Implementation of Fast Hydraulic Erosion Simulation and Visualization on GPU

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Overview:

- Motivation
- Shallow Water Equations
  - What are they?
  - Why are they used?
- Implementation
  - Height Maps
  - Pipes Model
  - Parallelization
- Expected Results
- Limitations

Motivation

- Enhance terrain generation through the physical simulation of water erosion.
- Interactive frame rates allow results to be viewed in real time.
    - Water movement over the terrain
    - Soil movement and deposition
    - Evaporation
- Provides an important perspective for terrain modelers and soil scientists.
    - Could potentially be expanded to handle terrains of multiple soil types

Shallow Water Equations

- Equations derived from Navier-Stokes Equations
  - Physical equations that describe viscous fluid motion
  - Used as the foundation for various simulations: Weather, ocean currents, pipe flow, etc.
  - Vertical derivation removes need to calculate vertical velocity
- Conserve mass and linear momentum
  - Helps keep realism in the simulation
- Considers fluid to be a continuous substance
  - Helps lower the scaling cost of computation with increased detail compared to particle system

Shallow Water Equations

Conservation of Mass: $\frac{\delta(\rho h)}{\delta t} + \frac{\delta(\rho h u)}{\delta x} + \frac{\delta(\rho h v)}{\delta y} = 0$

Conservation of Momentum (X-Axis): $\frac{\delta(\rho h u)}{\delta t} + \frac{\delta}{\delta x}\left(\rho h u^2 + \frac{1}{2}\rho g h^2\right) + \frac{\delta(\rho h u v)}{\delta y} = 0$

Conservation of Momentum (Y-Axis): $\frac{\delta(\rho h u)}{\delta t} + \frac{\delta(\rho h u v)}{\delta x} + \frac{\delta}{\delta y}\left(\rho h v^2 + \frac{1}{2}\rho g h^2\right) = 0$

Where $\rho = fluid\ density$, $h = height\ of\ fluid\ at\ a\ specific\ point\ and\ time$,
$x = horizontal\ flow\ velocity\ in\ x - direction$, and $y = horizontal\ flow\ velocity\ in\ y - direction$

Implementation: Height Maps

- Utilize height maps and meshes to store data for water and terrain surface.
  - Each vertex in the mesh represents a “column” of water and terrain, and has its height changed according to values from adjacent vertices.
- Columns are made of water height, terrain height, and sediment content.

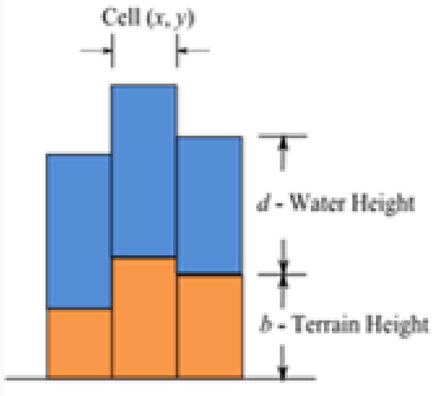

Figure 1. Simulation Data Structure [Mei et al. 2007]

Implementation: Pipes Model

- Virtual Pipes Model is commonly used to help with the calculations used to determine changes in column height.
  - Assumes pipes connect each adjacent column and water flows through the pipes
  - The amount of water flowing through the pipe is called Flux
- Outflow Flux - Inflow Flux = Change in water volume in column

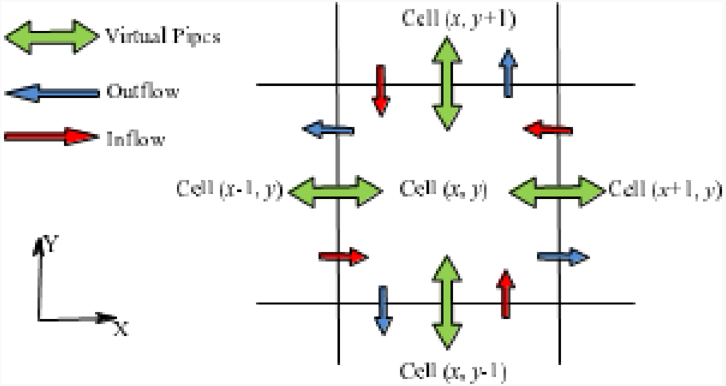

Figure 2. Virtual Pipes Model [Mei et al. 2007]

Implementation: Parallelization

- Textures are utilized by Graphics Processing Unit (GPU) to store data
  - Can be modified using parallel computational power of GPU and shaders
- Data values for columns, flux, and flow velocities are stored in textures
  - 3 Textures needed:
    - Terrain height, water height, and sediment content
    - Outflow flux to left, right, top, and bottom adjacent columns
    - Flow velocities in x-direction and y-direction

Expected Results

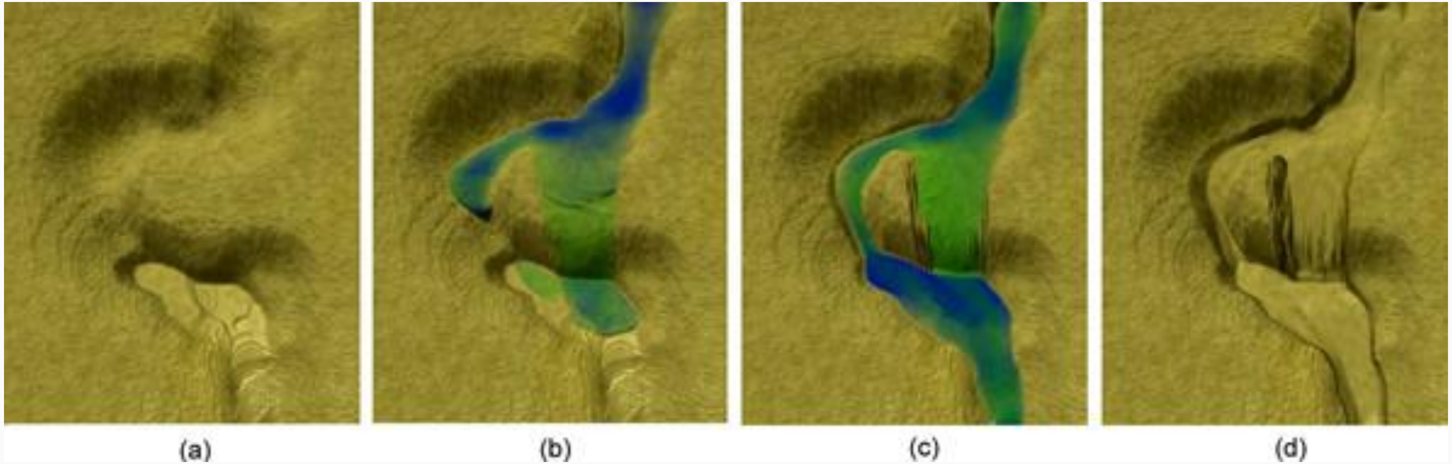

Figure 3. Snapshots of final implementation of simulation while running [Mei et al. 2007]

Limitations of Shallow Water Equations

- Breaking waves need special consideration
  - Vertices would need to consider empty space between crest of the wave and rest of the water
  - Particle effects need to be implemented to make breaking waves look natural
- Not the most realistic water simulation, but trades that realism for calculation efficiency when implemented on the GPU.

Citation

Xing Mei, Philippe Decaudin, Bao-Gang Hu. Fast Hydraulic Erosion Simulation and Visualization on GPU. Marc Alexa and Steven J. Gortler and Tao Ju. PG ’07 - 15th Pacific Conference on Computer Graphics and Applications, Oct 2007, Maui, United States. IEEE, pp.47-56, 2007, Pacific Graphics 2007. <10.1109/PG.2007.15>.

Thank You.
Any Questions?