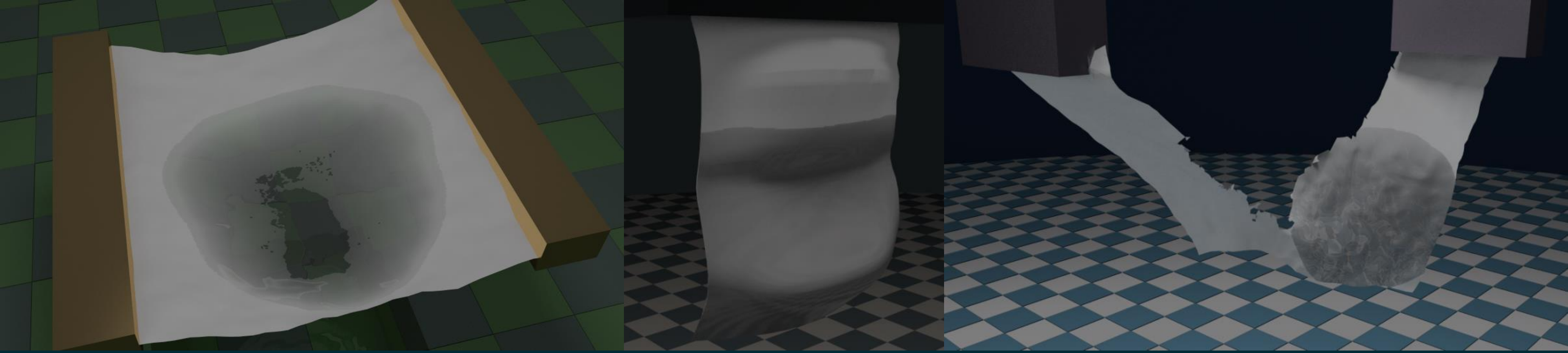

Porous Deformable Shell Simulation with Surface Water Flow and Saturation

Kiwon Um[1], Tae-Yong Kim[2], Youngdon Kwon[3], and JungHyun Han[1]

[1] Korea University
[2] NVIDIA
[3] Sungkyunkwan University

CASA 2013

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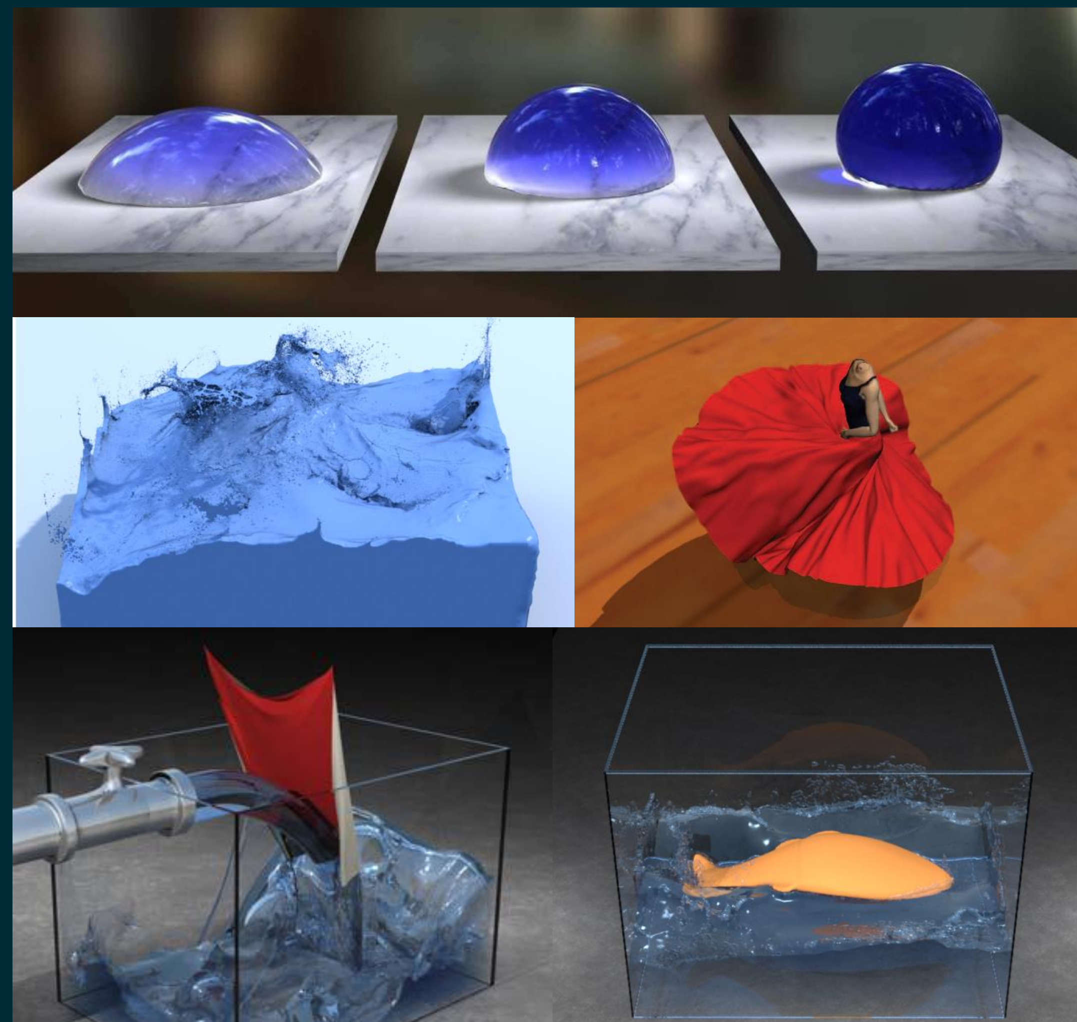
Motivation

- Fluids
  - Small scale
  - Large scale
- Objects
  - Rigid
  - Deformable
- Interaction
  - Waterproof?

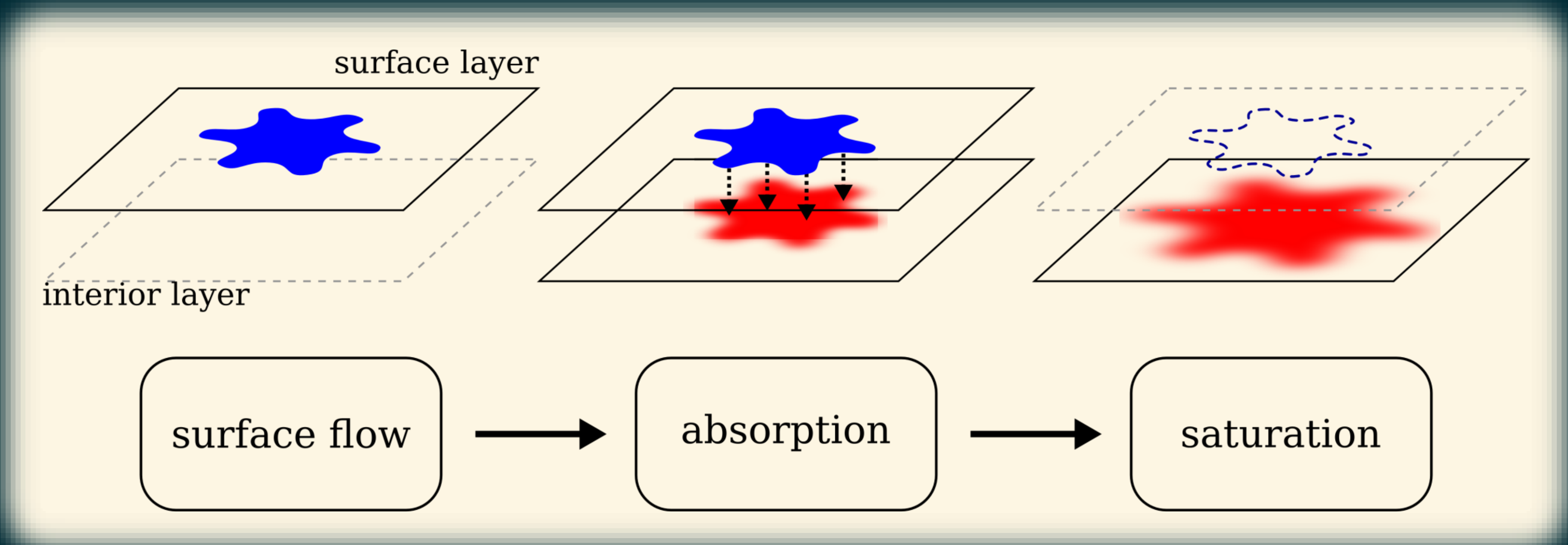


Related Work

- Lenaerts *et al*.
  - 2008, SIGGRAPH, Porous flow in particle-based fluid simulations
- Huber *et al*.
  - 2011, CGI, Wet cloth simulation
- Patkar and Chaudhuri
  - 2013, TVCG, Wetting of porous solids

Two-Layer Model

- Surface layer
- Interior layer

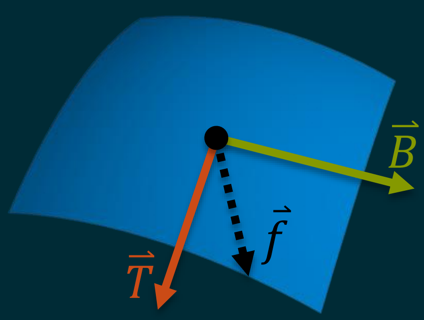


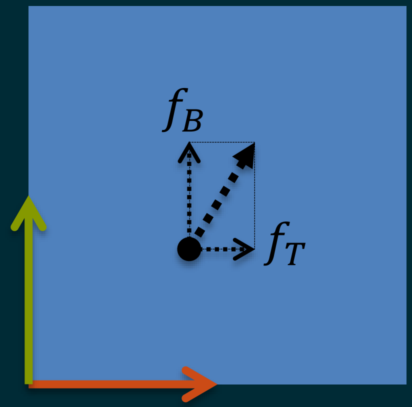
Surface Flow

- Fluid simulation in 2D (texture space) with the variational approach [Mullen *et al.*]

- External forces
  - Projected onto the 2D domain

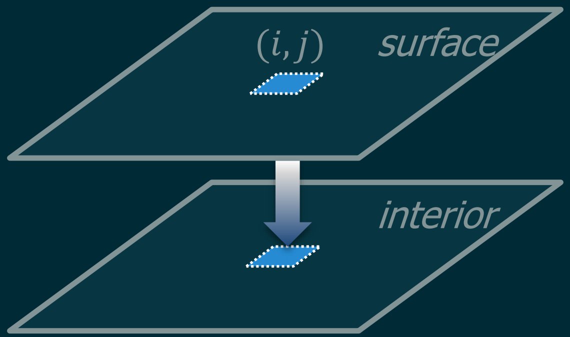
$$\begin{bmatrix} f_T \\ f_B \end{bmatrix} = \begin{bmatrix} \vec{T} \cdot \vec{f} \\ \vec{B} \cdot \vec{f} \end{bmatrix}$$





Capillary Flow

- Absorption: surface → interior



$$\Delta m_{(i,j)} = \rho_w H_{(i,j)} \epsilon \left(\frac{\sigma \psi \cos \Phi}{\eta d_c} \right)^{\frac{1}{2}} A \Delta t^{\frac{3}{2}}$$

$$H_{(i,j)} = \begin{cases} 1 & \rho_{(i,j)} \cdot \left(1 - S_{(i,j)}\right) > 0 \\ 0 & otherwise \end{cases}$$

ρ_w: constant water density
ϵ: porosity
σ: surface tension
ψ: permeability
Φ: contact angle
η: dynamic viscosity
d_c: effective pore radius
A: contact area
$\rho_{(i,j)}$: mass density computed through surface flow simulation
$S_{(i,j)}$: saturation degree

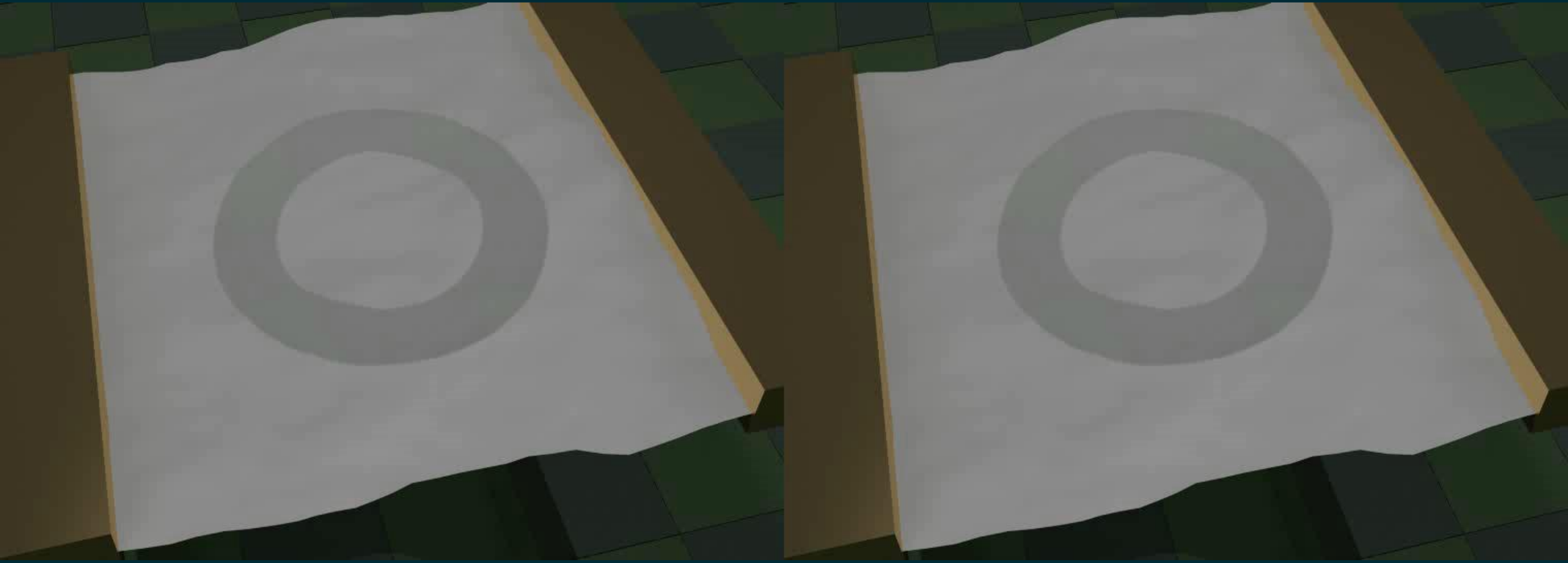
Capillary Flow (cont'd)

- In a cell (i, j)
  - Volume of cell
    - V
  - Mass contained at cell (i, j) of the surface layer
    - $m^{s}_{(i,j)} = \rho_w \rho_{(i,j)} V$
  - Capacity of mass at cell (i, j) of the interior layer
    - $m^{i}_{(i,j)} = \epsilon \rho_w (1 - S_{(i,j)}) V$

$$\Delta m'_{(i,j)} = \min\left(m^{s}_{(i,j)}, m^{i}_{(i,j)}, \Delta m_{(i,j)}\right)$$

Capillary Flow (cont'd)

- Different permeabilities



Low permeability vs. High permeability

Capillary Flow (cont'd)

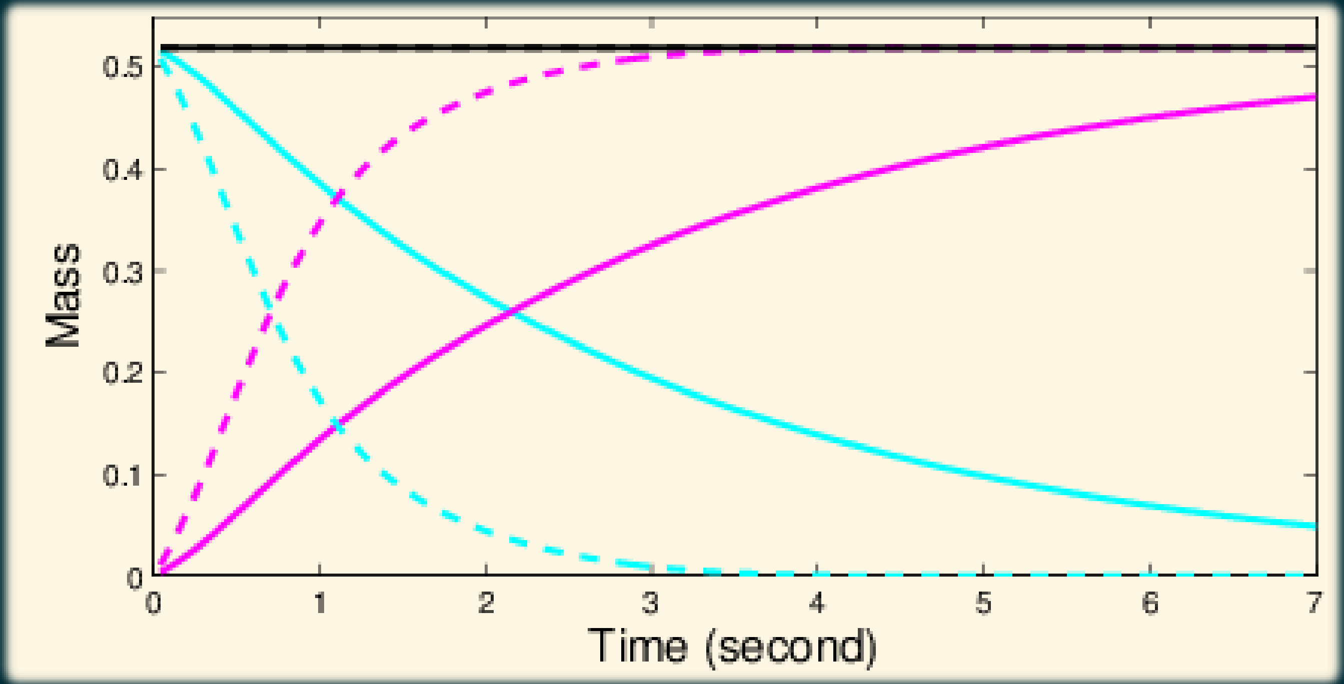
- Mass change

  Surface layer: cyan

  Interior layer: magenta

  High-permeability: dotted

  Low-permeability: solid



Capillary Flow (cont'd)

- Diffusion: interior

$$\frac{\partial S}{\partial t} = \nabla \cdot (D \nabla S) \qquad D(\epsilon_l) = \frac{3\sigma \cos\Phi \sin^2\beta \, d_c \epsilon_l}{20\eta\epsilon}$$

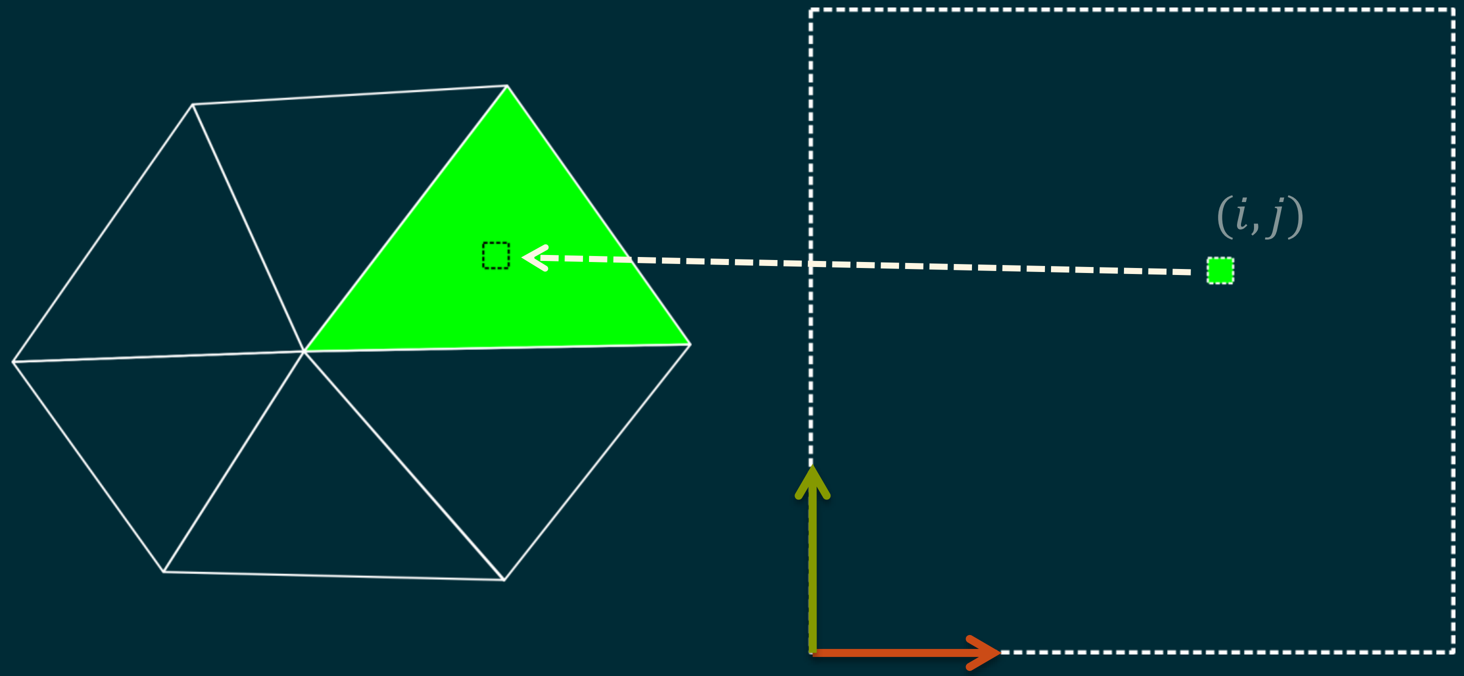
ϵ_l: fraction of the cell volume occupied by water

β: average angle between the capillaries and the surface of the object

  - Solve numerically…

Capillary Flow (cont'd)

- Reference to the state variables
  - Mass density: $\rho_{(i,j)}$
  - Saturation degree: $S_{(i,j)}$



Changes in Material Properties

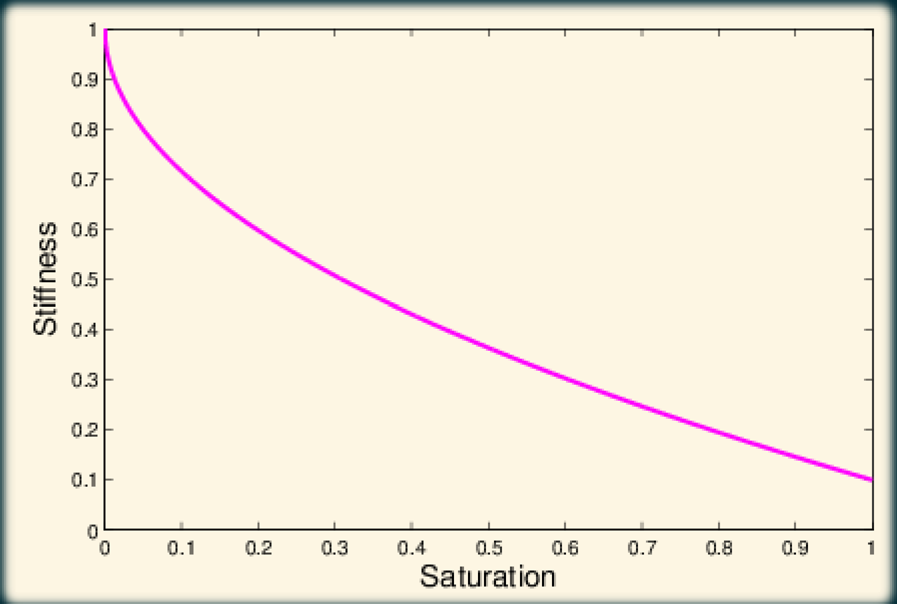
- Mass: porous material + water

$$M_{(i,j)} = \left(\rho_o(1-\epsilon) + \rho_w \epsilon S_{(i,j)} + \rho_{(i,j)}\right)V$$

ρ_o: density of the porous material
V: volume of a cell

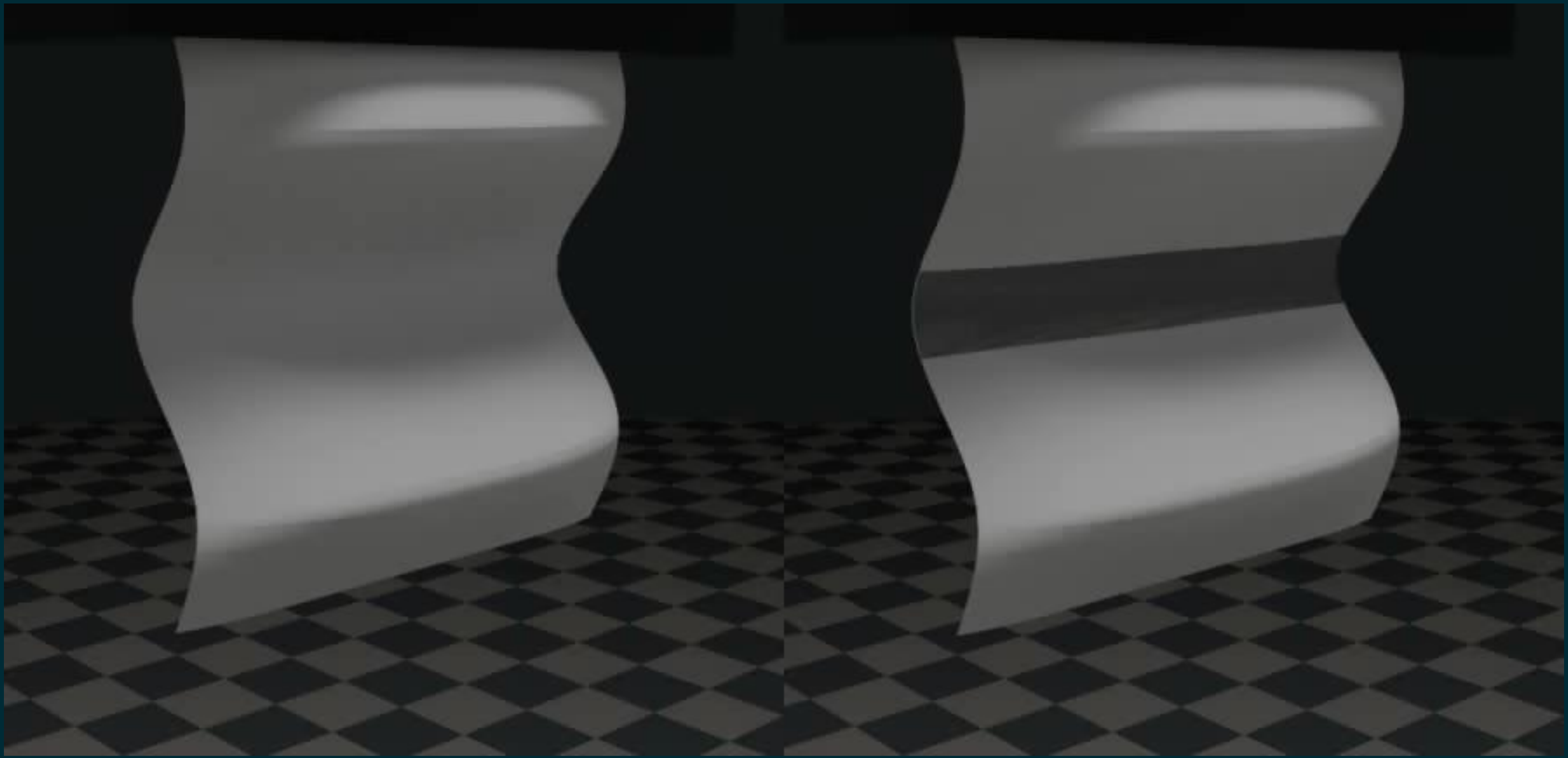
- Stiffness
  - Stretching
  - Bending

$$k_s' = (k_{min} - k_s)\sqrt{S_e} + k_s$$



Changes in Material Properties (cont'd)

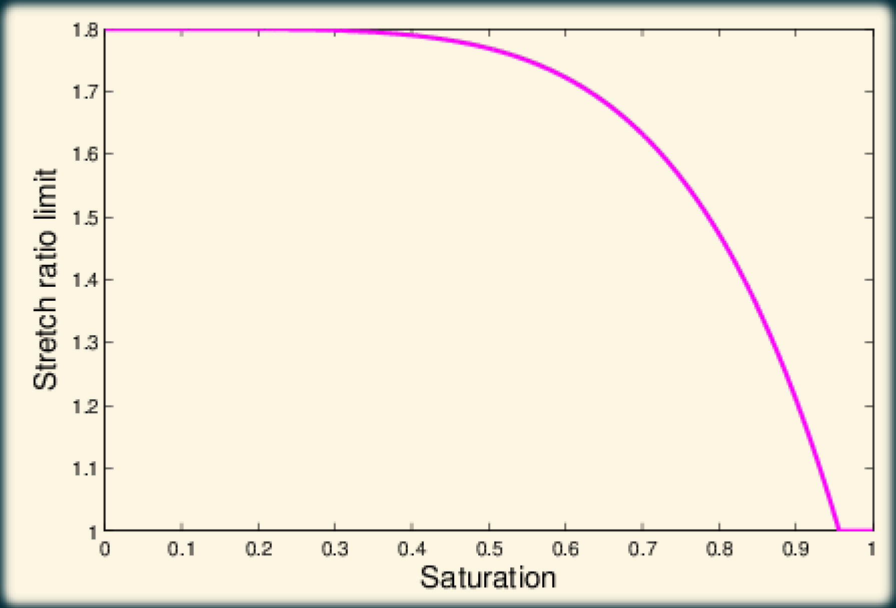
- Effects of changes in mass and stiffness



Changes in Material Properties (cont'd)

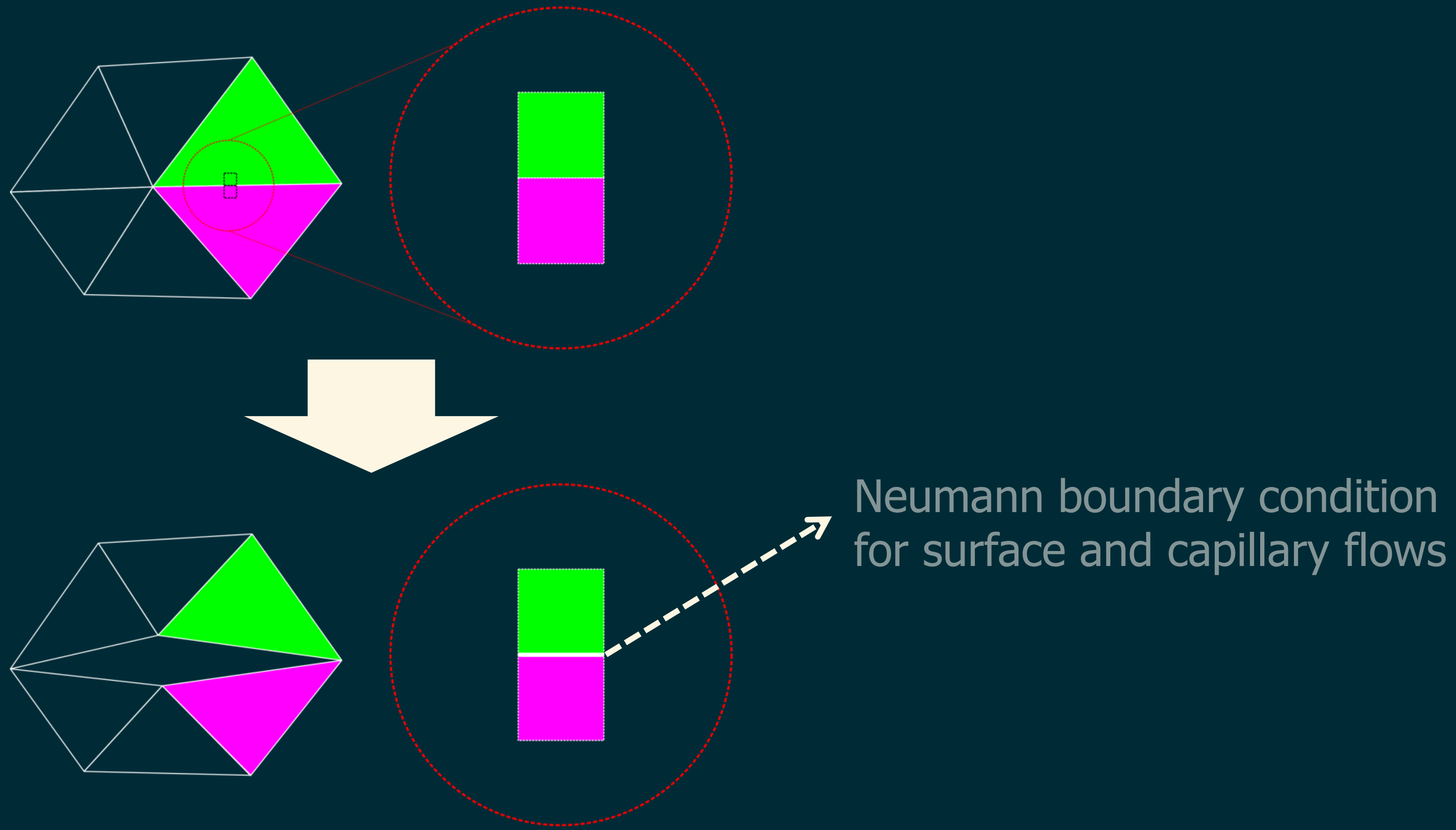
- Tearing
  - Stretch ratio limit: ε

$$\varepsilon' = \max(\varepsilon - \alpha(S_e)^{\gamma}, \varepsilon_{min})$$



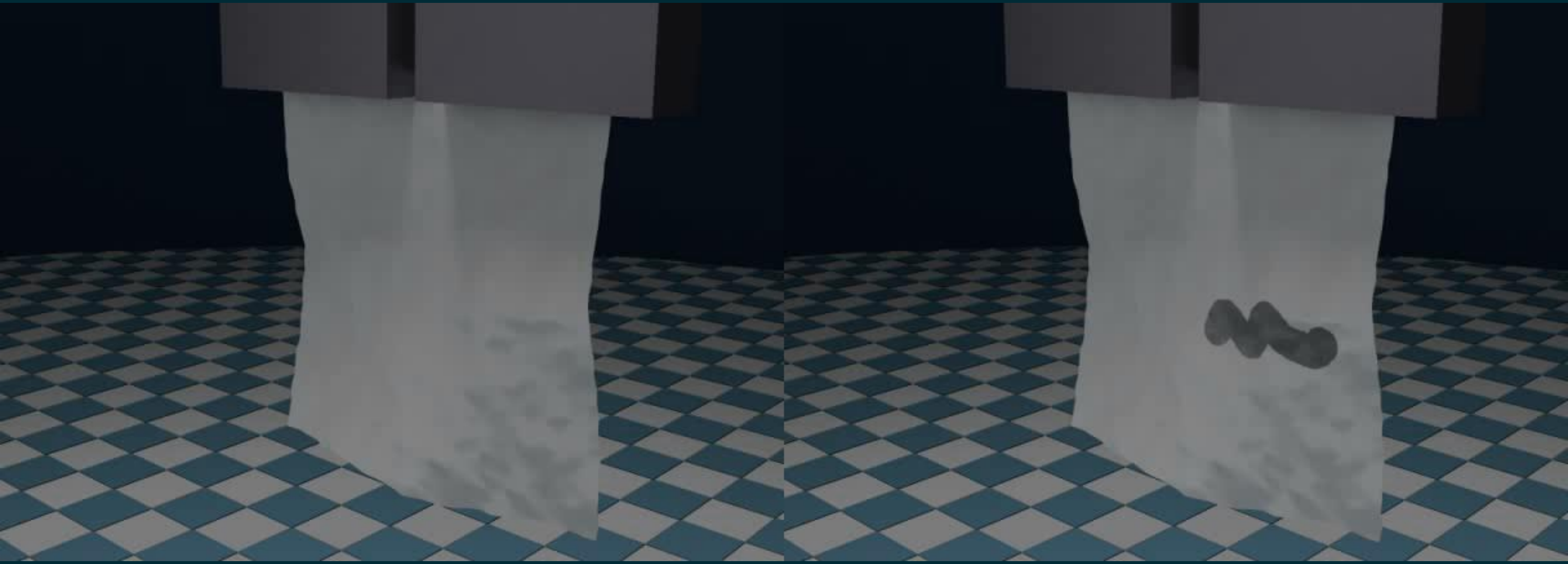
Changes in Material Properties (cont'd)

- Discontinuity after tearing



Changes in Material Properties (cont'd)

- Comparison of tearing effects



Experiment

- System
  - Intel Core i5-2500K 3.30GHz CPU
  - 8GB memory
- Fluid
  - CFL: 1
  - 512 x 512
- Deformable shells
  - 4K vertices and 8K polygons
- Simulation time
  - 3~4 sec./frame

Conclusion and Future Work

- Simulation
  - Dynamics of deformable shells (with PBD)
  - Surface water flow
  - Capillary flow involving absorption and diffusion of water

- Future work
  - Various full 3D effects: squeezing, sinking, dissolving, evaporation, condensation, etc.

Q/A

Thank you