Permeable and Absorbent Materials in Fluid Simulations

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Motivation

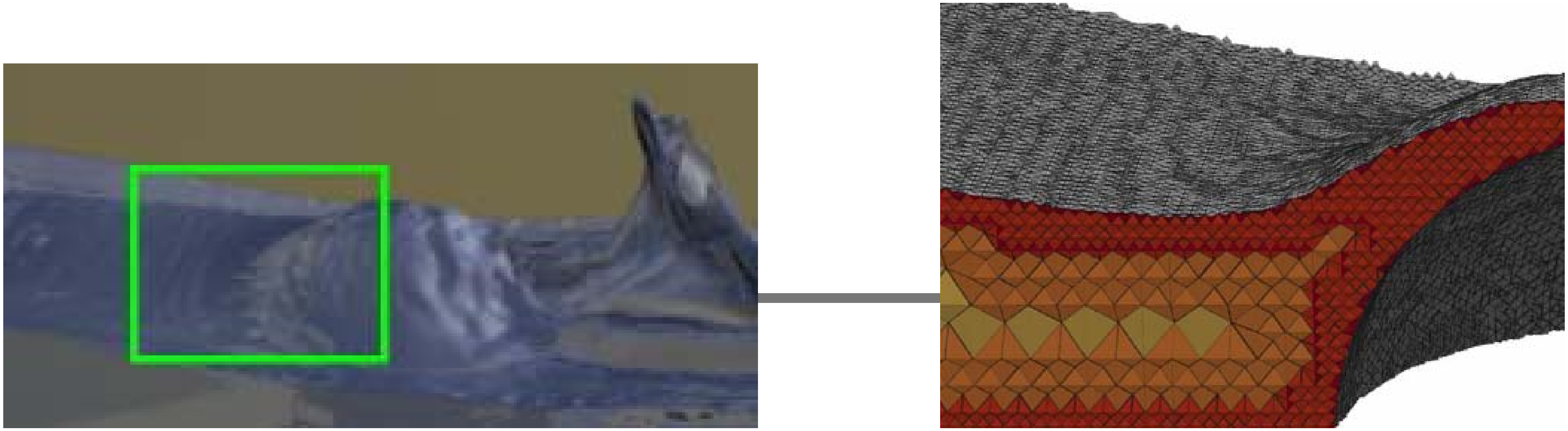
- Fluid simulations are geared toward impermeable materials
  - What if you want to include a sponge?
- Shrek's Gingerbread Man being tortured
  - Milk does not soak in – instead falls off

Water Simulation Background

- Discretize Scene
- Navier-Stokes Equations
- Material-Liquid Interaction
- Update Fluid Volume

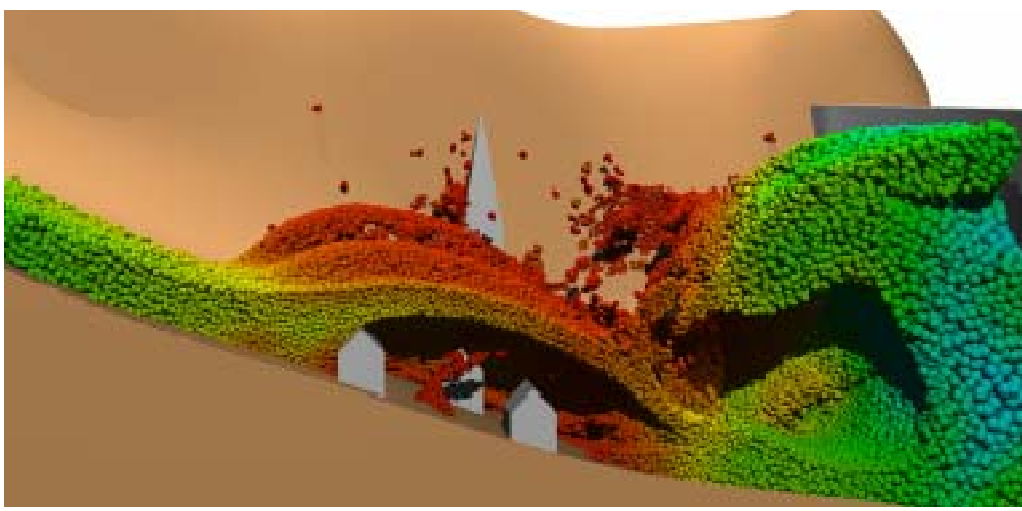
Discretize Scene

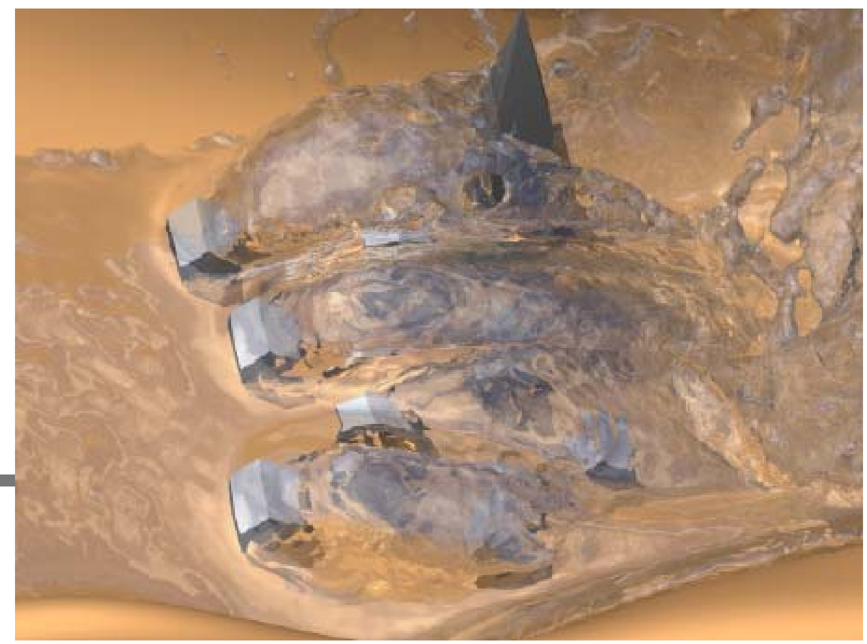
- Eulerian – Voxels (or cells)
  - Pressure defined at center of cell
  - Velocity defined at faces
- Need high resolution to capture details
- Example: Chentanez et al., “Liquid Simulation on Lattice-Based Tetrahedral Meshes”



Discretize Scene

- Lagrangian – Particles
  - Add and remove particles depending on level of detail
- Example: Adams et al., “Adaptively Sampled Particle Fluids”





Navier-Stokes Equations

- Conservation of Mass $\nabla \cdot \mathbf{u} = 0$

- Important for liquids
- Solve linear system of equations
  - High computation cost

Navier-Stokes Equations

- Conservation of Momentum

$$\mathbf{u}_t = \nu\nabla\cdot\left(\nabla\mathbf{u}\right) - \left(\mathbf{u}\cdot\nabla\right)\mathbf{u} - \frac{1}{\rho}\nabla p + \mathbf{g}$$

- CFL condition – high computation cost
  - Update the velocity when nothing "significant" happens
    - For Eulerian, velocity should be small enough so that fluid cannot move over an entire cell
  - Reduce time step to satisfy condition

Material-Liquid Interaction

- Boundary Conditions
  - Non-Slip
    - Set fluid’s normal velocity to zero
  - Free-Slip
    - Set object’s inner tangential velocity to the tangential velocity of fluid – introduces a resisting velocity

Update Fluid Volume

- Use new velocity to update the position of the liquid
- Eulerian
  - Volume loss near detailed features
- Lagrangian
  - Visual artifacts when too few particles
- Hybrid approaches
  - Example: Foster and Fedkiw, “Practical Animation of Liquids”

Fluid Solver Extensions

- Framework already in place for absorbent materials
  - Base an extension on physical equations
- Extend:
  - Boundary condition
  - Navier-Stokes
  - Fluid volume update

Physical Equations

- Darcy's Law
  - Created based on observation
  - Later derived from Navier-Stokes

$$q = \frac{-\kappa}{\mu}(\nabla \mathbf{P} - \rho g)$$

- Capillary Action Equation

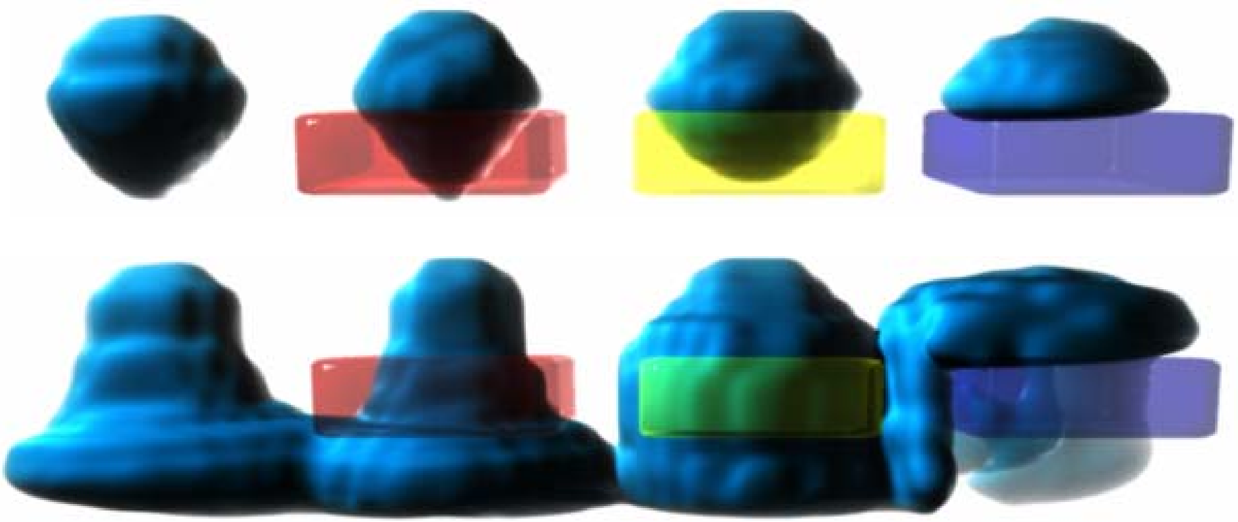
$$h = \frac{2\gamma \cos\theta}{\rho g r}$$

New Parameters

- Permeability – the ability of a material to transport liquid
- Porosity – maximum amount of open space in a material
- Capillary Action – the ability of a material to draw liquid into itself and retain it

Permeability

- Materials given values [0%, 100%]
  - 0% = impermeable
  - 100% will be treated as if no material was present

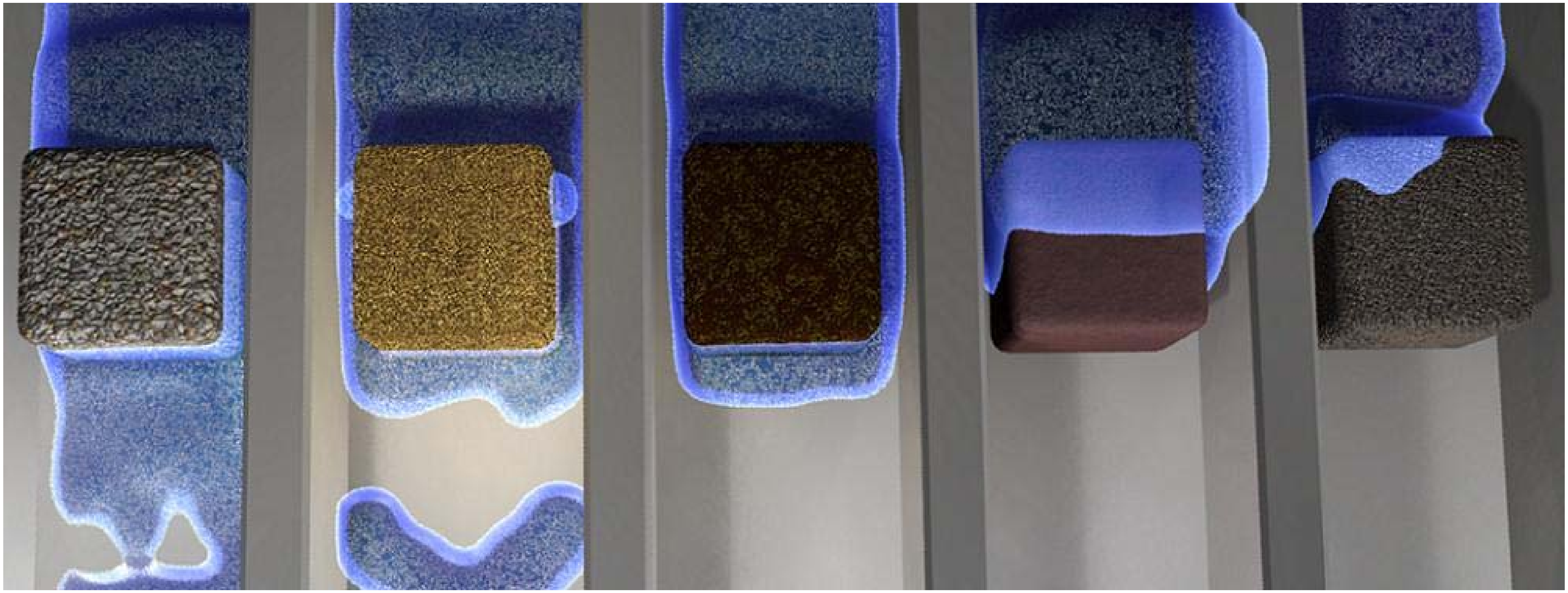


Porosity

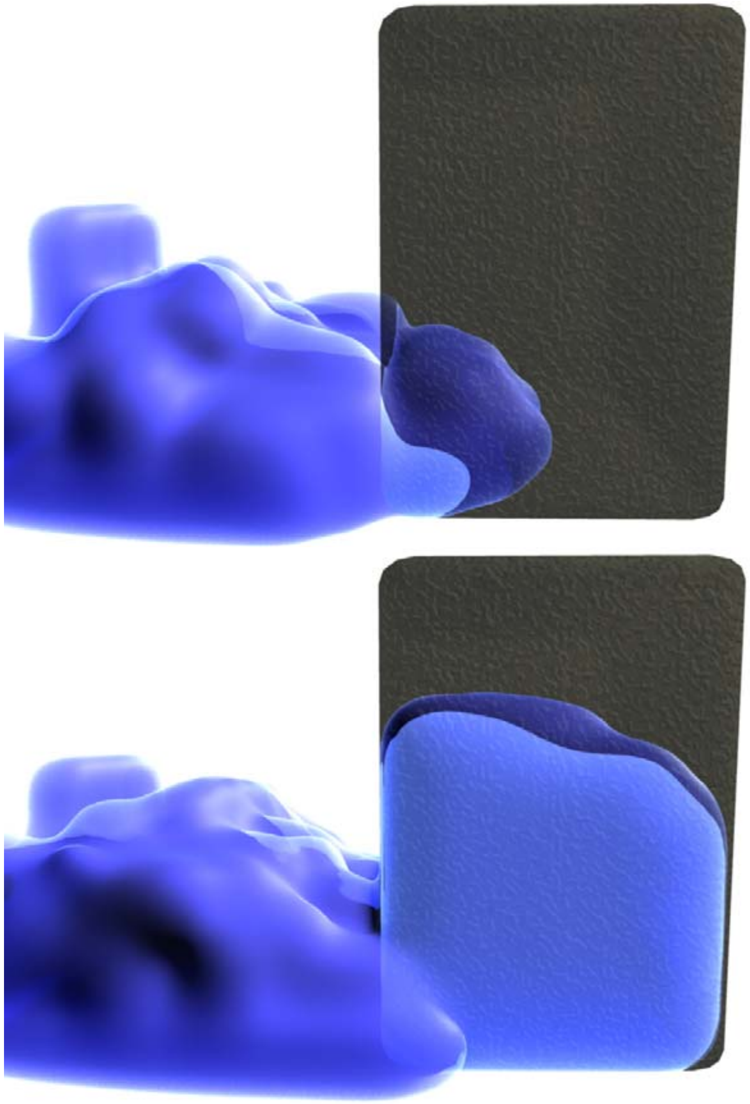
- Materials given values [0%, 100%]
  - 0% = no fluid allowed in
  - Often related to permeability, but not always the case (i.e. clay)

Different Permeability and Porosity

Gravel Sand Soil Clay Shale



Capillary Action



- Reduce capillary action equation to a single parameter
  - Represents a localized force created by the suction of the material

Air

- Treat air as any other material
  - Do not have to make distinction in code to treat fluid-air interaction vs fluid-material
  - Permeability = 100%
  - Porosity = 100%
  - Capillary Action = 0

Boundary Condition

- Extended Non-Slip Condition

$$\mathbf{v_{i+\Delta t}} = \mathbf{v_i}\kappa$$

- Extended Free Slip Condition

$$\mathbf{v_{object}} = \mathbf{v_{fluid}}(1-\kappa)$$

Navier-Stokes

- Extended conservation of momentum

$$\mathbf{u}_t = \nu \nabla \cdot (\nabla \mathbf{u}) - (\mathbf{u} \cdot \nabla)\mathbf{u} - \frac{1}{\rho}\nabla p + \mathbf{g}$$

$$\downarrow$$

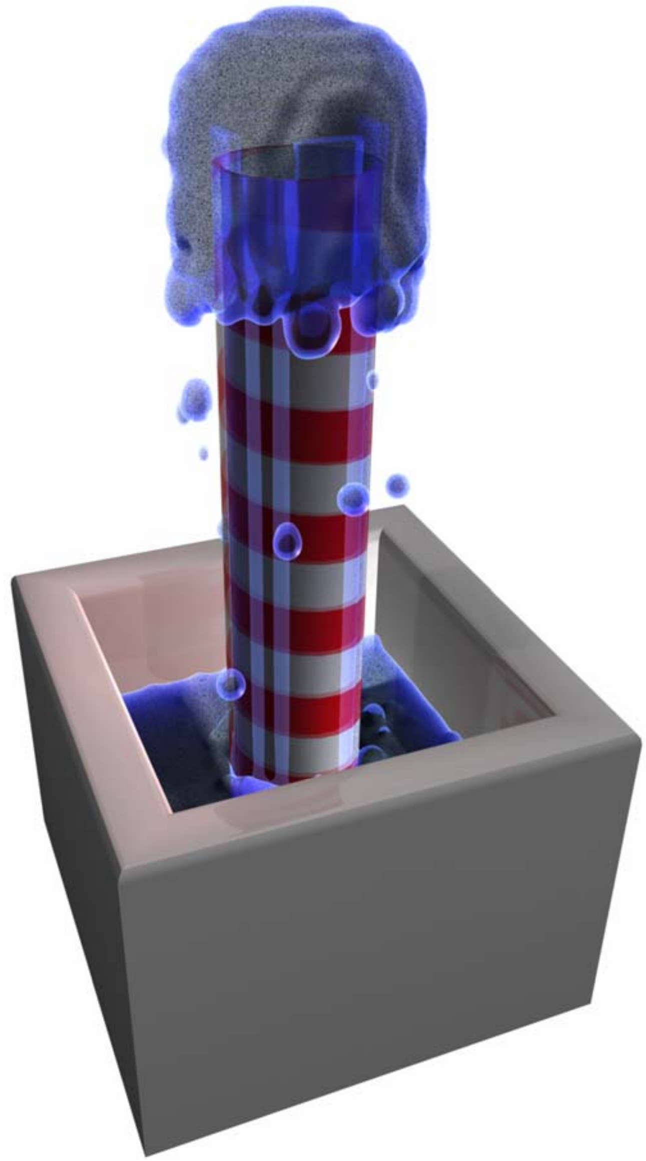
$$\mathbf{u_t} = [v\nabla \cdot (\nabla \mathbf{u}) - (\mathbf{u} \cdot \nabla) - \frac{1}{\rho}\nabla \rho + \mathbf{g} + \mathbf{F_L}]\kappa$$

Fluid Volume Update

- Already methods in place to move water from overly filled positions
  - Take into account the porosity of the material

Controlling Animation

- Use new parameters to give animator more control of their simulation
  - Set a material with a very high porosity
  - Give air capillary action



Creating Fluid Scenes

- Modeled in Maya
- Imported into fluid solver
- Exported back to Maya for rendering
  - “Clean-up” scene – Matt Brisbin
  - Use Maya’s fluid solver plug-in for rendering
    - With photon mapping and caustics, 5-15 minutes per frame

Video

Future Work

- Apply to erosion techniques
- A sponge grows as it sucks up more water
- Wet a material then let it dry
  - Cracked soil
  - Paper dries in a deformed way
- Material properties, such as tensile strength, are changed when wet

Questions