3D MOVING MESH TECHNIQUE FOR MICROSCALE TWO-PHASE FLOWS

Workshop Energy and Environment
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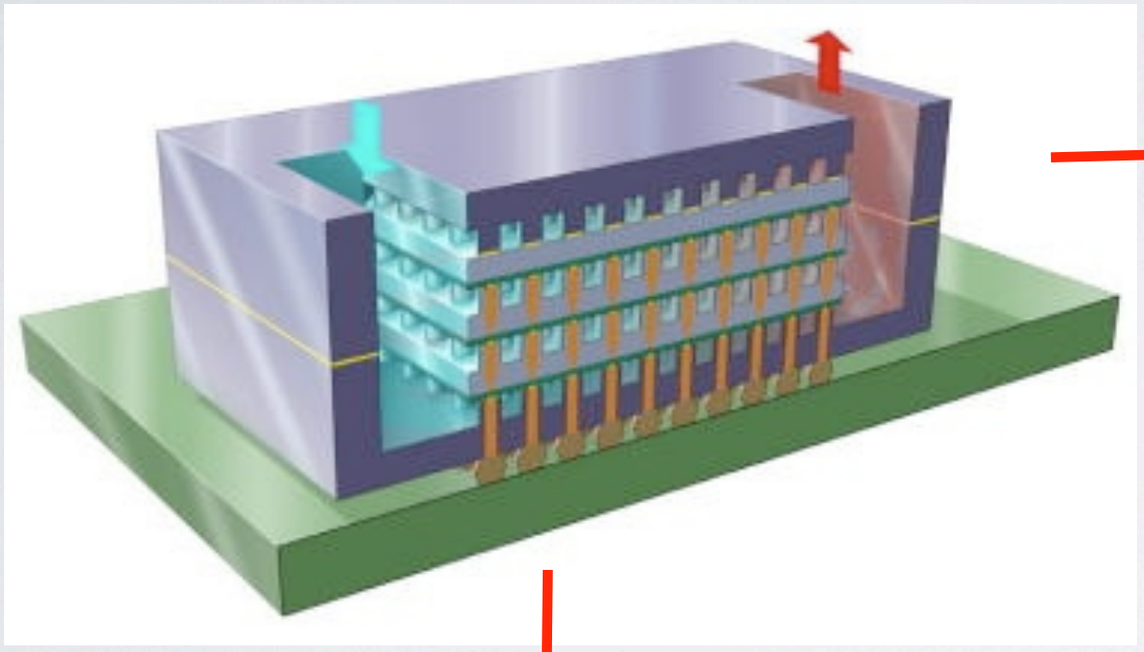
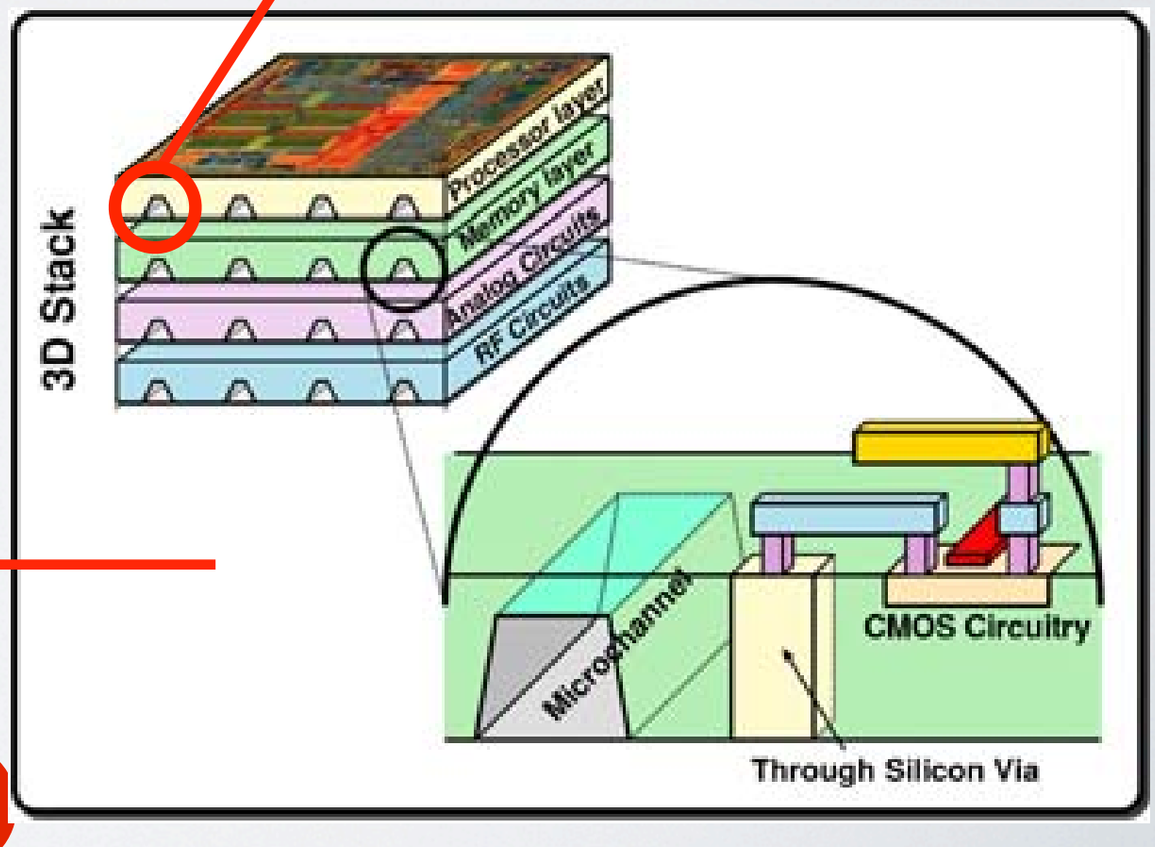
SUMMARY

- CMOSAIC/Nano-Tera swiss project;
- numerical code formulation;
  - Navier-Stokes equations (ALE framework);
  - meshing treatment;
  - surface tension force;
- preliminary results;
- conclusions and further work.

NANO-TERA PROJECT



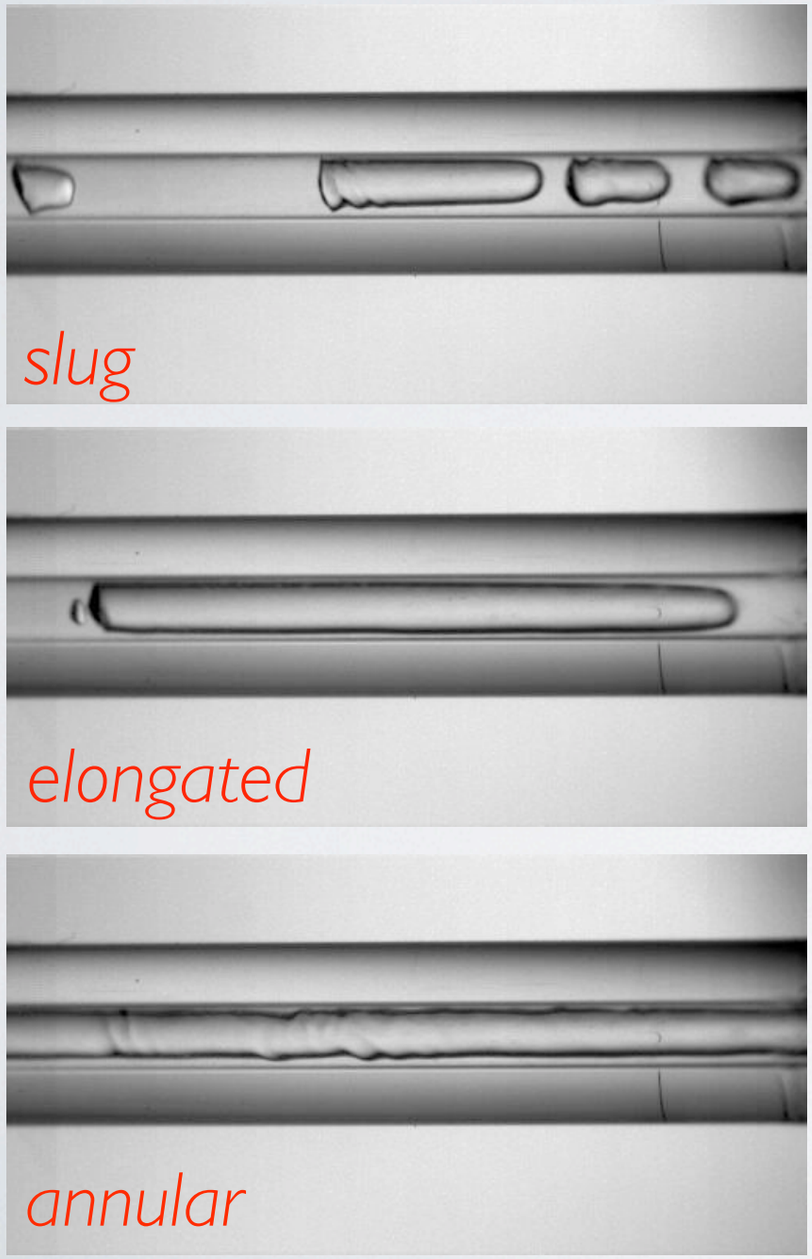
channel shapes:
rectangular, circular,
square, trapezoidal

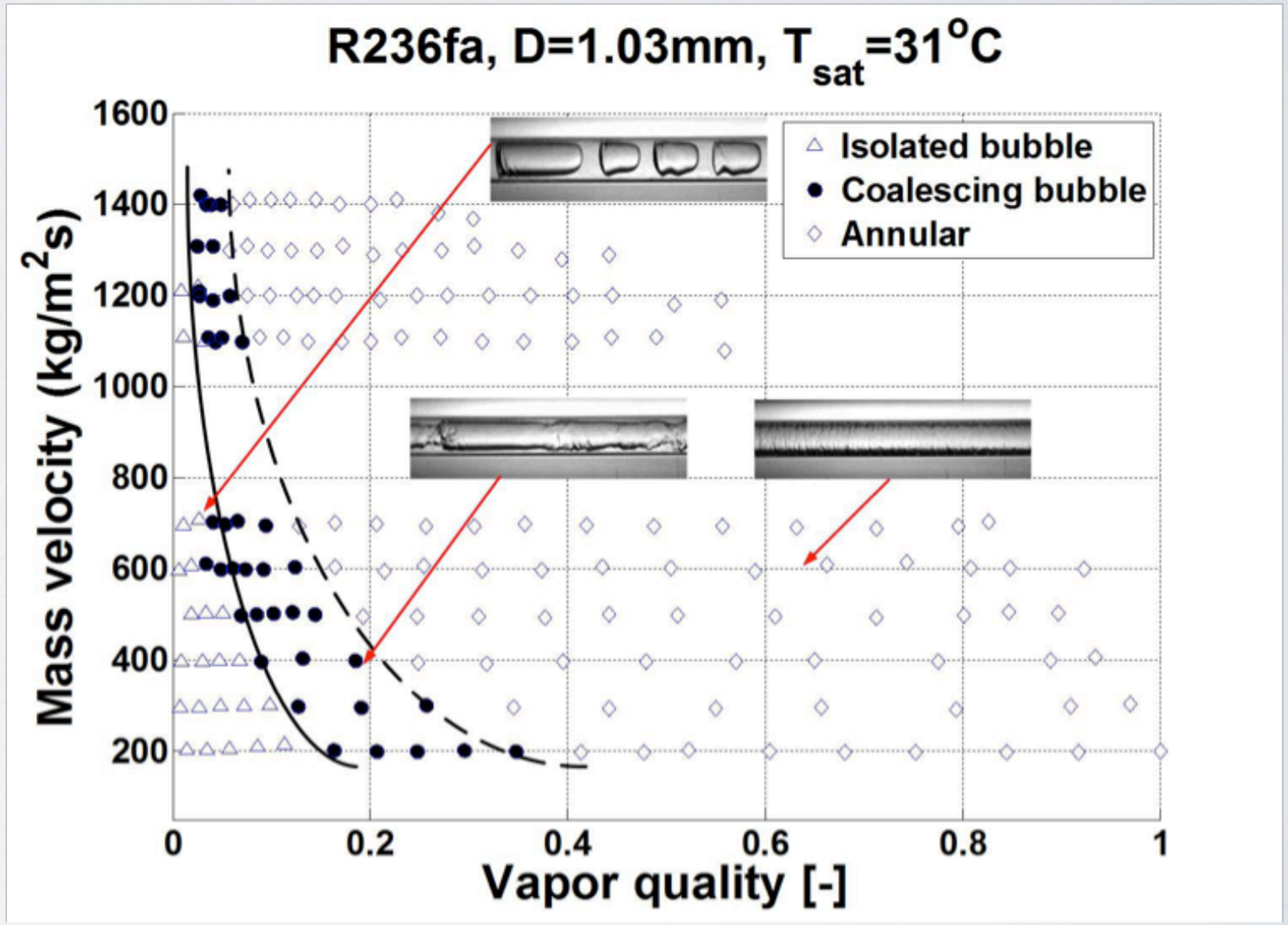


channel sizes: 50µm to 200µm

fluids: water, nanofluids
and refrigerants

MICROSCALE TWO PHASE FLOW REGIMES

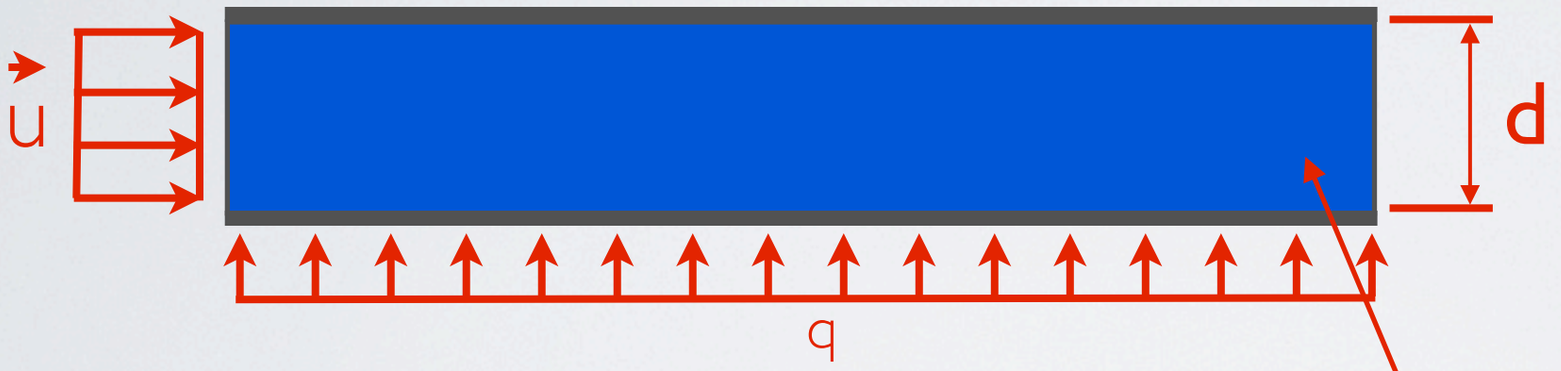




Ph.D. Thesis - Chin Lee Ong (2010)

HEAT TRANSFER ANALYSIS

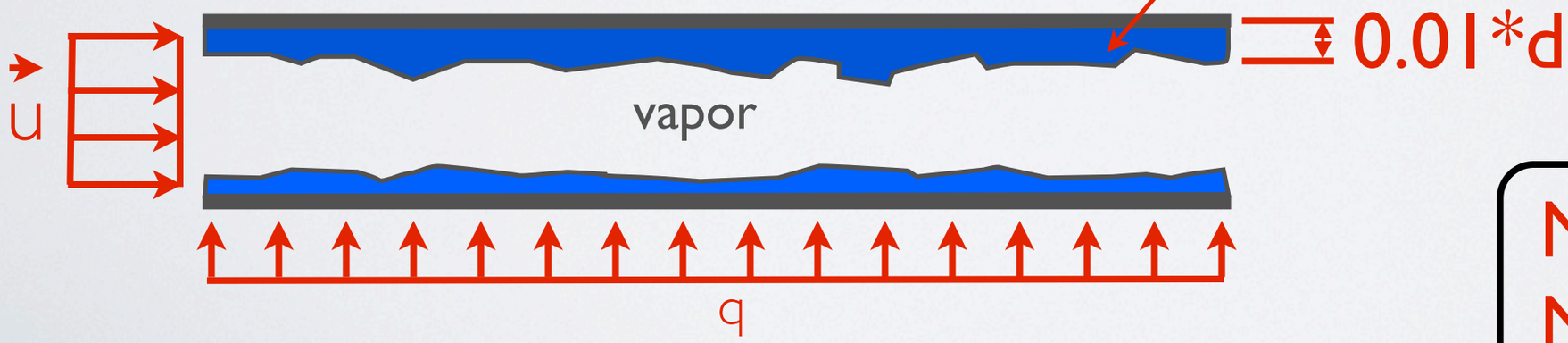
single phase



$$Nu = \frac{\text{convection}}{\text{conduction}}$$

$$Nu = \frac{h(T-Tf)}{k(T-Tf)/D}$$

two-phase - annular flow



Nusselt number
Nu = hD/k

OBJECTIVES

- Efficient Cooling of Electronics;
- develop a platform for two-phase flow studies;
- 3D ALE Two-Phase code (one fluid);
- predict flows in micro-scale geometries;
- work with complex geometries;
- couple heat transfer and two-phase flow.

NAVIER-STOKES EQUATIONS

$$\frac{D(\rho \mathbf{u})}{Dt} + \nabla p = \frac{1}{Re} \nabla \cdot [\mu(\nabla \mathbf{u} + \nabla \mathbf{u}^T)] + \frac{\rho}{Fr^2}\mathbf{g} + \frac{1}{We}\mathbf{f}$$

surface tension

$$\nabla \cdot \mathbf{u} = 0$$

ALE formulation:

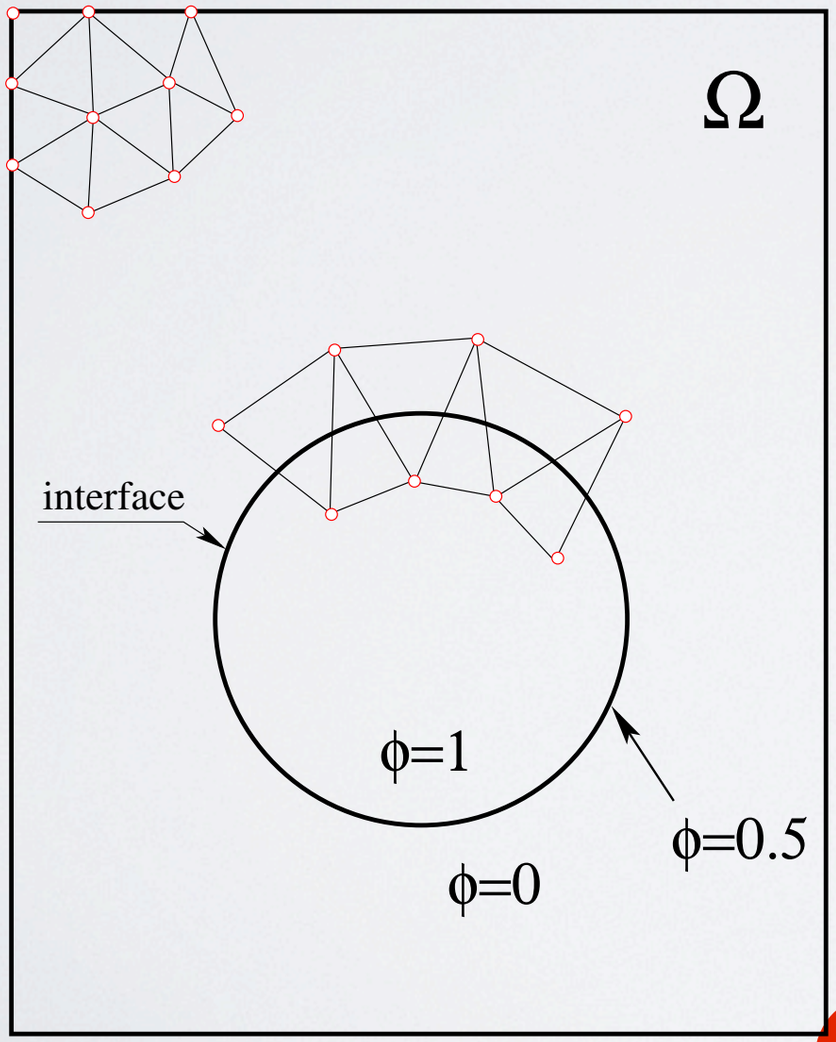
$$\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} - \hat{\mathbf{u}}) \cdot \nabla \mathbf{u}$$

$\hat{\mathbf{u}} = \mathbf{u}$ → Lagrangian

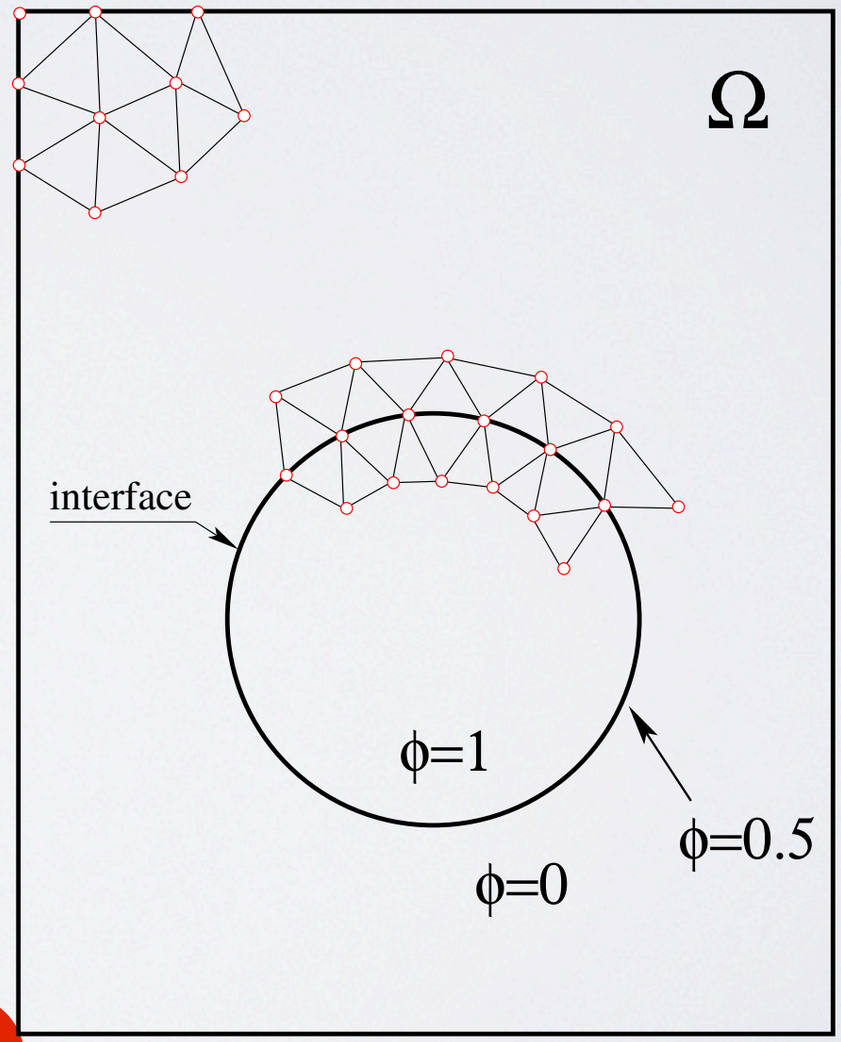
$\hat{\mathbf{u}} = 0$ → Eulerian

MARKER FUNCTION (Φ)

- Eulerian approach: (fixed mesh)



- Lagrangian approach: (moving mesh)



SURFACE TENSION

$$\mathbf{f} = \sigma \kappa \mathbf{n} \delta$$

continuum surface force model

Brackbill and Kothe (1992)

σ : surface tension coefficient

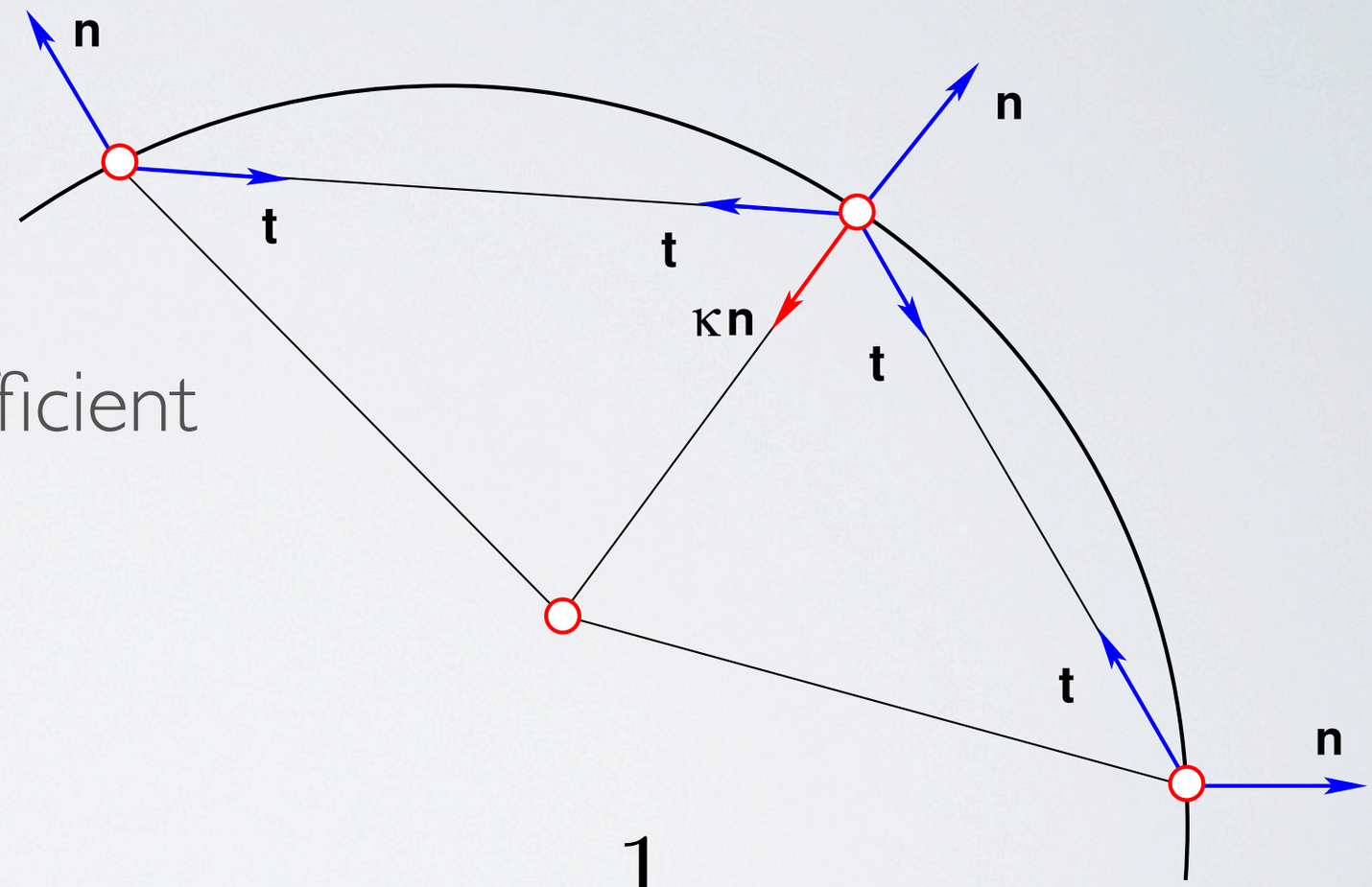
κ : curvature

δ : Dirac delta function

$\mathbf{n}$: normal vector

$\mathbf{t}$: tangent vector

H : marker function

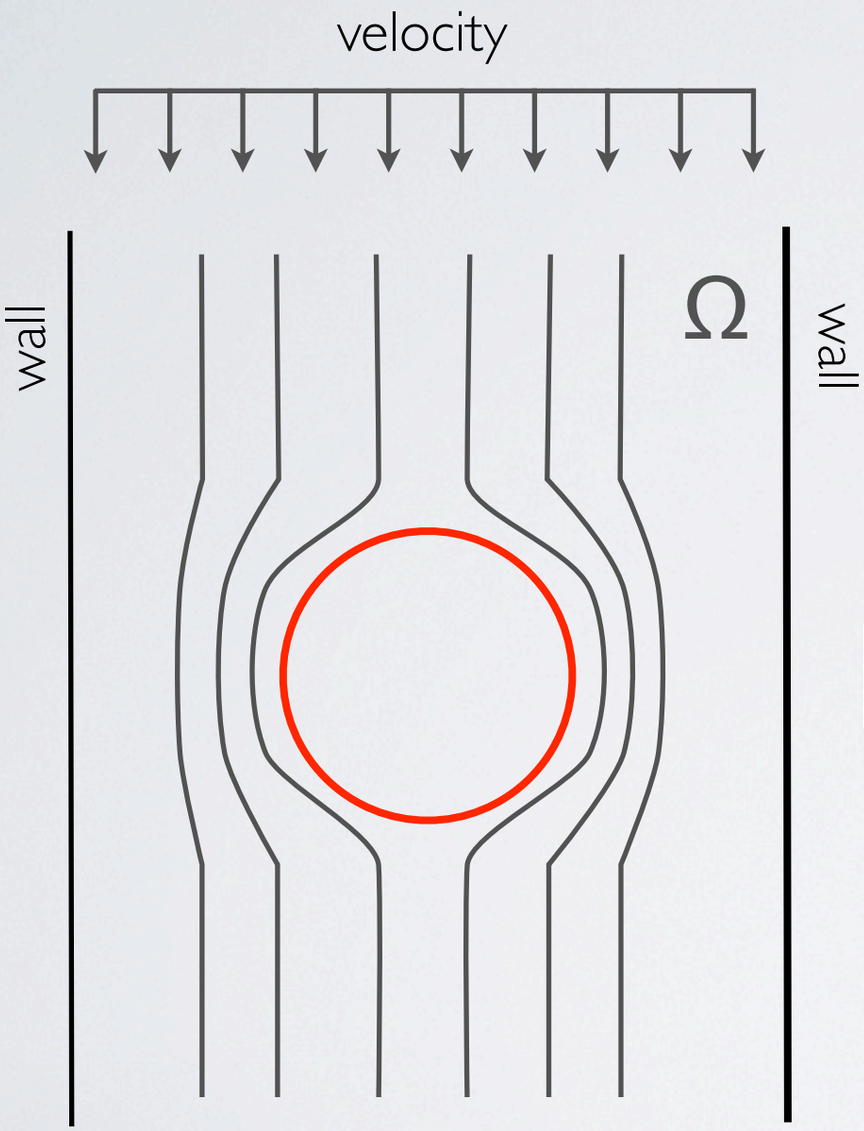


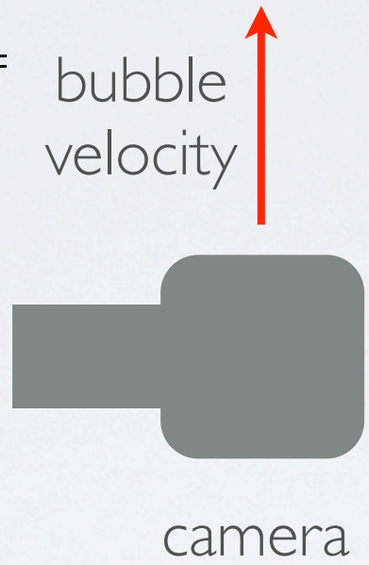
$$\mathbf{f} = \frac{1}{We} \kappa \mathbf{n} \nabla H$$

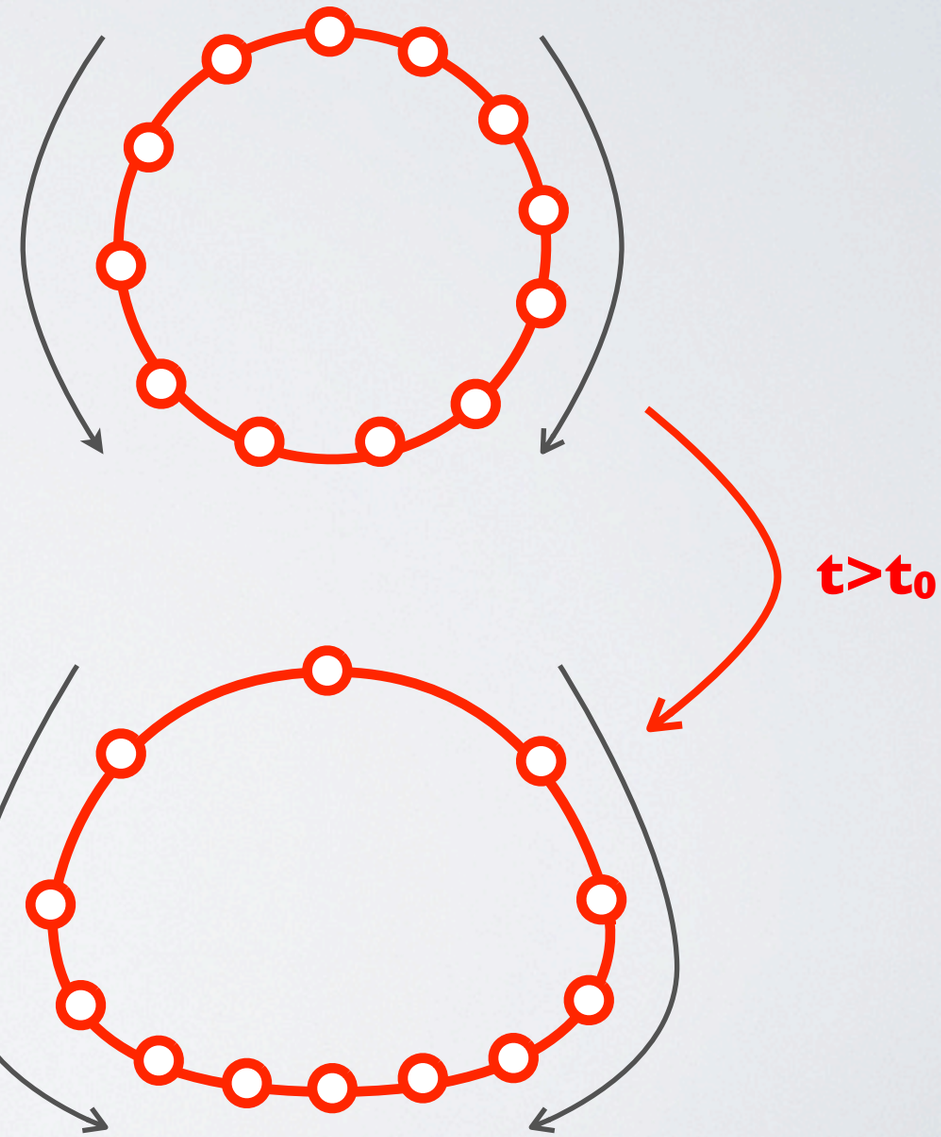
discrete surface tension force

TEST

(3D -fixed- rising bubble)

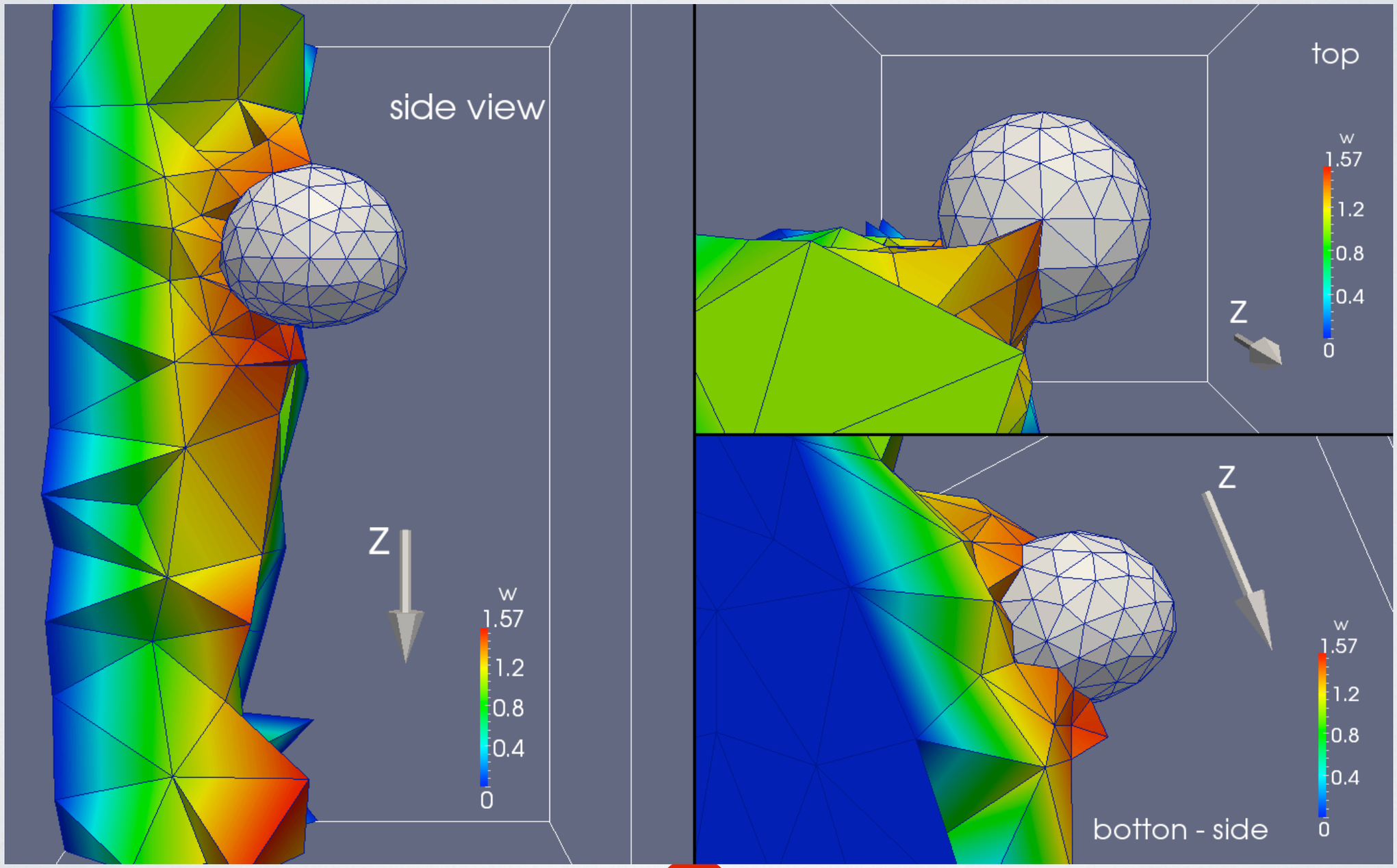






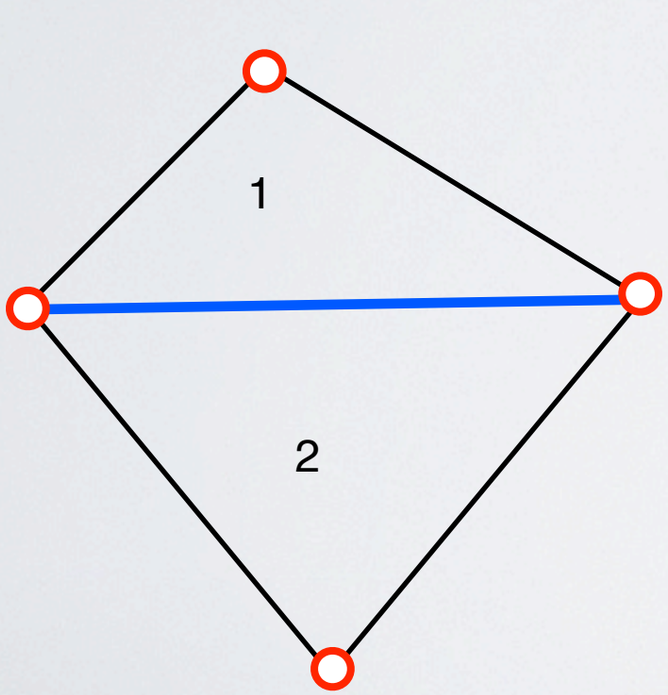
TEST

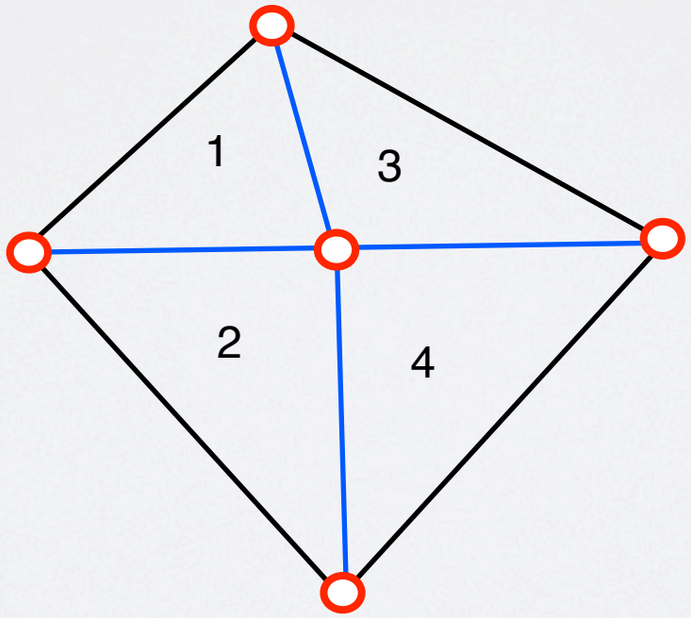
(3D -fixed- rising bubble)



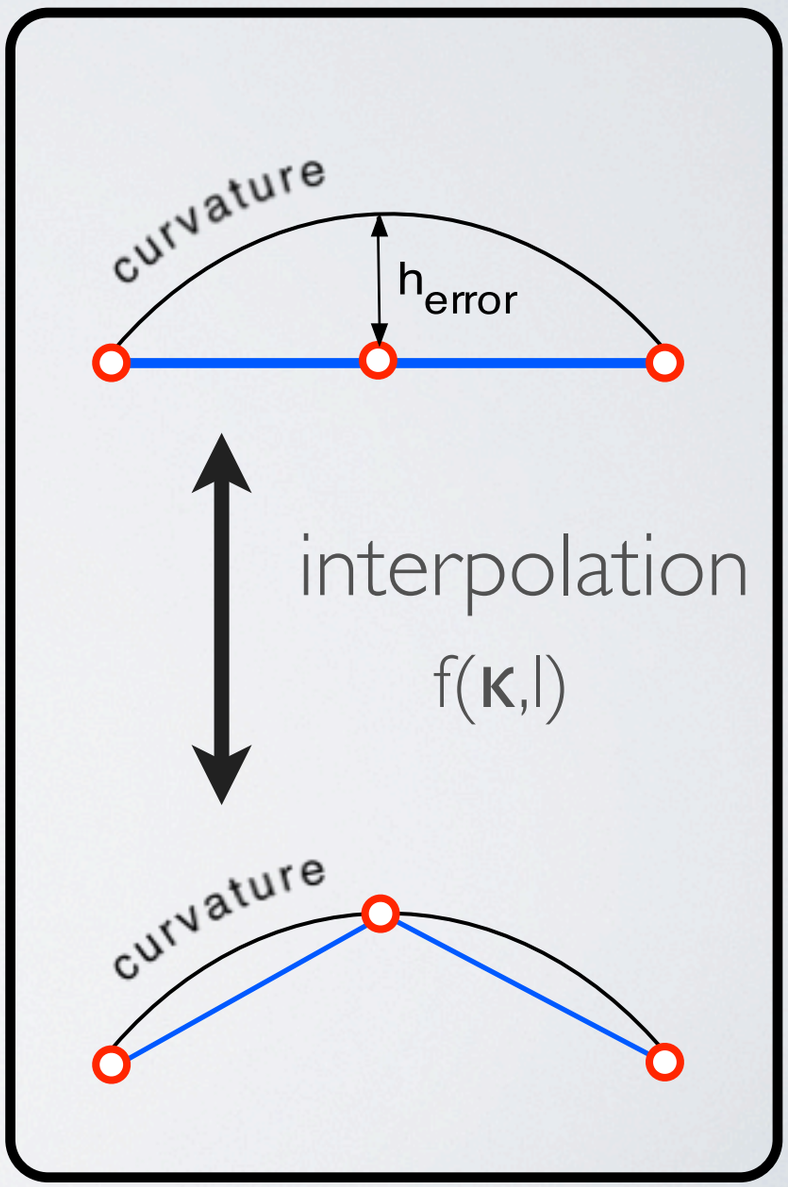
INSERTION STRATEGY

3D Surface - Triangles:
edge size > input parameter





2D view:

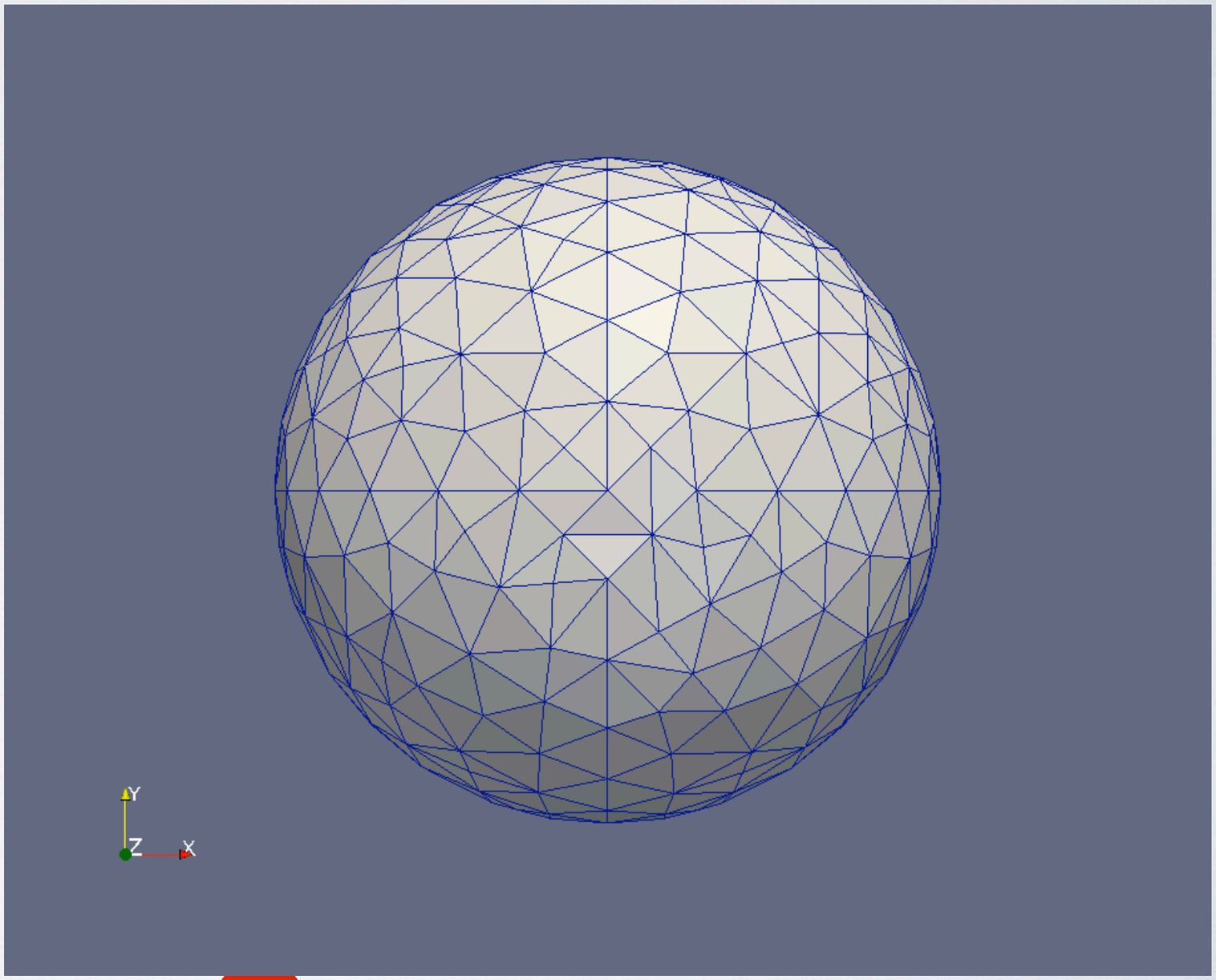


INSERTION STRATEGY

(example)

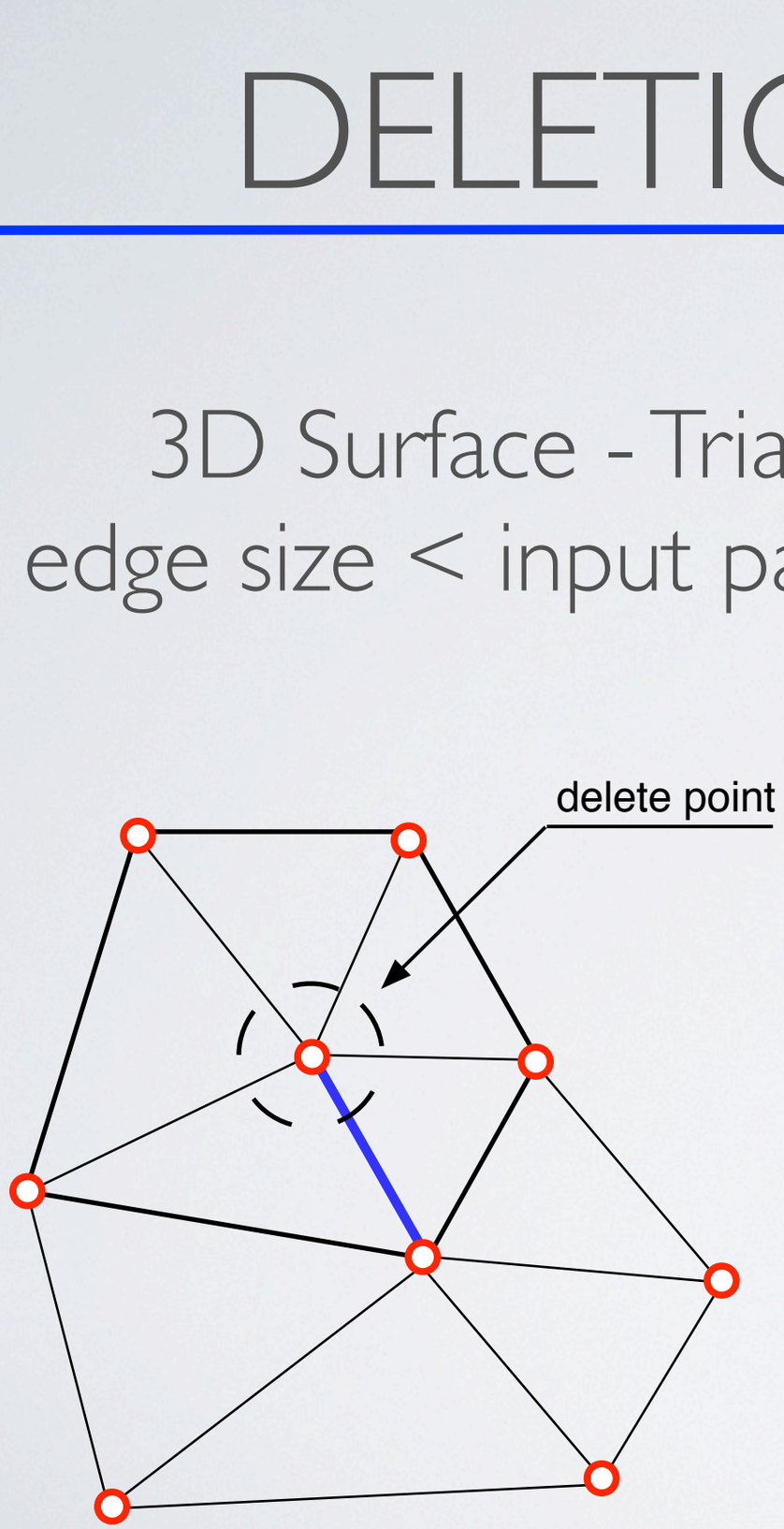
3D Rising bubble:

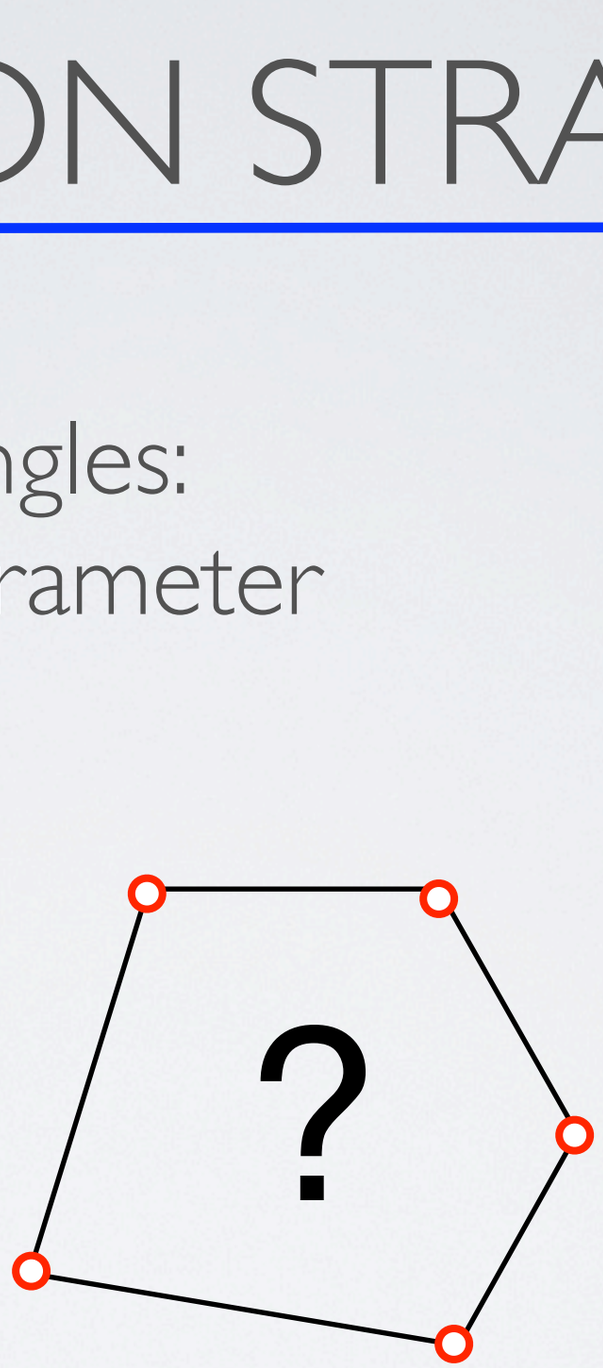
view: TOP;
strategy: inserting points by length.



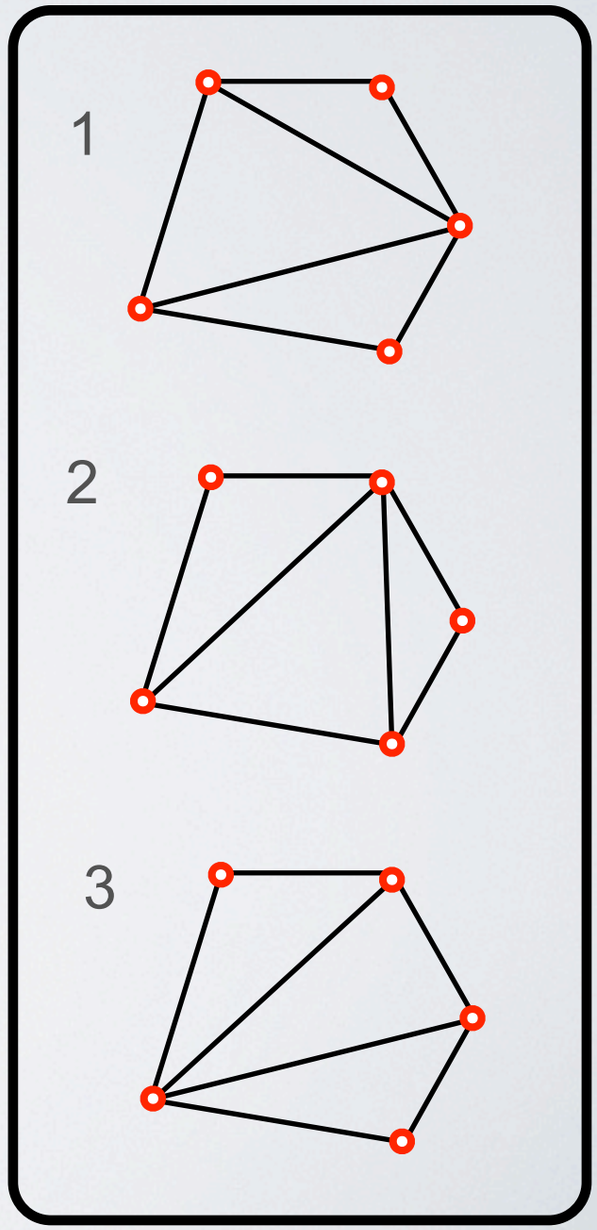
DELETION STRATEGY

3D Surface - Triangles:
edge size < input parameter



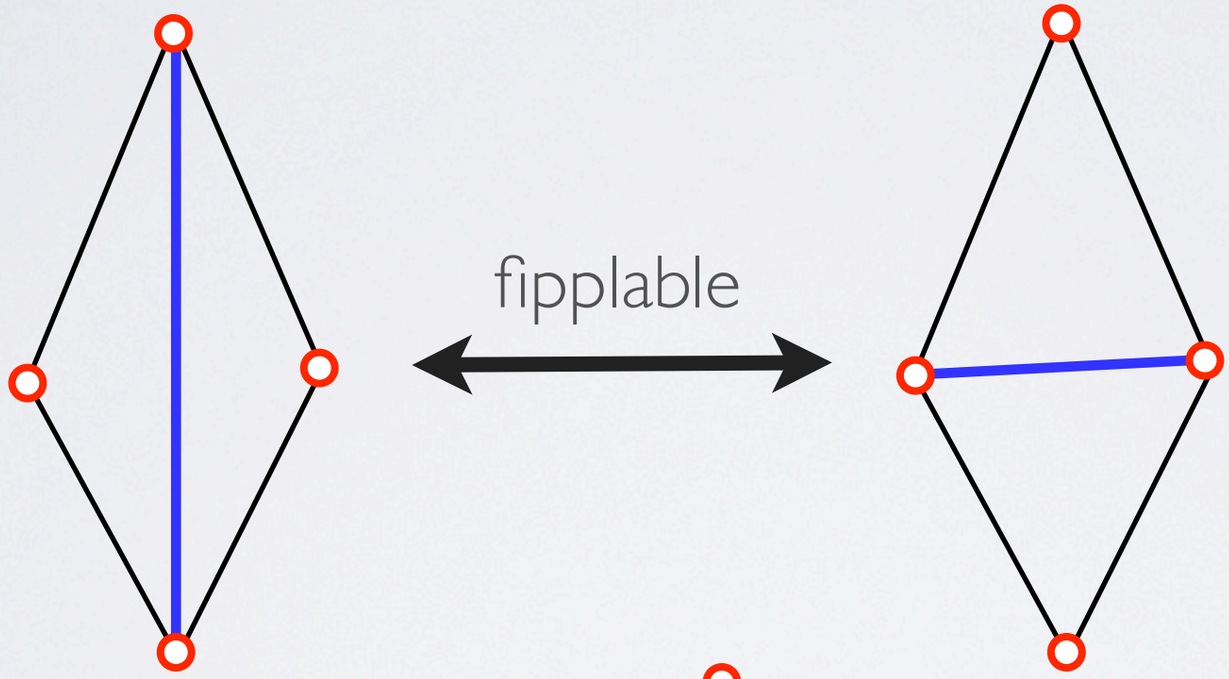


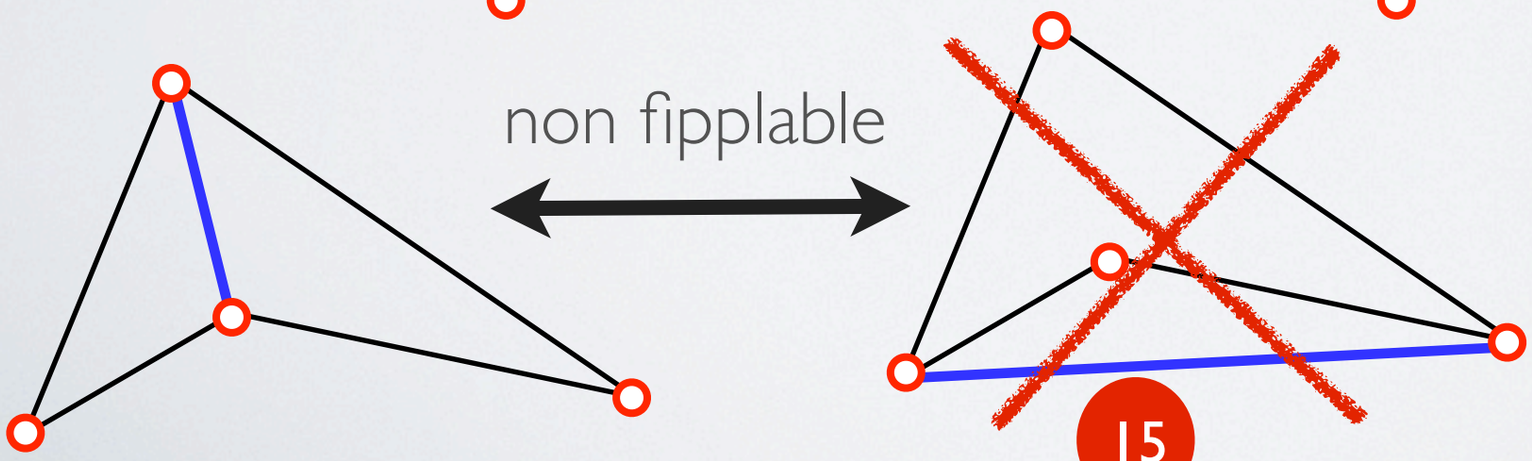
options:



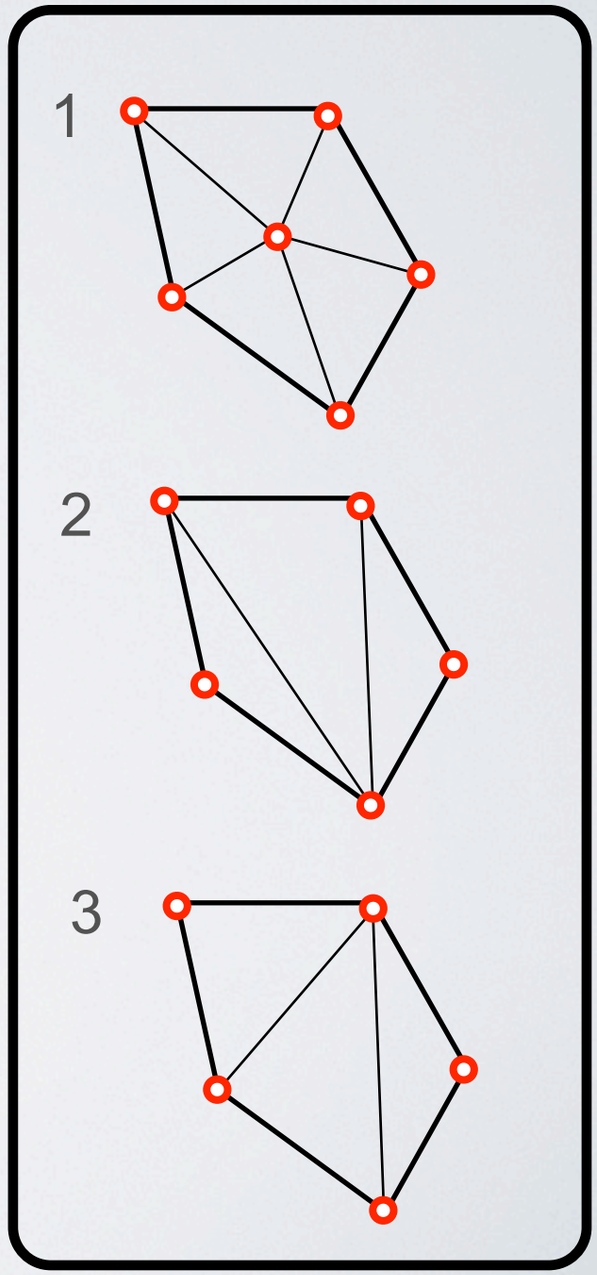
FLIPPING STRATEGY

3D Surface - Triangles:
old triangle quality < new triangle quality





example:

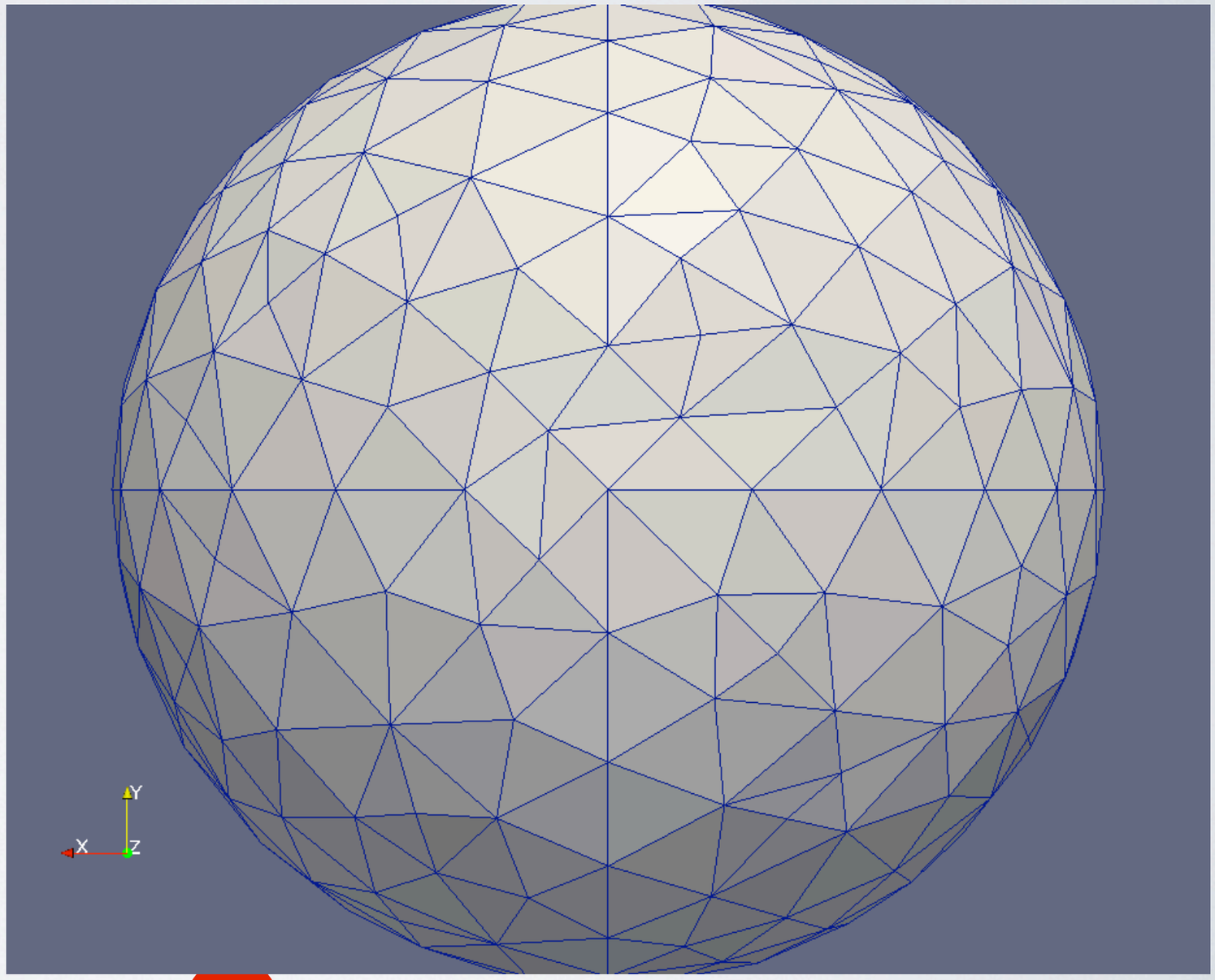


DELETION/FLIPPING STRATEGY

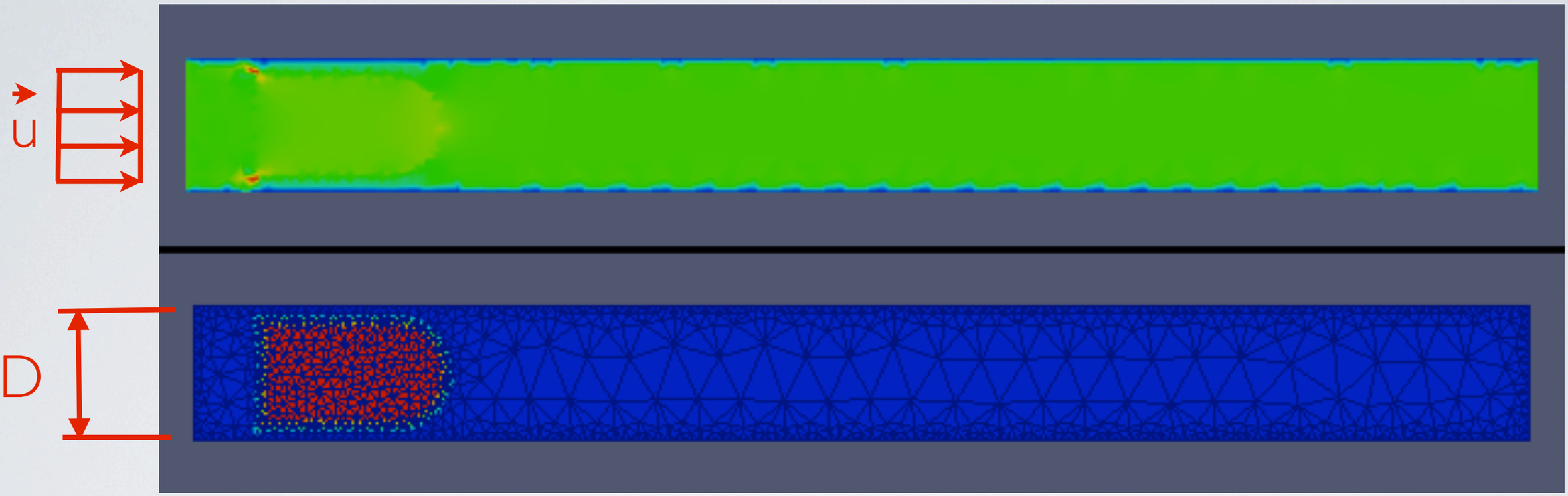
(example)

3D Rising bubble:

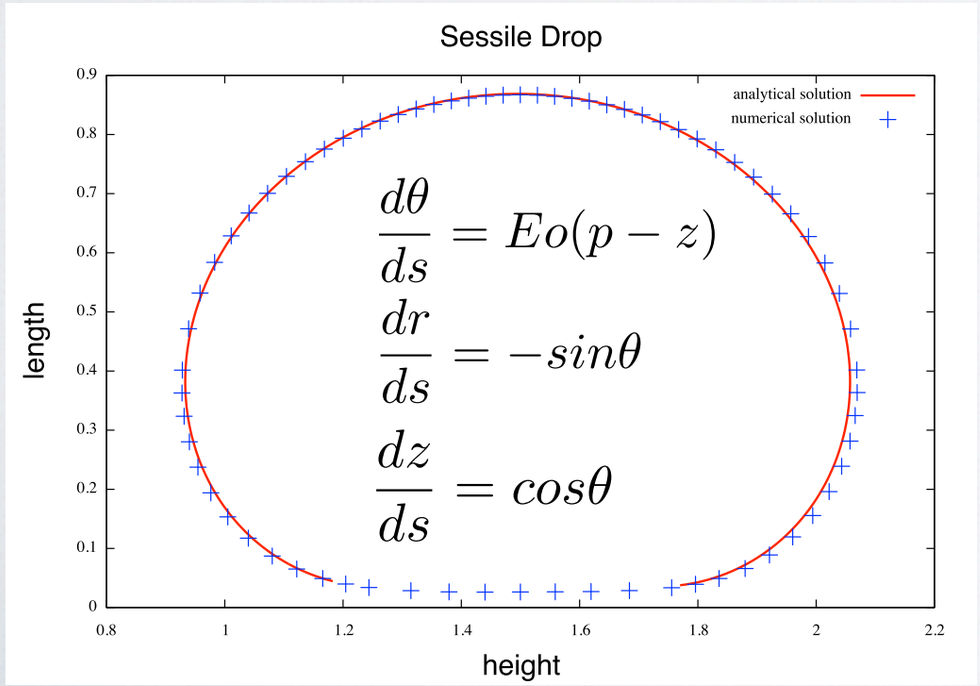
view: BOTTOM;
strategy: removing points by length.

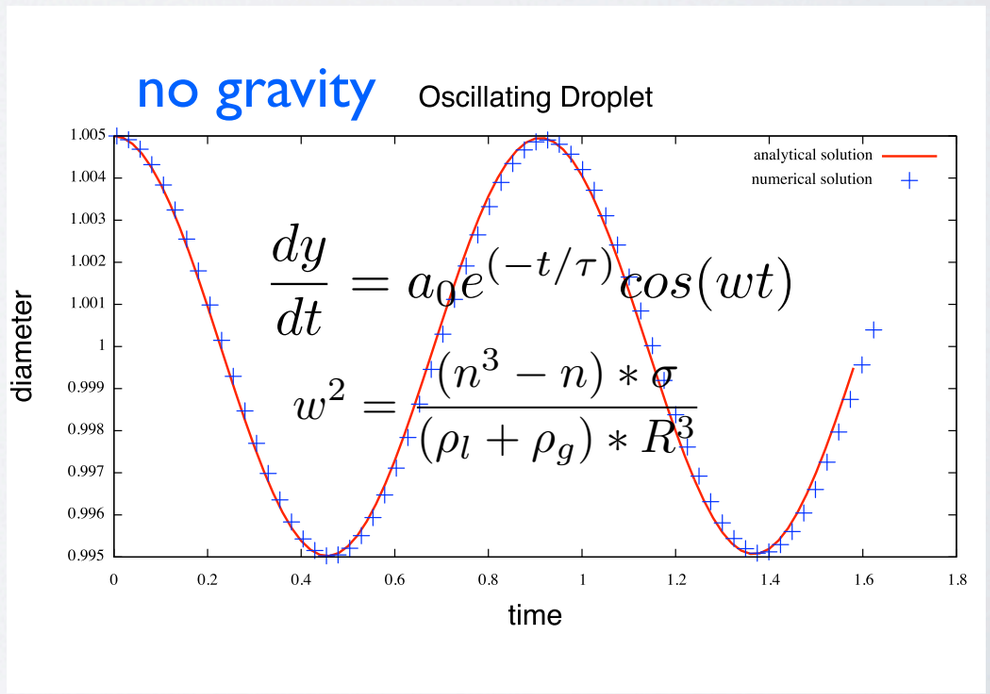


2D RESULTS

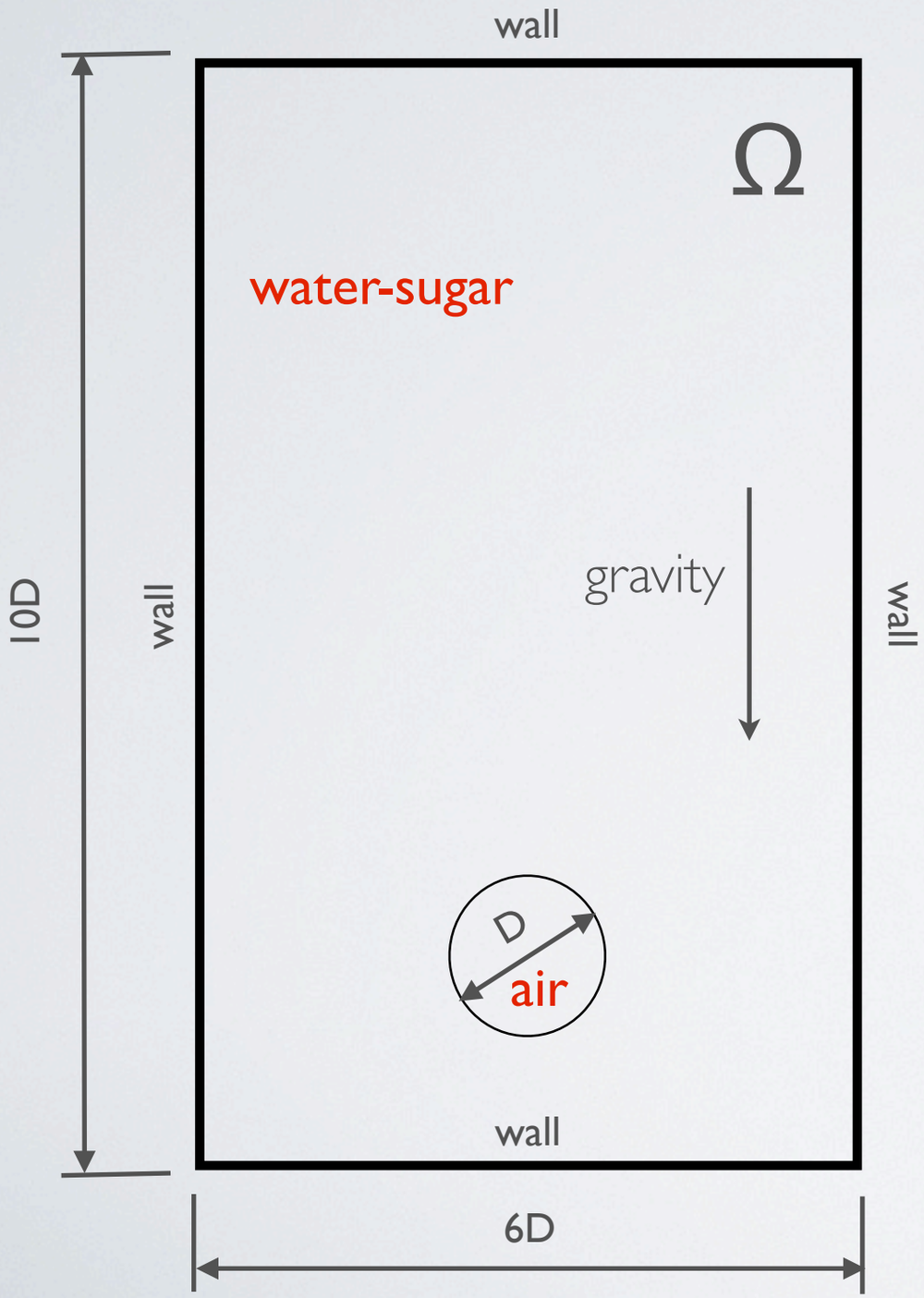


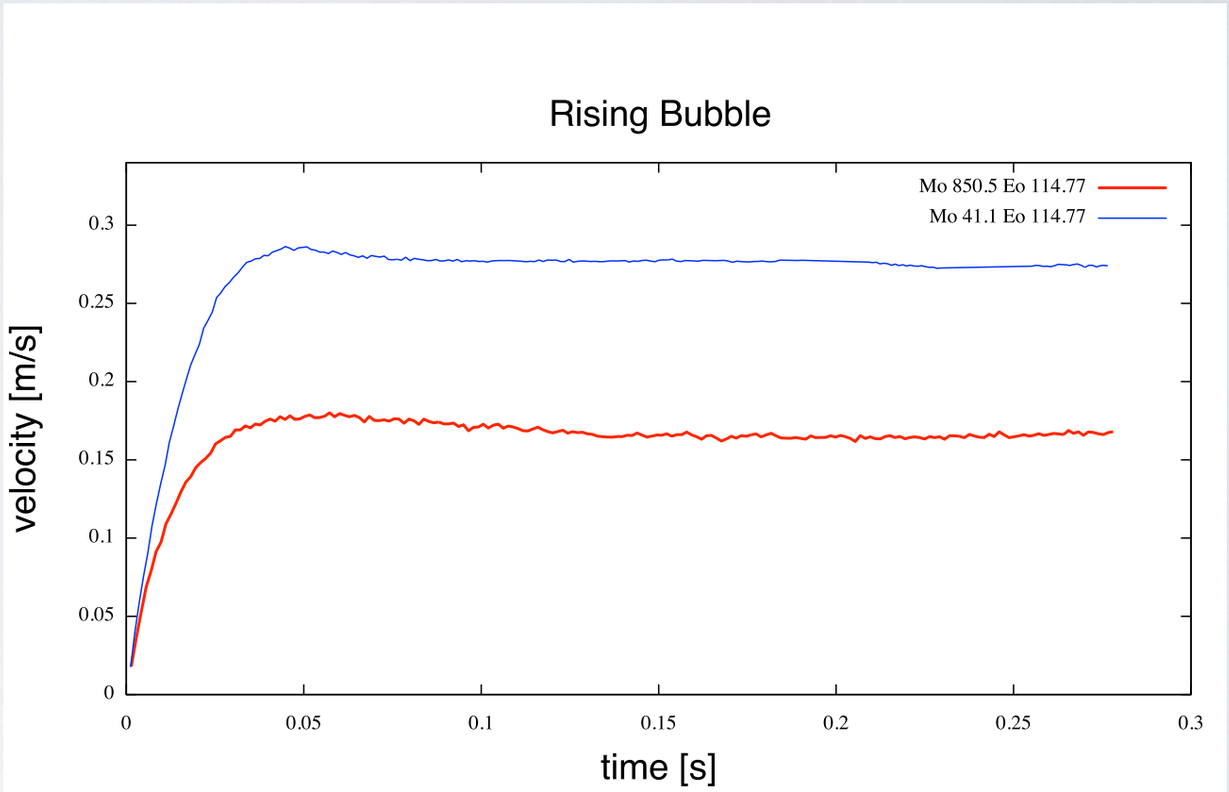
gravity





3D RESULTS





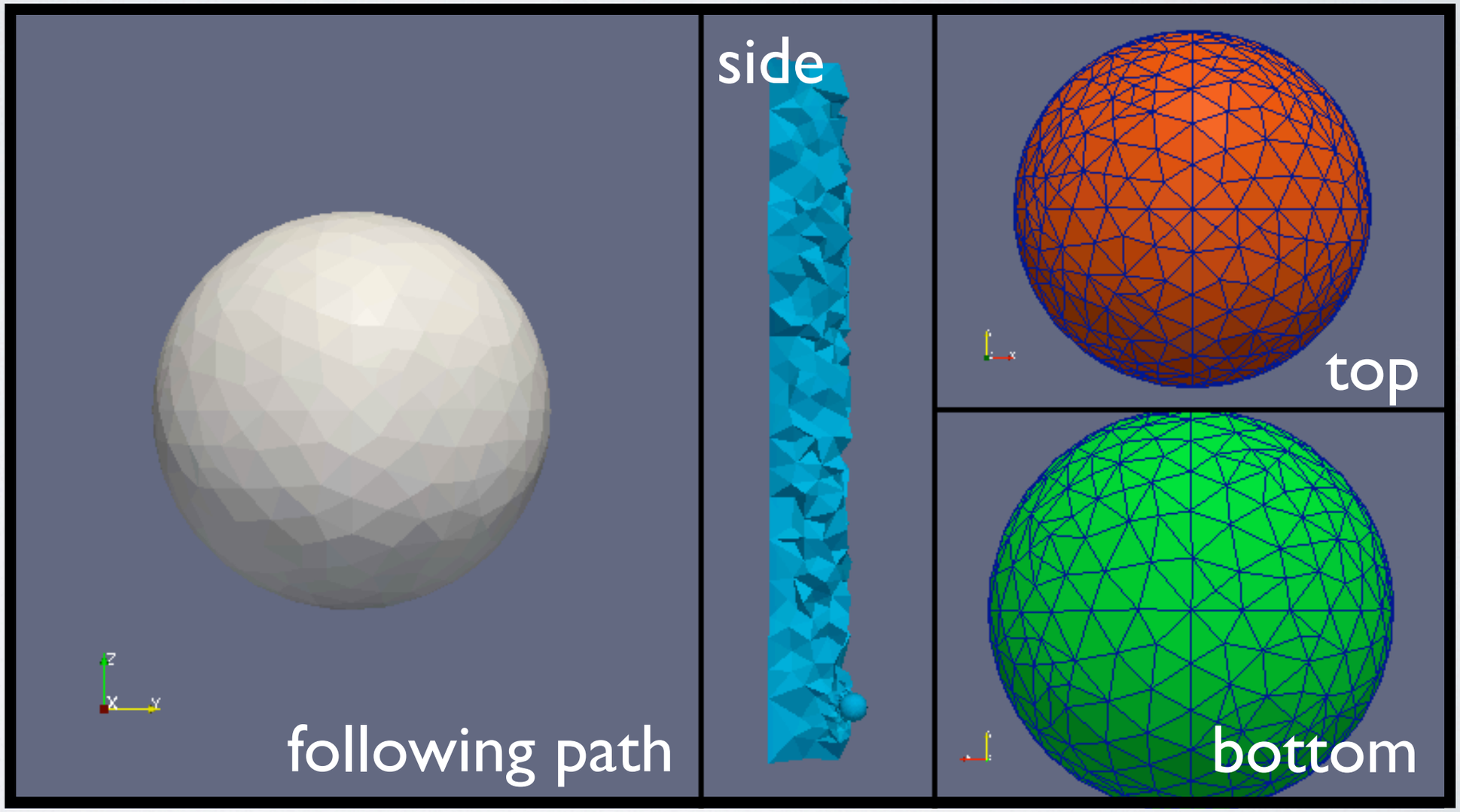
Bhaga and Weber, JFM 1981

	Mo	Eö	Renum	Re	ε[%]
case 1	850.5	114.77	2.07	2.09	<1.0
case 2	41.1	114.77	7.35	7.55	2.7

3D RESULTS

air-water

D=5mm
sigma=0.072 N/m
mu_in = 1.7894E-05 Ns/m^2
mu_out = 0.001 Ns/m^2
rho_in = 1.225 kg/m^3
rho_out = 1000 kg/m^3
Mo = 2.66E-11
Ar = 33.27
Eö = 3.4
domain: 6Dx6Dx10D



CONCLUSIONS AND FURTHER WORK

- 2D FEM-ALE code → 1st. approach, test case;
- 3D FEM-ALE code:
  - ALE flexible for two-phase flow;
  - surface tension calculation fast and precise;
  - interpolations → mass conservation errors;
  - strategy for surface points → smoothing technique;
- micro-channel validations and error analysis;
- couple heat transfer and two-phase flow;
- develop a platform for two-phase flow studies;
- predict flows in micro-scale geometries → cooling systems

THANK YOU!