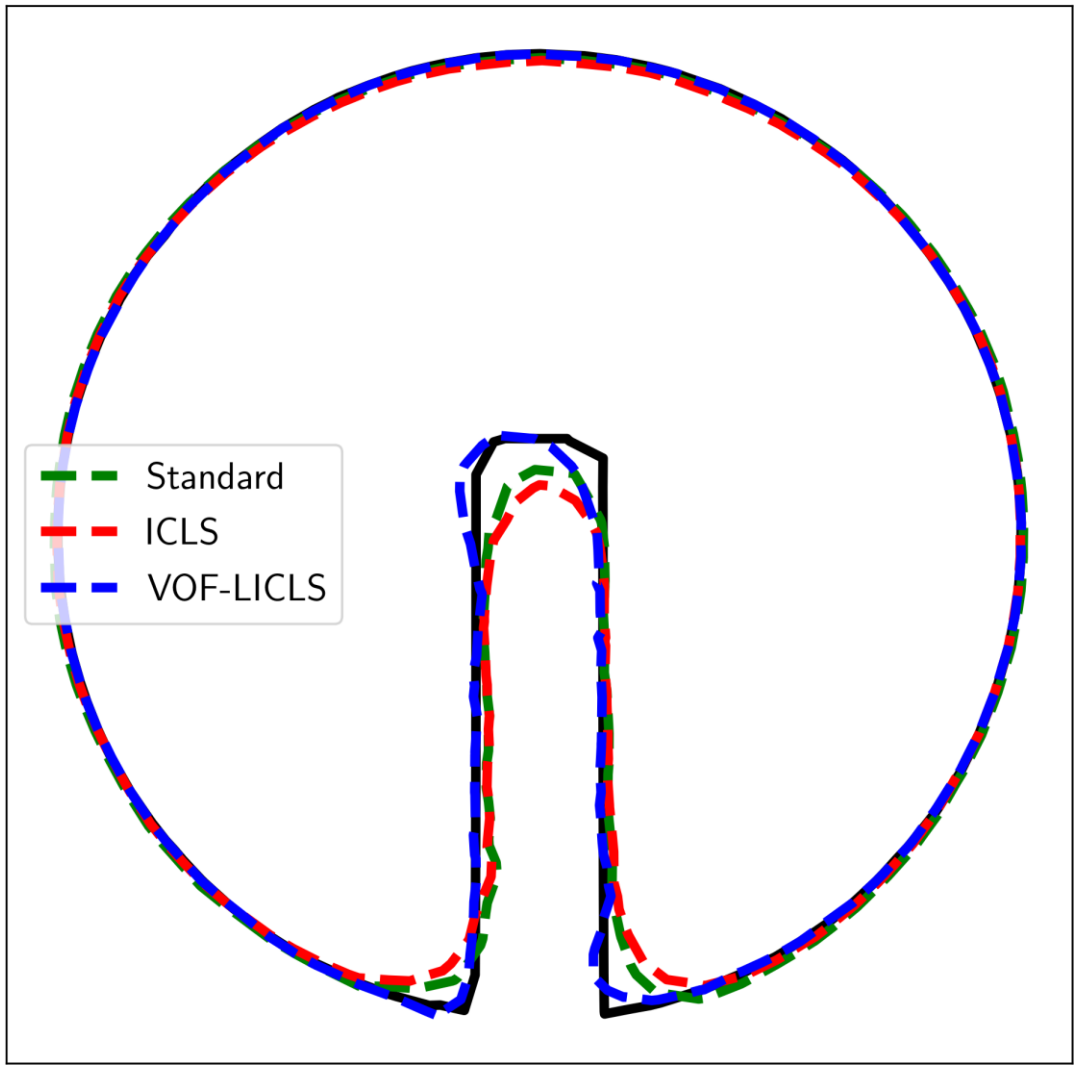
Results: Zalesak's disk

- Zalesak's disk
- Rotating flow



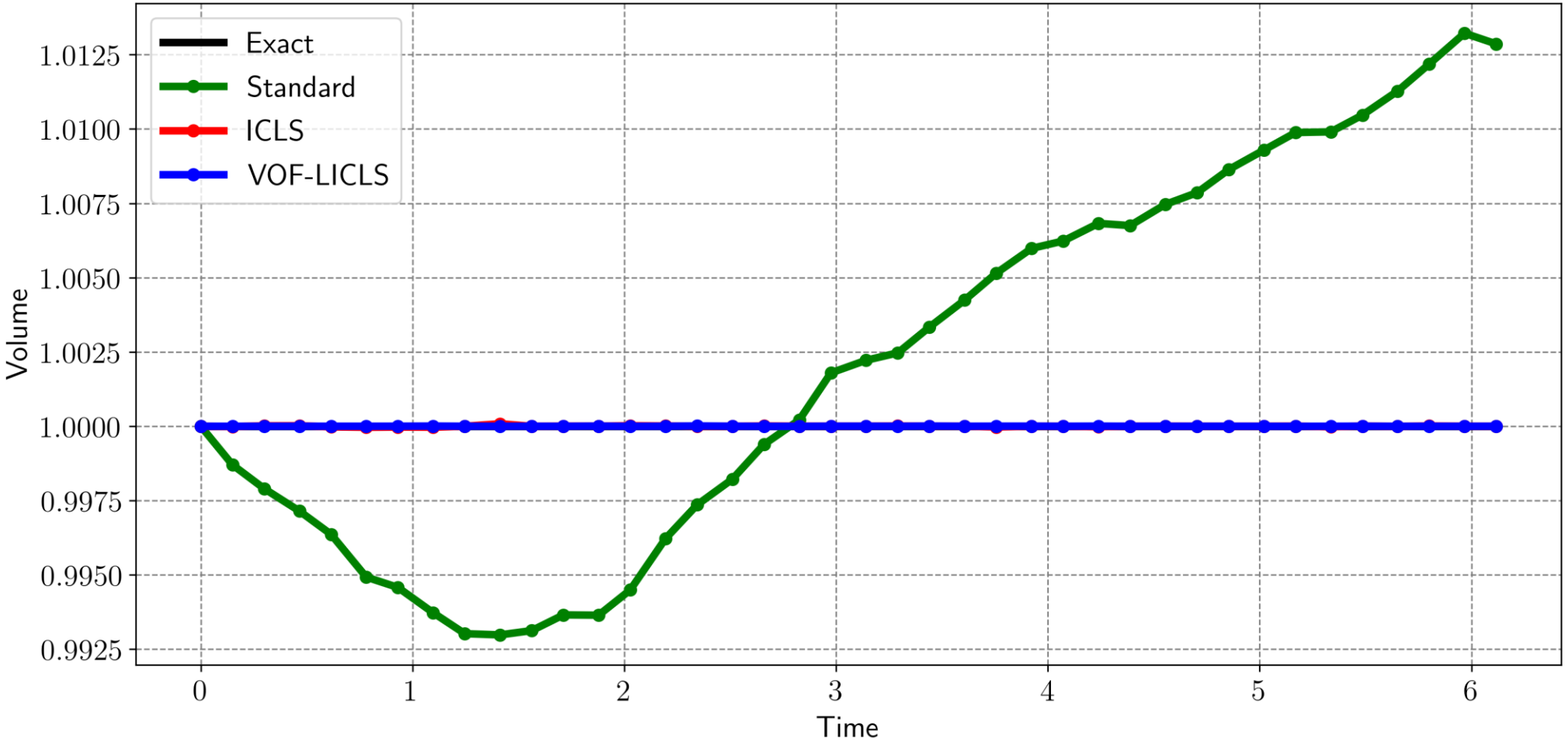
Results: Zalesak's disk

- Interface position



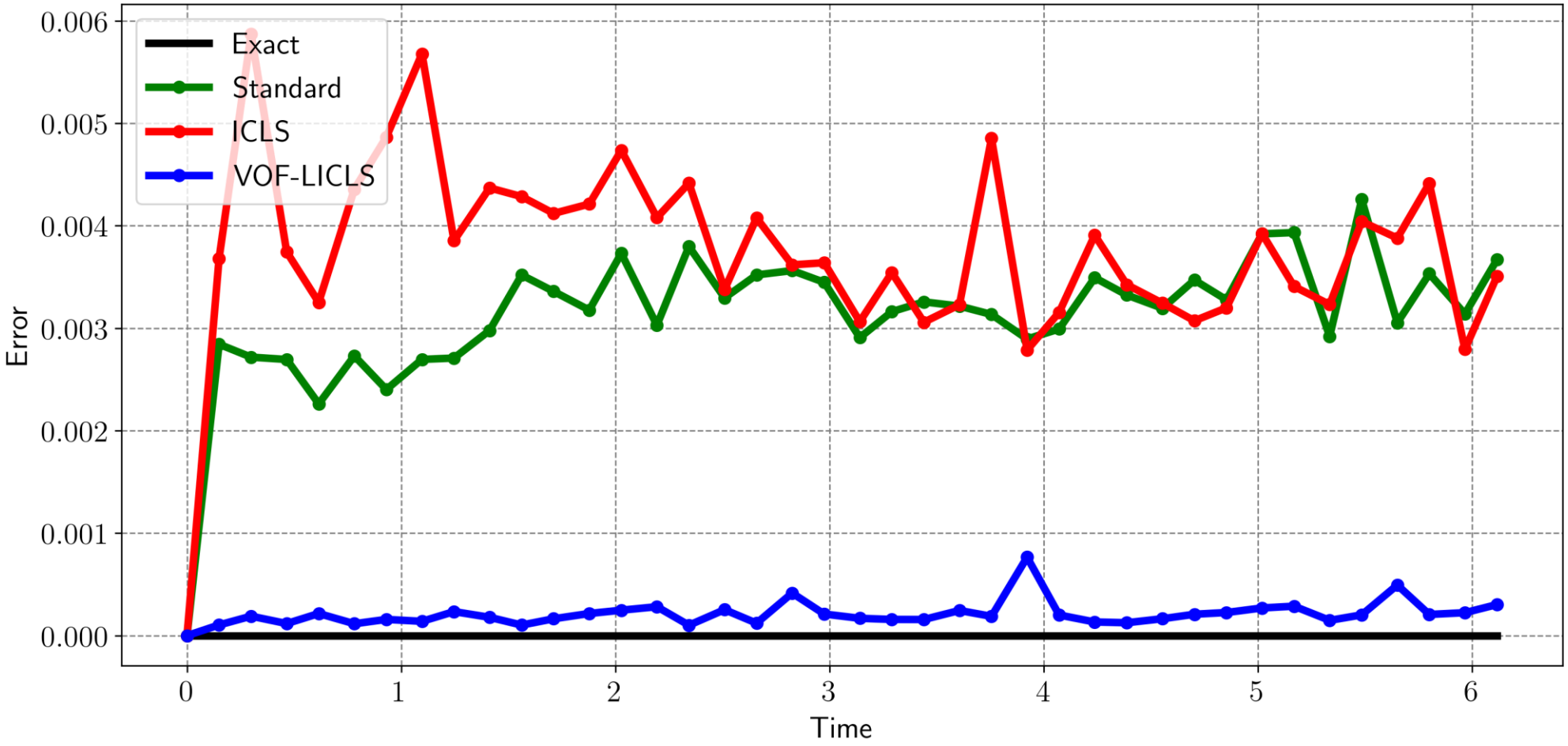
Results: Zalesak's disk

- Global volume



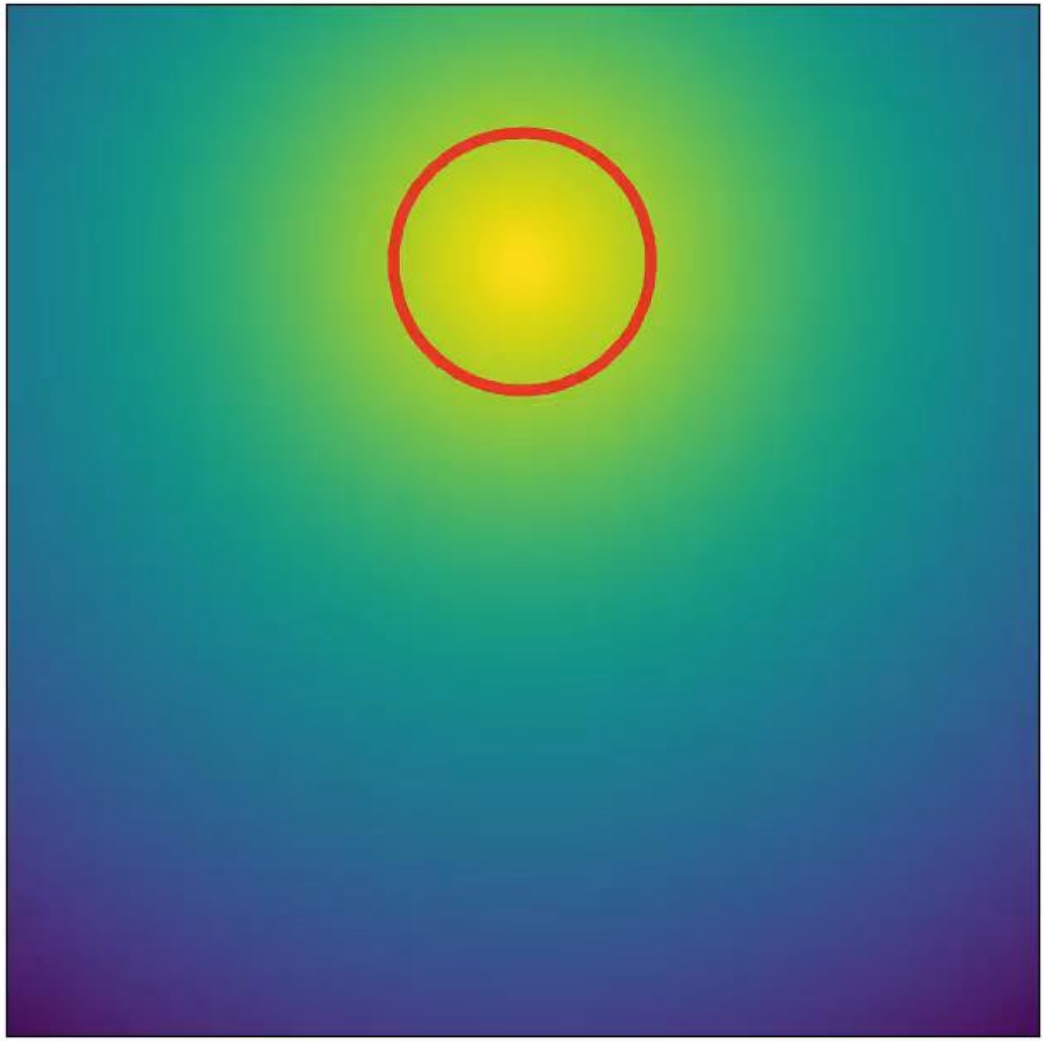
Results: Zalesak's disk

- Local volume errors



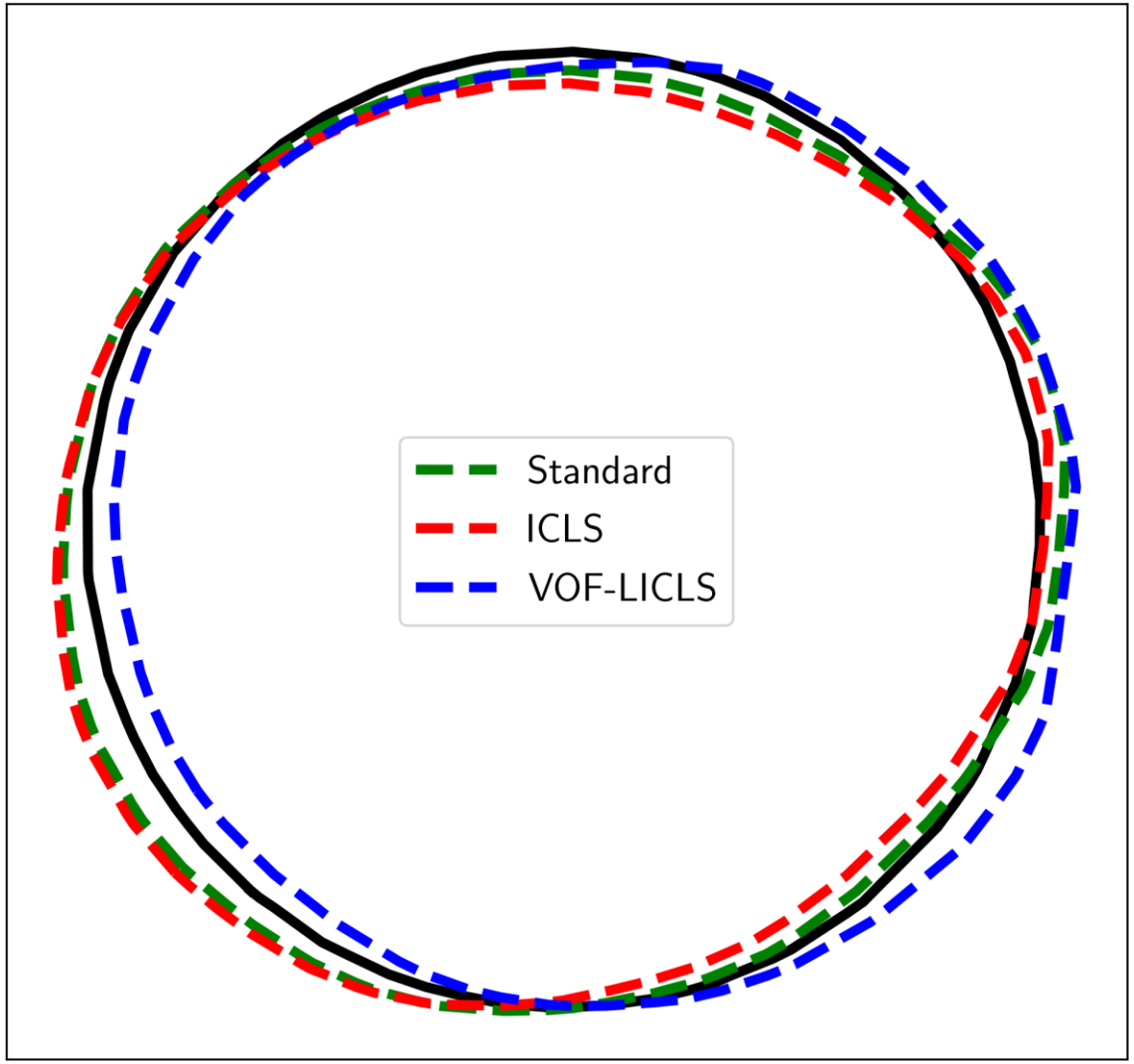
Results: Reverse-vortex flow

- Circle
- Reverse-vortex flow



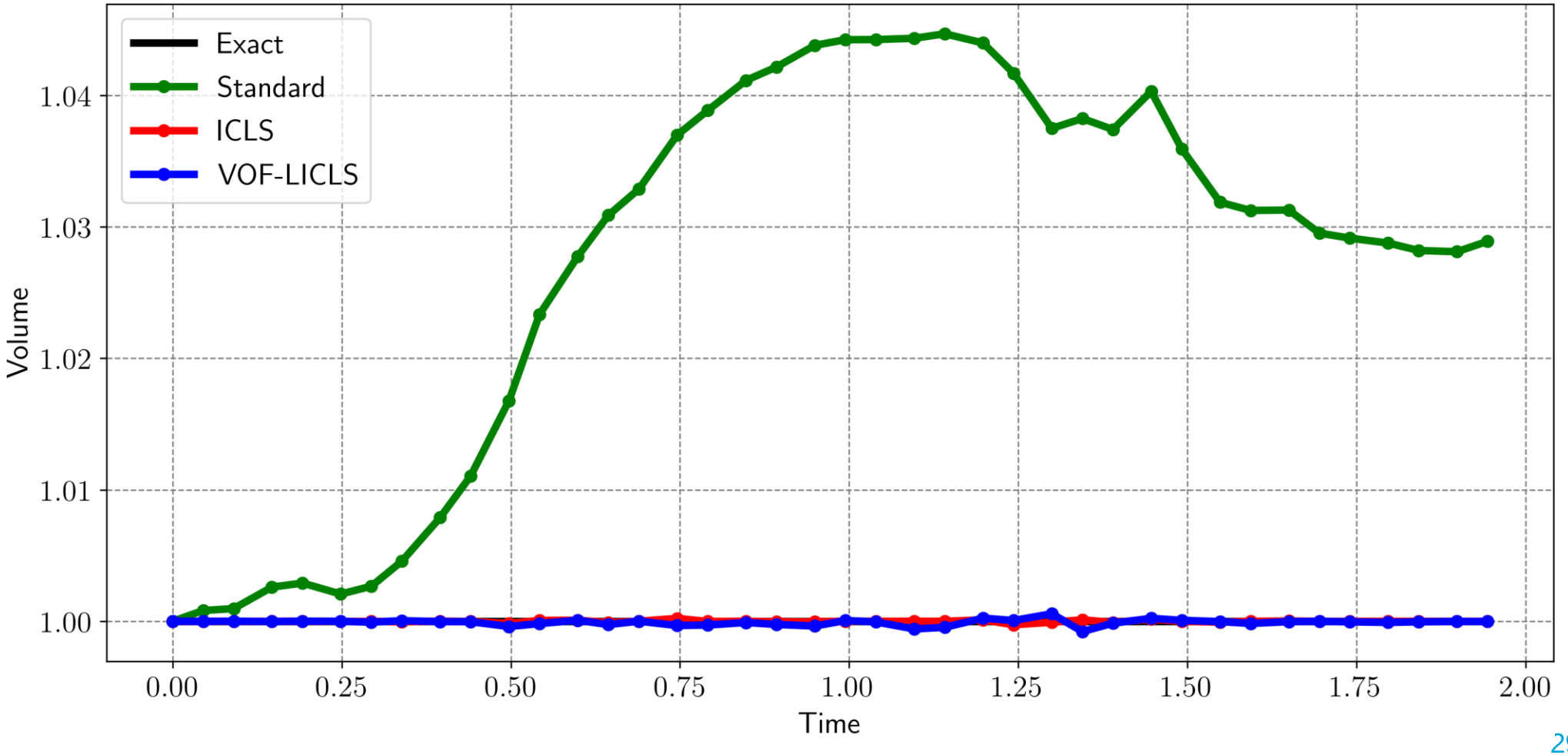
Results: Reverse-vortex flow

- Interface position



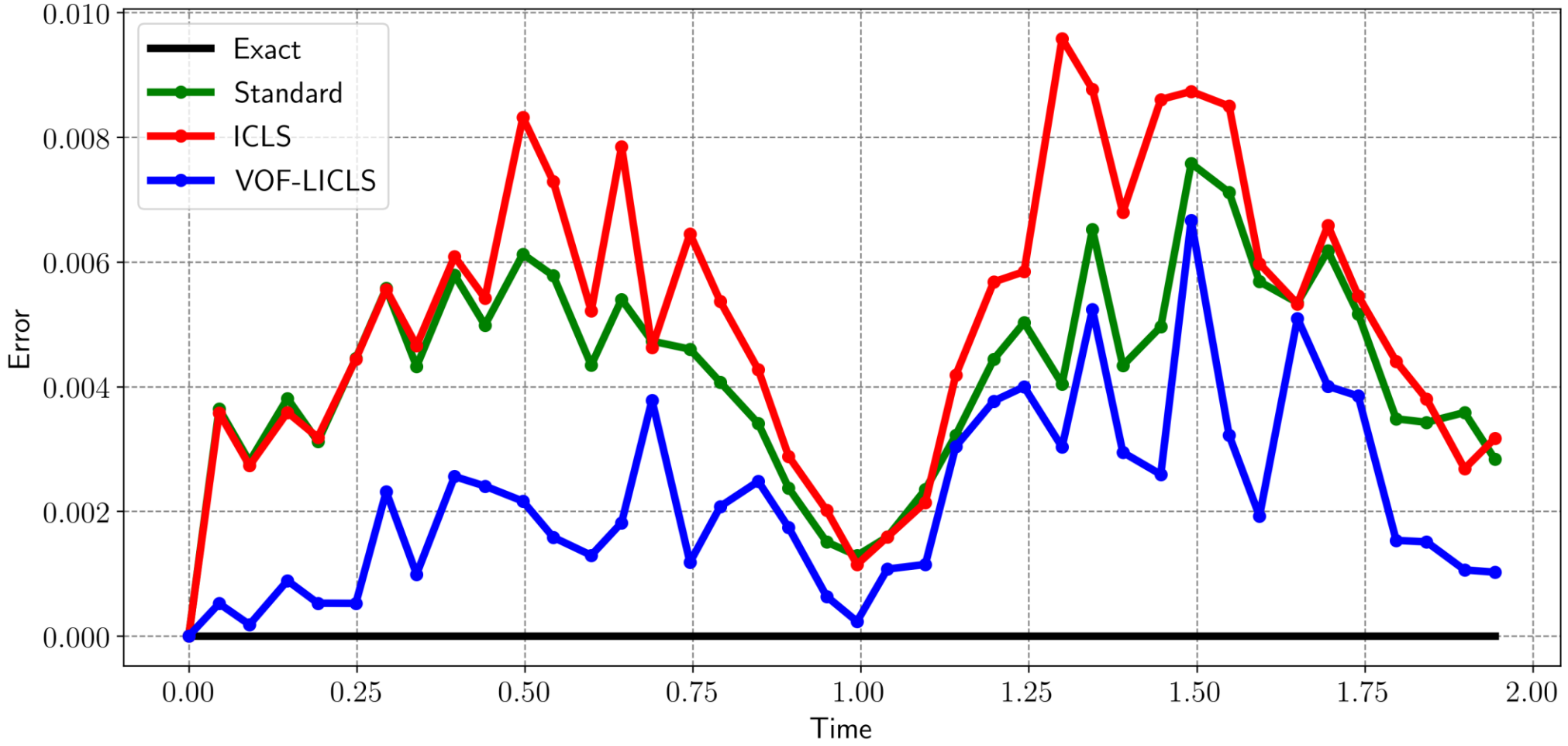
Results: Reverse-vortex flow

- Global volume



Results: Reverse-vortex flow

- Local volume errors



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- Volume-of-fluid-based local interface-correction level-set method (VOF-LICLS)
- Uses correction-velocity
- Combination with volume-of-fluid (VOF) method
- Aims to restore volume locally and globally

Conclusion: goal of project

Goal: *develop a level-set method that…*

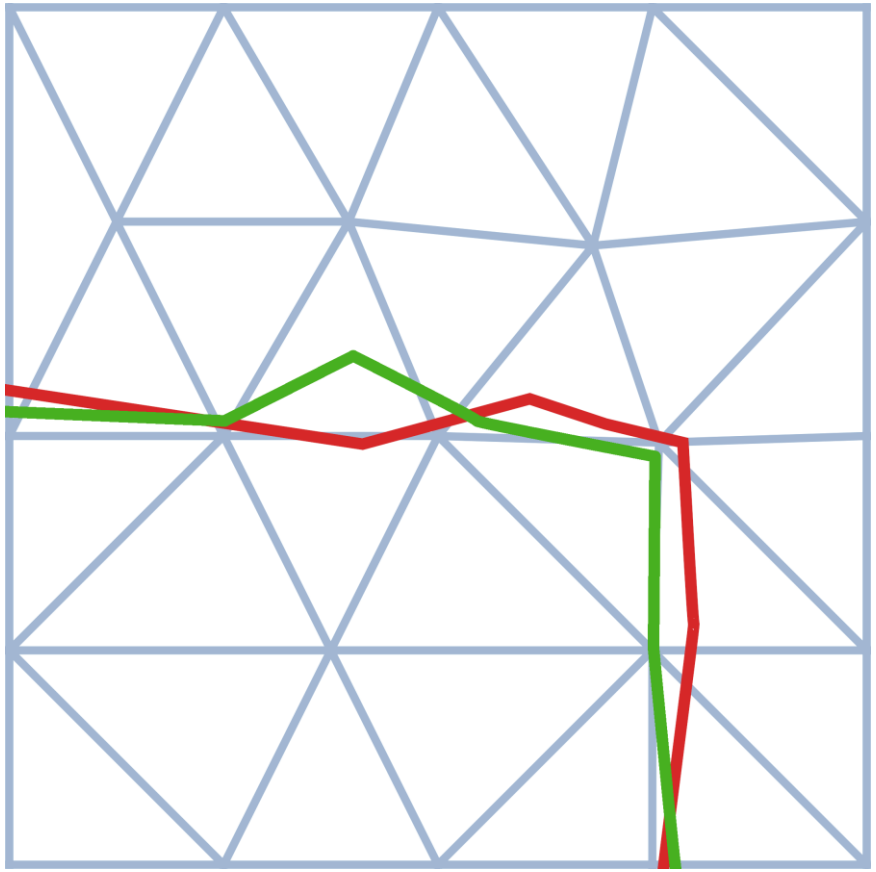
- conserves volume ✓
- has a continuous description of the interface ✓
- tracks interface accurately ✓
- is able to handle unstructured triangular meshes ✓

Conclusion

- Same global volume conservation as ICLS
- Better local volume conservation than ICLS
- In general, more accurate interface position than ICLS

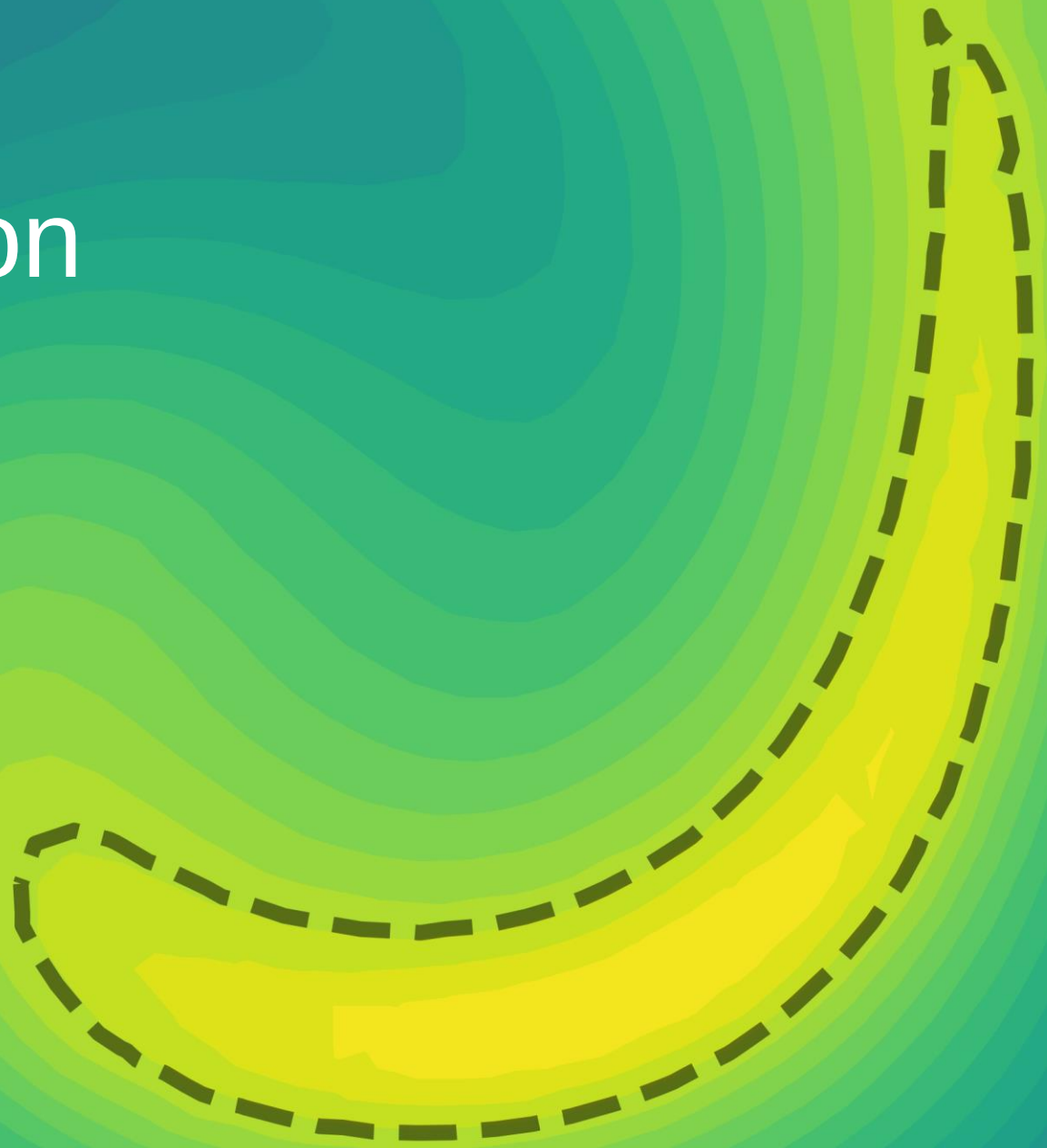
Open problems

- Emergence of peaks



End of presentation

Arthur Kerst



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Properties

- Iterative procedure (circa 10 iterations)

- Extra step after local volume correction