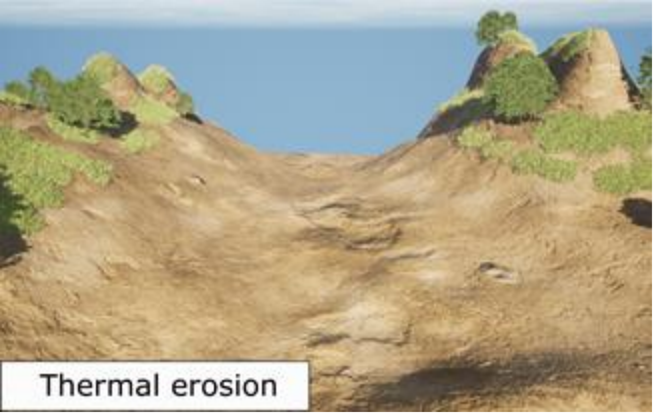
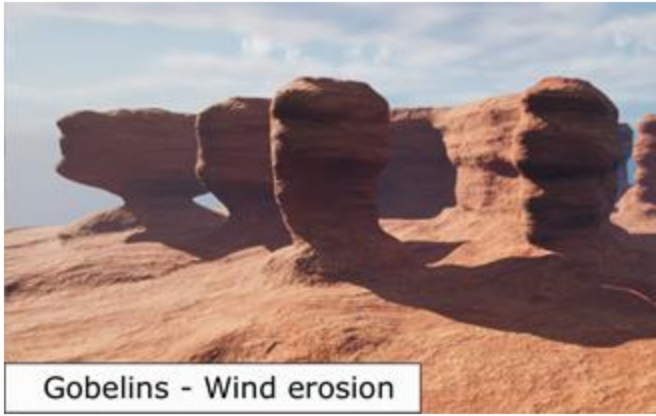
Flexible Terrain Erosion Compatible with Multiple Representations



Marc Hartley [1]
Nicolas Mellado [2]
Christophe Fiorio [1]
Noura Faraj [1]



[1] University of Montpellier, LIRMM
[2] IRIT, University of Toulouse

CGI2024

Terrain generation

- For cinema,
- Video games,
- Simulations,
- ...

Avatar: The Way of Water (2022). Directed by J. Cameron

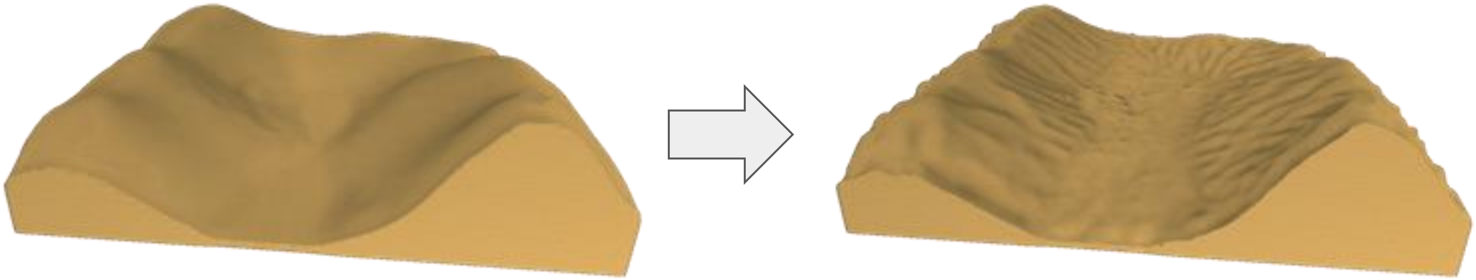
Red Dead Redemption II (2018). Rockstar Studio

Pierre Ecormier-Nocca et al.. Authoring Consistent Landscapes with Flora and Fauna. ACM Transactions on Graphics, 2021

A common terrain generation pipeline

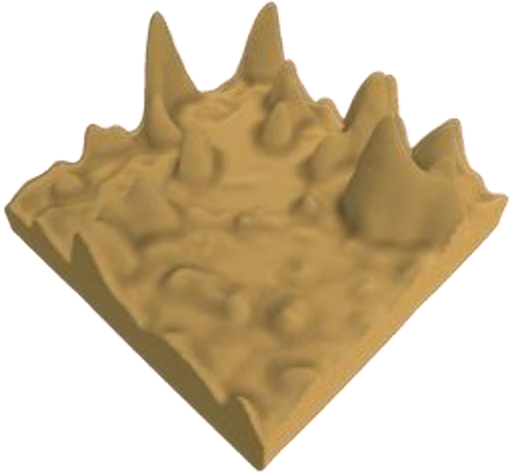
1. Generate a base geometry

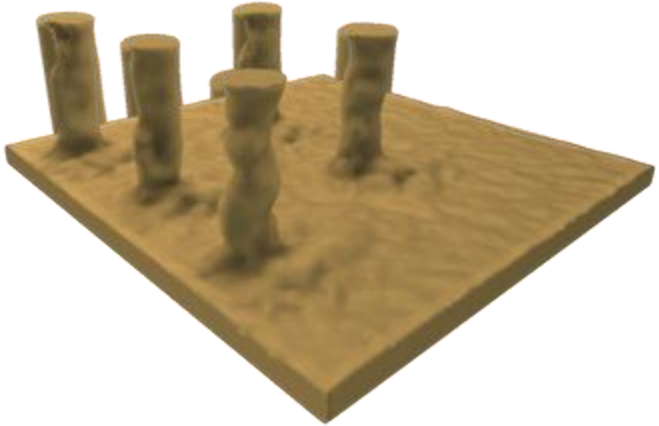
2. Increase the realism



Erosion simulation

- Modeling of physical phenomena on a synthesised terrain



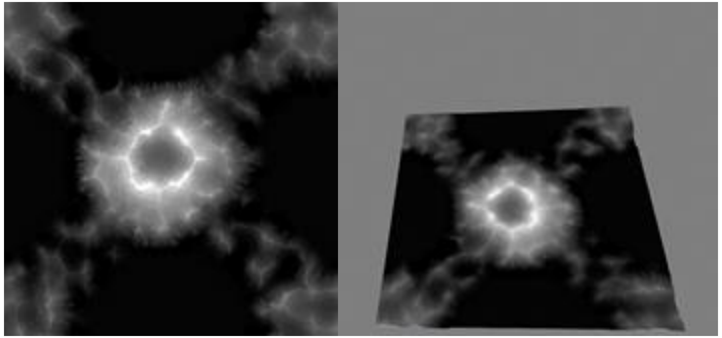


Multiple representations

- Height fields
- Layered terrain
- Voxel grids
- Implicit terrains
- Etc…

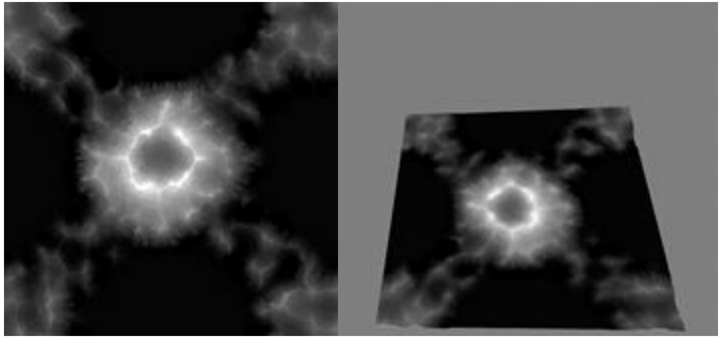
Multiple representations

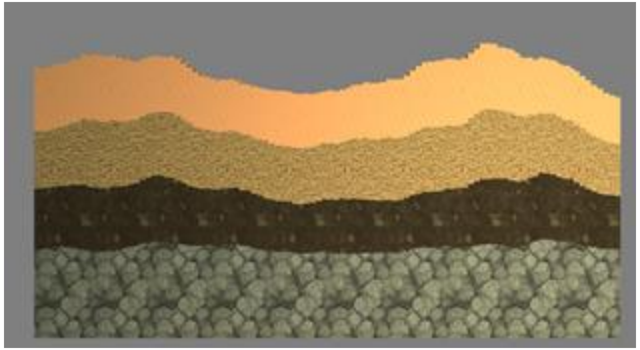
- **Height fields**
- Layered terrain
- Voxel grids
- Implicit terrains
- Etc…



Multiple representations

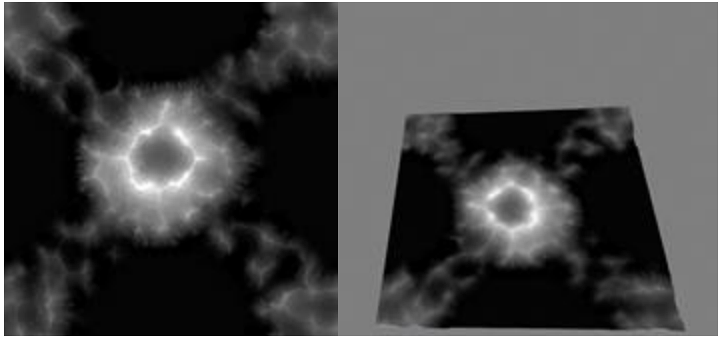
- Height fields
- **Layered terrain**
- Voxel grids
- Implicit terrains
- Etc…



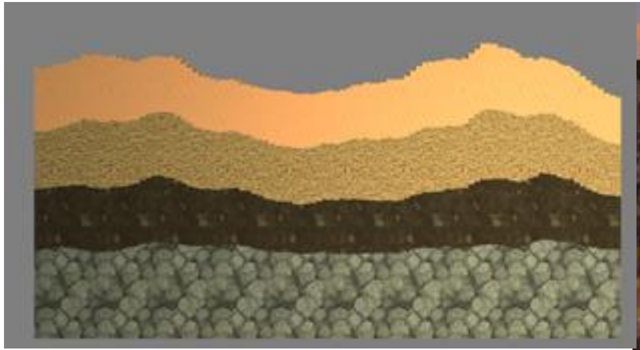


Peytavie, A., Galin, E., Grosjean, J., Merillou, S.: Arches: a framework for modeling complex terrains. CGF 28, 457–467 (2009)

Multiple representations



- Height fields
- Layered terrain
- **Voxel grids**
- Implicit terrains
- Etc…

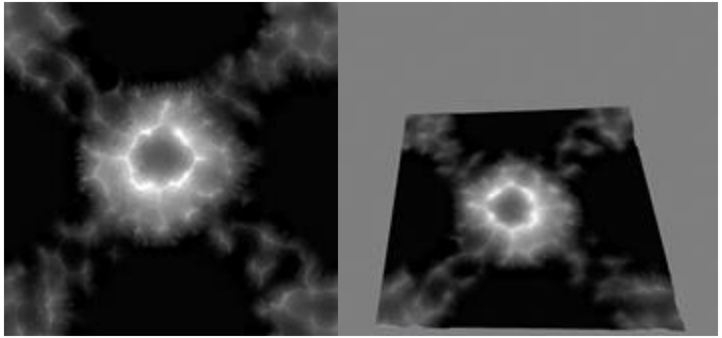


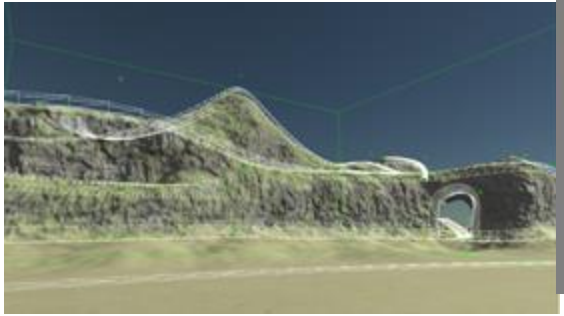
Peytavie, A., Galin, E., Grosjean, J., Merillou, S.: Arches: a framework for modeling complex terrains. CGF 28, 457–467 (2009)

Source : Minecraft

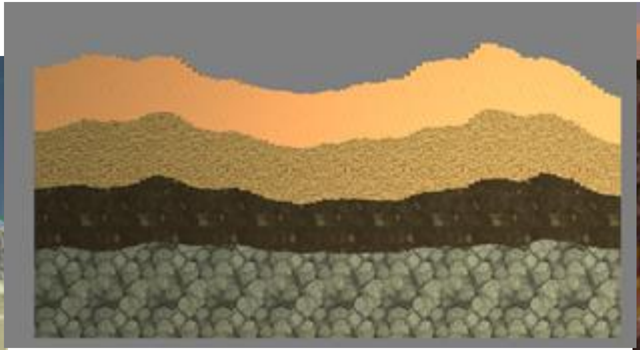
Multiple representations

- Height fields
- Layered terrain
- Voxel grids
- **Implicit terrains**
- Etc…





M. Becher, et al. “Feature-Based Volumetric Terrain Generation.” *Proceedings - I3D 2017: 21st ACM SIGGRAPH Symposium on Interactive 3D Graphics and Games*, 2017



Peytavie, A., Galin, E., Grosjean, J., Merillou, S.: Arches: a framework for modeling complex terrains. CGF 28, 457–467 (2009)

Source : Minecraft

Available simulations restricted to the representation

Thermal erosion
Hydraulic erosion
Aeolian erosion
~~Coastal erosion~~
~~Karst erosion~~
…

Height fields	Almost everything available
Layered terrain	
Voxel grids	
Implicit terrains	
Etc…	

Musgrave, F. Kenton, et al. "The Synthesis and Rendering of Eroded Fractal Terrains." 1989
Neidhold, B., et al. "Interactive Physically Based Fluid and Erosion Simulation." 2005
Roa, Toney, and Bedrich Benes. "Simulating Desert Scenery." 2004

Available simulations restricted to the representation

Thermal erosion
Hydraulic erosion
Aeolian erosion
~~Coastal erosion~~
~~Karst erosion~~
~~...~~

Height fields	Almost everything available
Layered terrain	Some adaptations proposed
Voxel grids	
Implicit terrains	
Etc…	

Beneš, Bedřich, et al. "Layered Data Representation for Visual Simulation of Terrain Erosion" 2001
Cordonnier, Guillaume, et al. "Authoring Landscapes by Combining Ecosystem and Terrain Erosion Simulation." 2017
Paris, Axel, et al. "Desertscape Simulation". 2020

Available simulations restricted to the representation

Thermal erosion
Hydraulic erosion
~~Aeolian erosion~~
~~Coastal erosion~~
~~Karst erosion~~
~~...~~

Height fields	Almost everything available
Layered terrain	Some adaptations proposed
Voxel grids	Very few
Implicit terrains	
Etc...	

Beardall, Matthew, et al. "Directable weathering of concave rock using curvature estimation". 2010
Beneš, Bedřich, et al. "Hydraulic Erosion." 2006

Available simulations restricted to the representation

~~Thermal erosion~~
~~Hydraulic erosion~~
~~Aeolian erosion~~
Coastal erosion
Karst erosion
~~…~~

Height fields	Almost everything available
Layered terrain	Some adaptations proposed
Voxel grids	Very few
Implicit terrains	Close to nothing
Etc…	

Paris, Axel and al. Terrain Amplification with Implicit 3D Features. 2019

Available simulations restricted to the representation

Thermal erosion
Hydraulic erosion
Aeolian erosion
Coastal erosion
Karst erosion
...

⟷ Our method ⟷

Height fields

Layered terrain

Voxel grids

Implicit terrains

Etc...

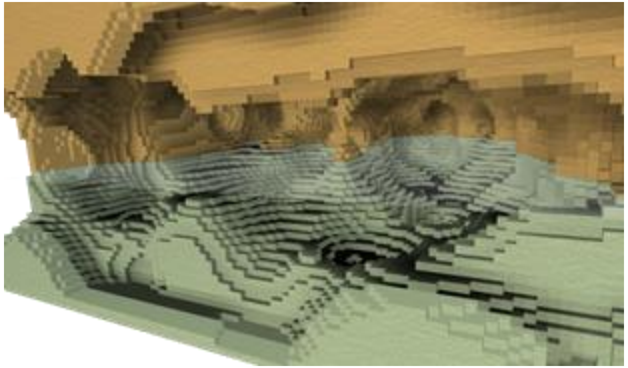
Contributions

- A generalized particle-based algorithm for erosion simulation.
- The decoupling of the erosion system from the fluid simulation.

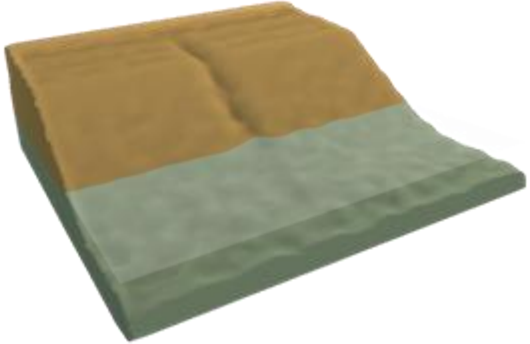
- Providing an algorithm easy to implement,
- With few intuitive parameters,
- Inducing a controllable erosion method.

Particle-based erosion method

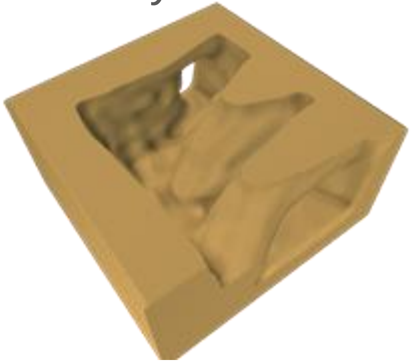
Karst – Binary voxels



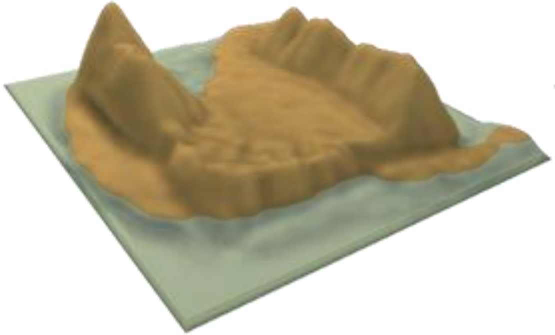
Rivers – Layered terrain



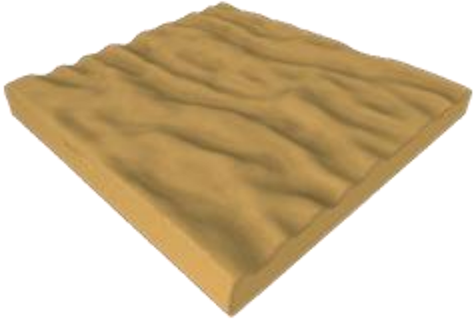
Water currents – Density-voxels



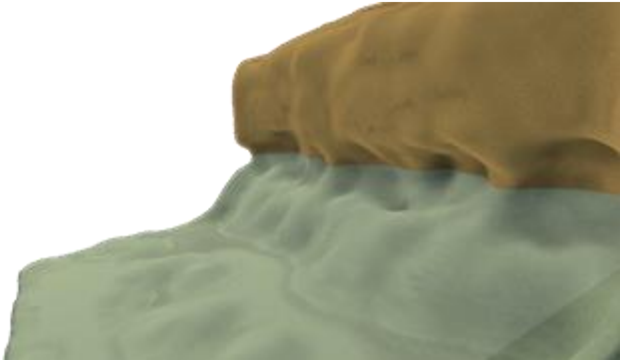
Hydraulic – Height field



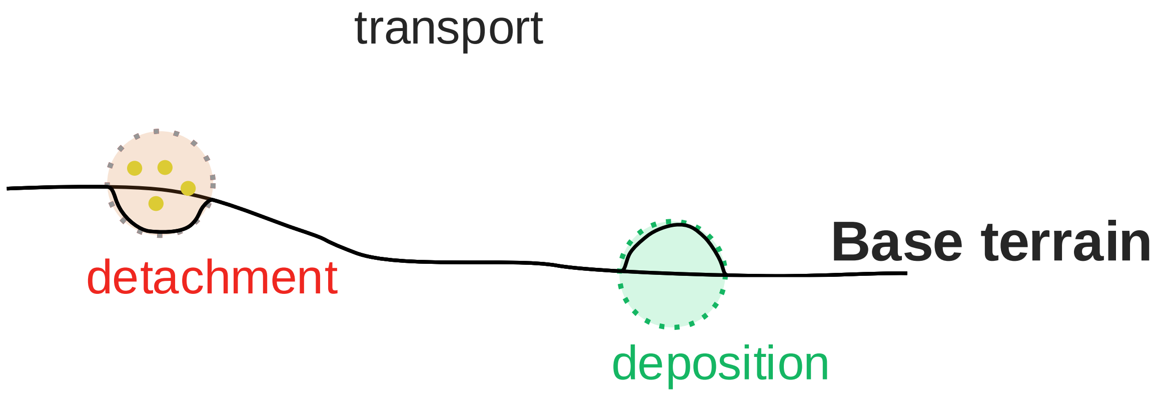
Wind – Height field



Coastal erosion – SDF



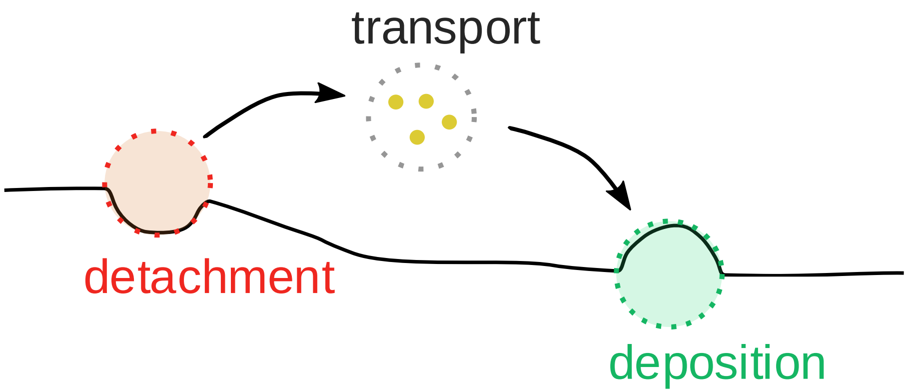
CGI2024



Terrain erosion principle: material is eroded by a fluid, transported and deposited elsewhere.

CGI2024

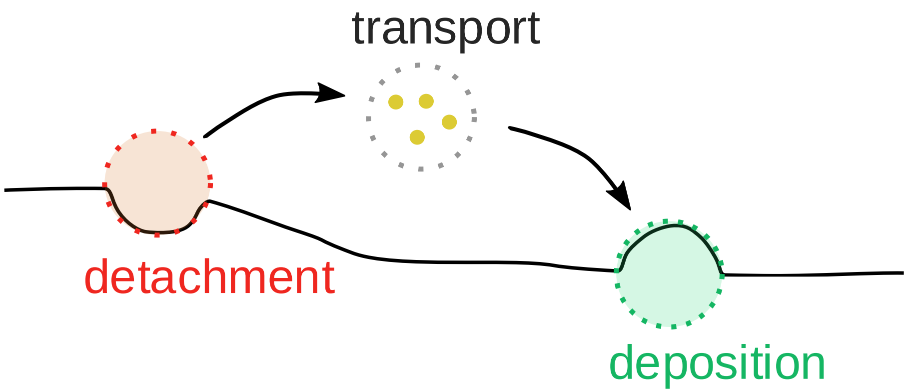
Material transport



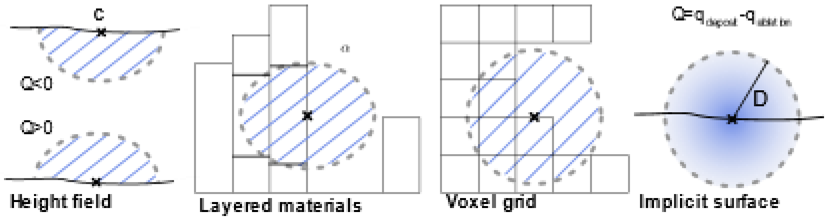
Terrain alteration

Terrain erosion principle: two main problems

Material transport

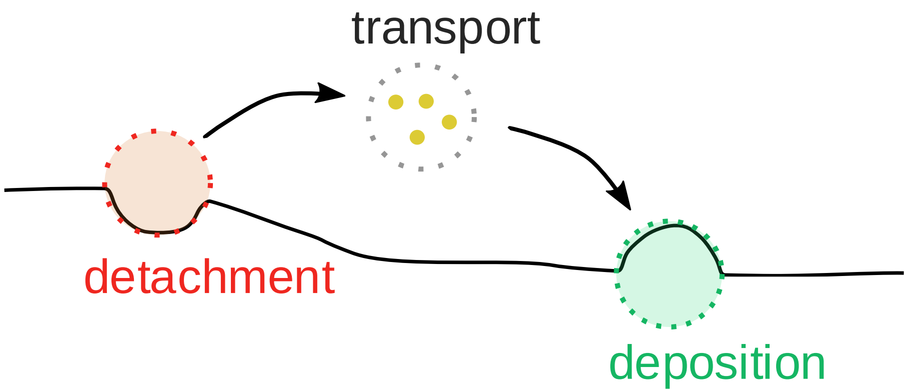


Terrain alteration

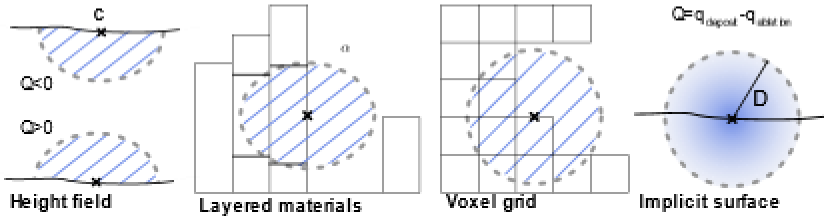


We propose to **decouple** terrain alteration

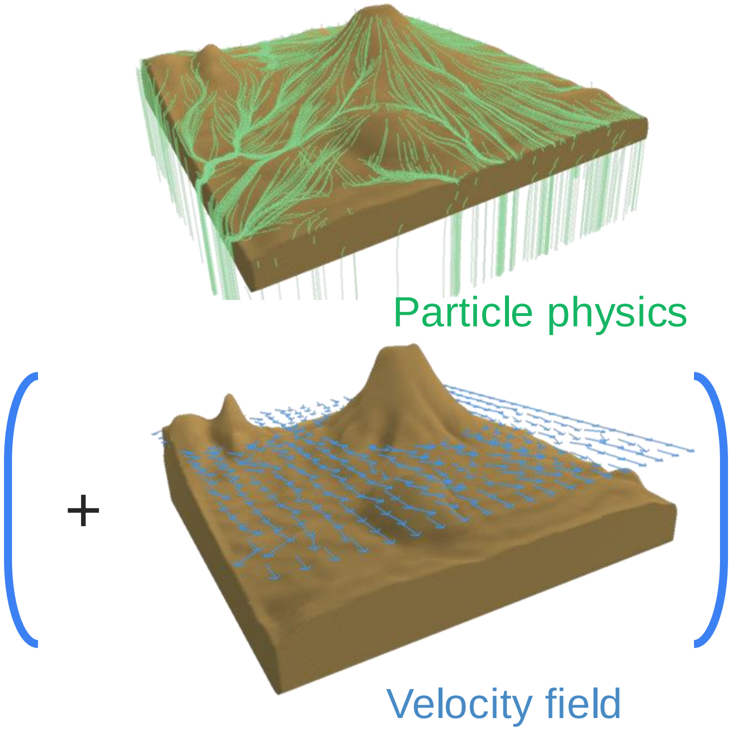
CGI2024



Terrain alteration



Material transport

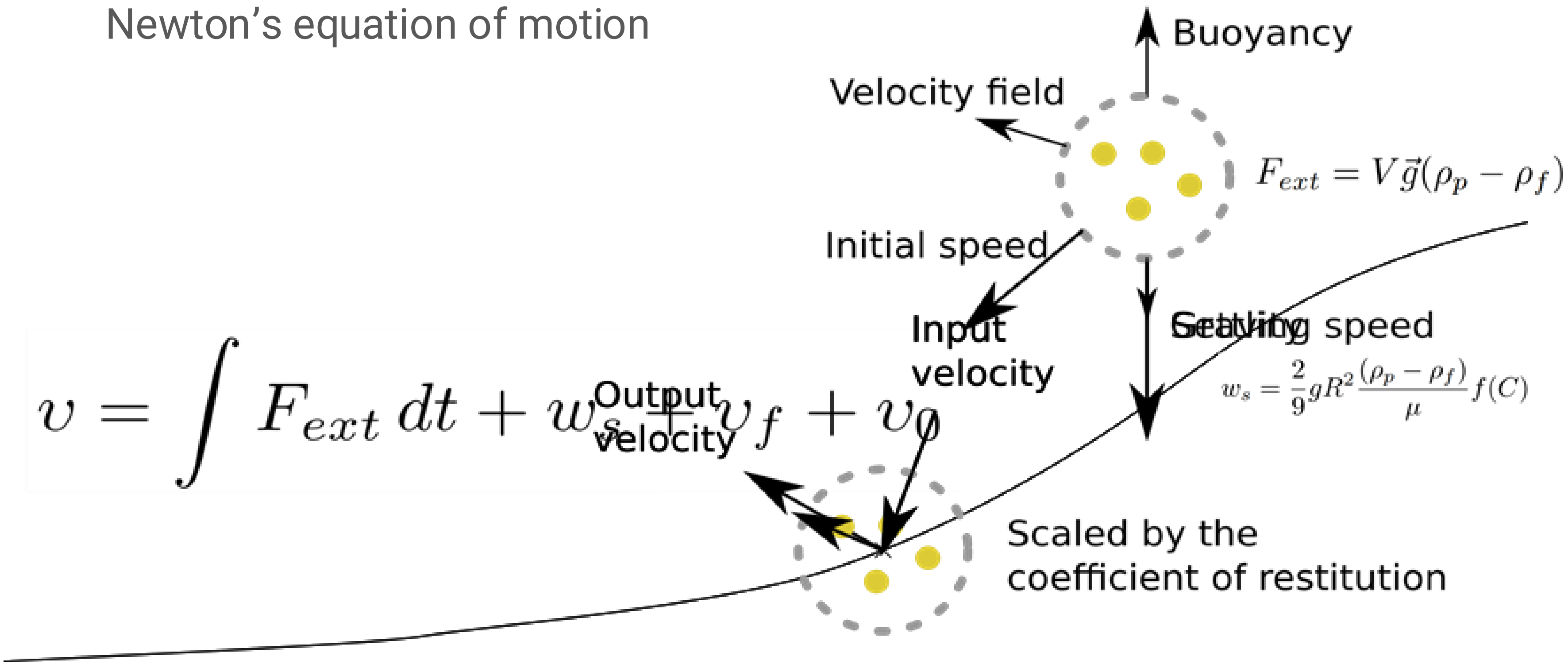


We propose to **decouple** terrain alteration from material transport using **independent particles system**.

Material transport

Newton's equation of motion

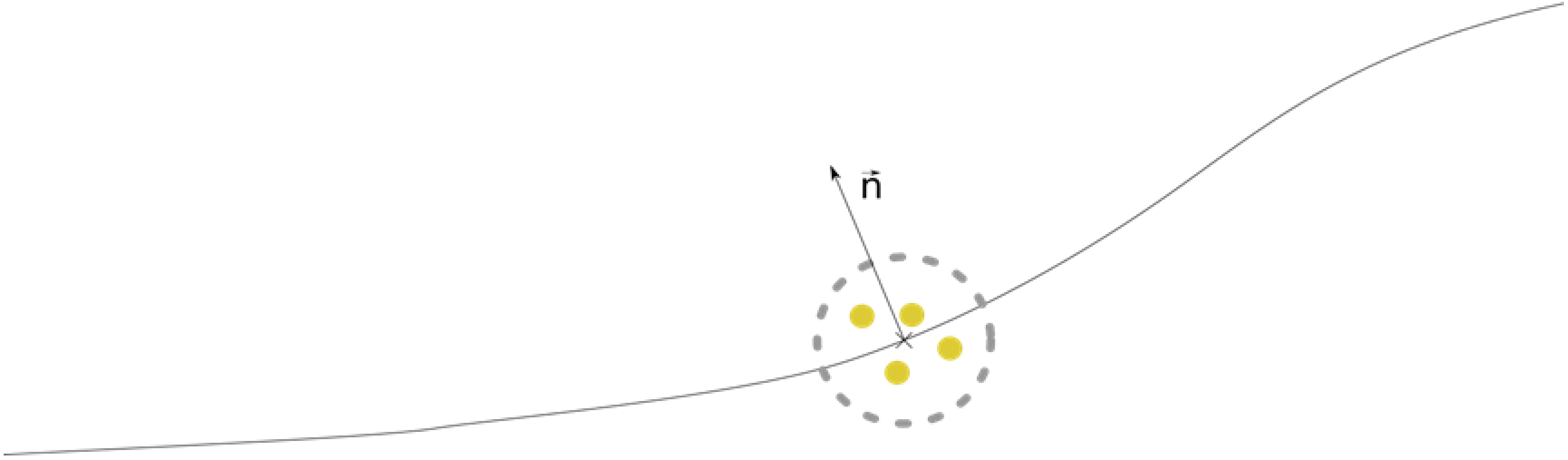
$$v = \int F_{ext}\, dt + w_s + v_f + v_0$$



Material transport

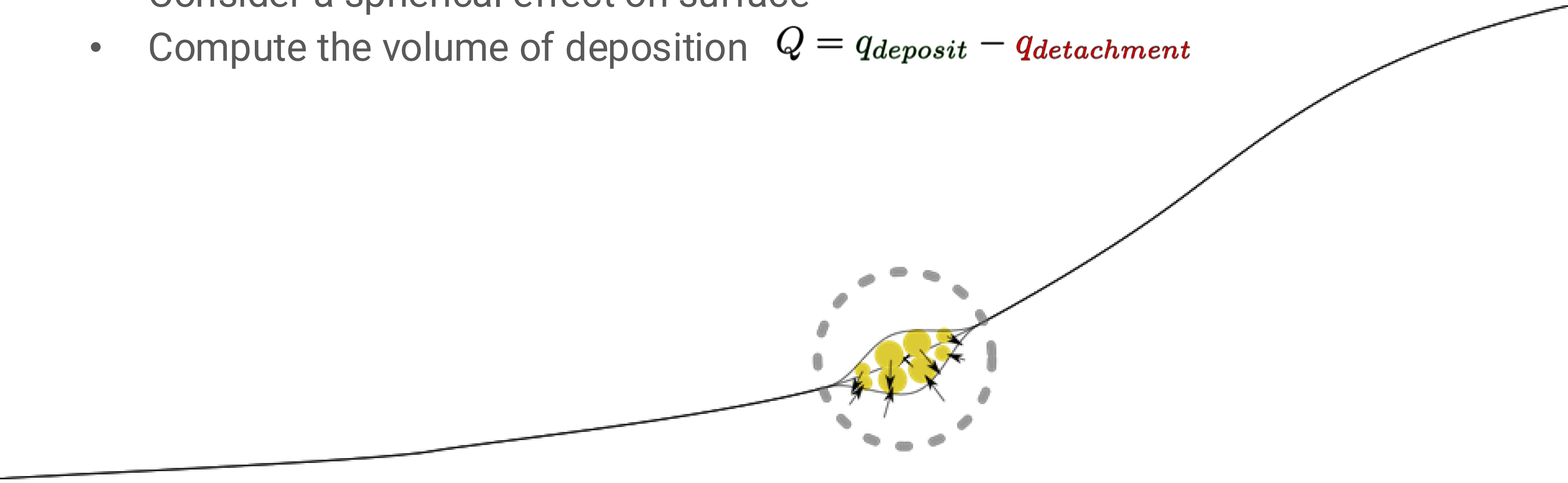
Requirements:

- Detect collisions
- Provide the normal at the surface



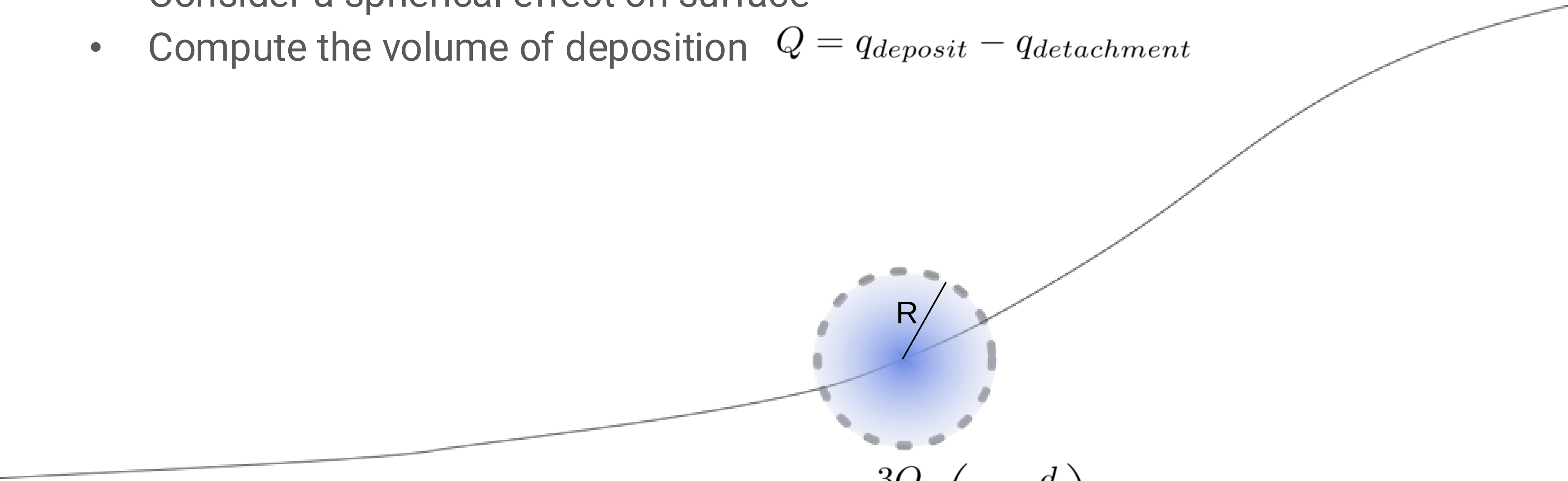
Terrain alteration

- Consider a spherical effect on surface
- Compute the volume of deposition $Q = q_{deposit} - q_{detachment}$



Terrain alteration

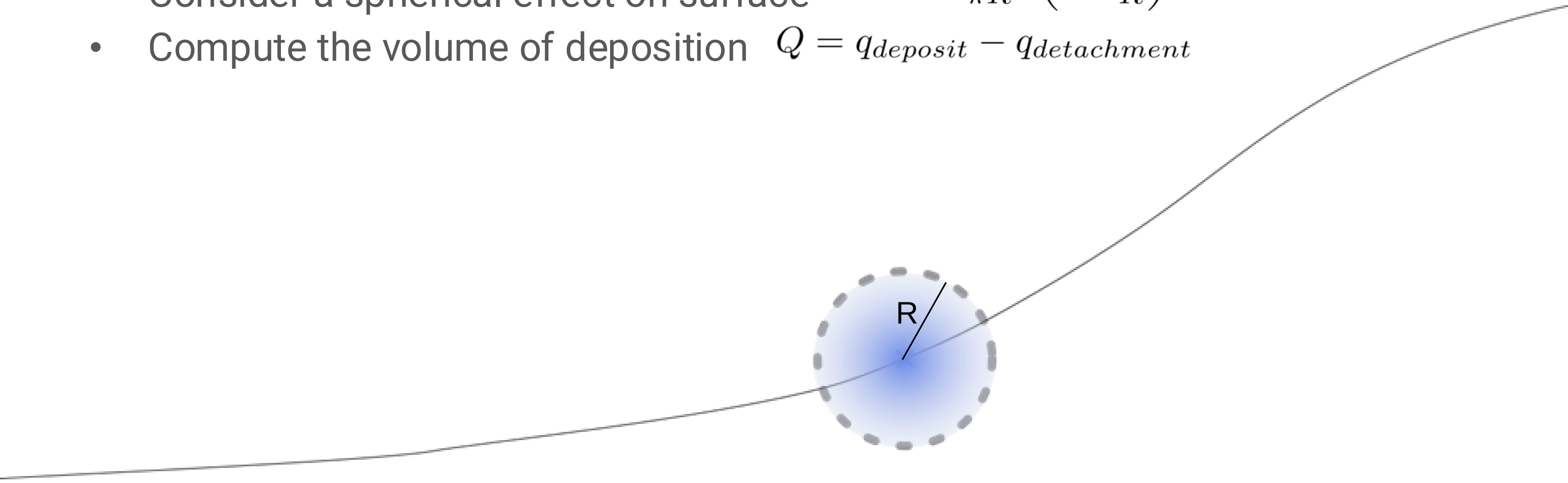
- Consider a spherical effect on surface
- Compute the volume of deposition $Q = q_{deposit} - q_{detachment}$



$$\Delta f(p) = \frac{3Q}{\pi R^3}\left(1 - \frac{d}{R}\right)$$

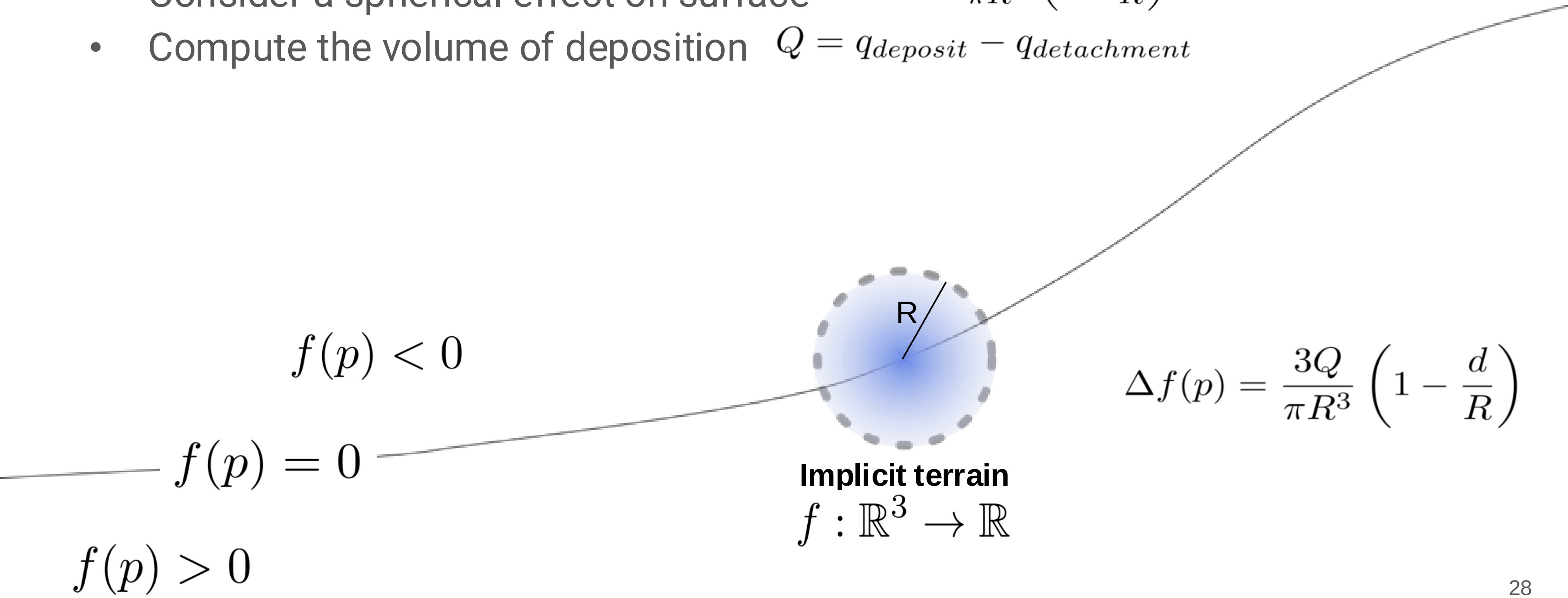
Terrain alteration

- Consider a spherical effect on surface $$\Delta f(p) = \frac{3Q}{\pi R^3}\left(1 - \frac{d}{R}\right)$$
- Compute the volume of deposition $$Q = q_{deposit} - q_{detachment}$$



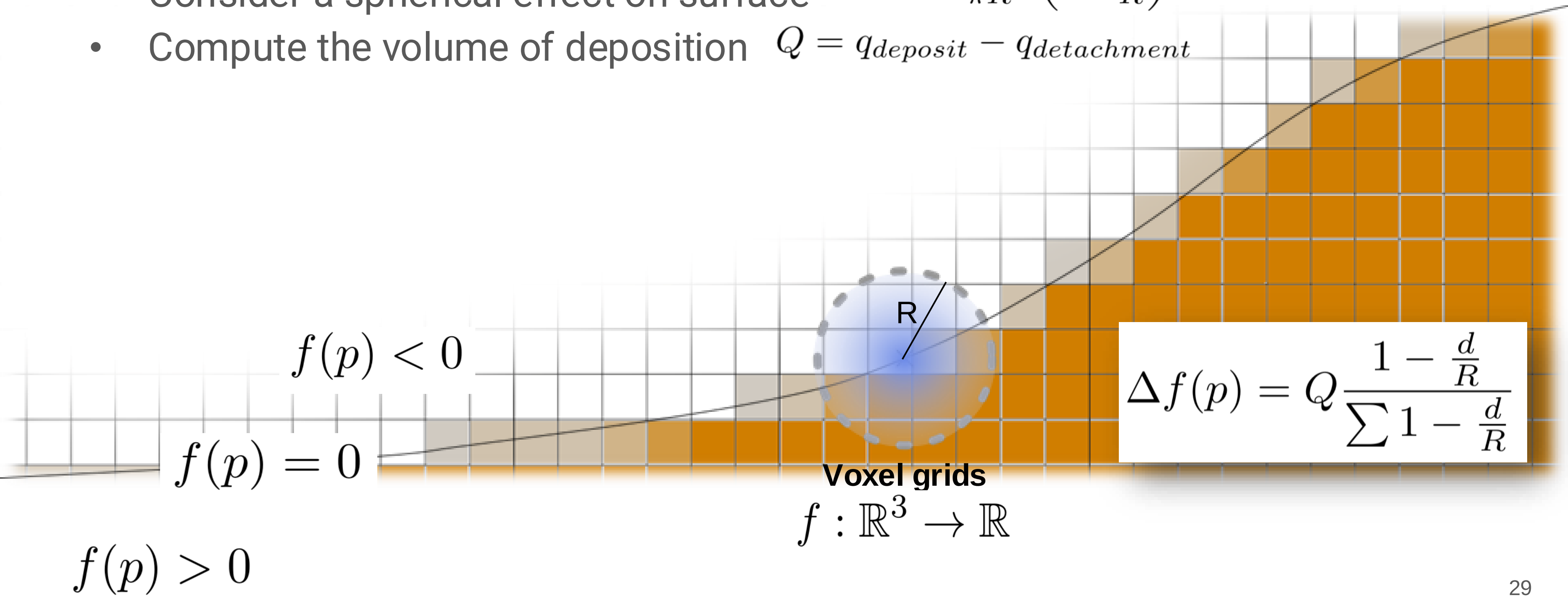
Terrain alteration

- Consider a spherical effect on surface $\Delta f(p) = \frac{3Q}{\pi R^3}\left(1 - \frac{d}{R}\right)$
- Compute the volume of deposition $Q = q_{deposit} - q_{detachment}$



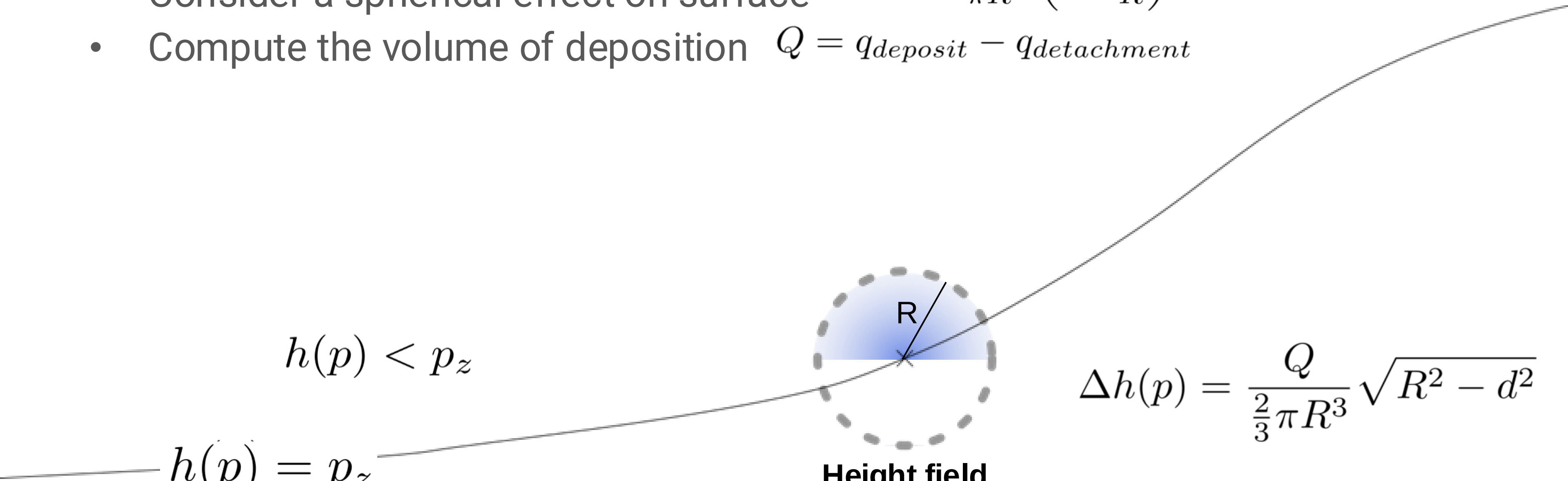
Terrain alteration

- Consider a spherical effect on surface $$\Delta f(p) = \frac{3Q}{\pi R^3}\left(1 - \frac{d}{R}\right)$$
- Compute the volume of deposition $$Q = q_{deposit} - q_{detachment}$$



Terrain alteration

- Consider a spherical effect on surface $\Delta f(p) = \frac{3Q}{\pi R^3}\left(1 - \frac{d}{R}\right)$
- Compute the volume of deposition $Q = q_{deposit} - q_{detachment}$



$$h(p) < p_z$$

$$h(p) = p_z$$

$$h(p) > p_z$$

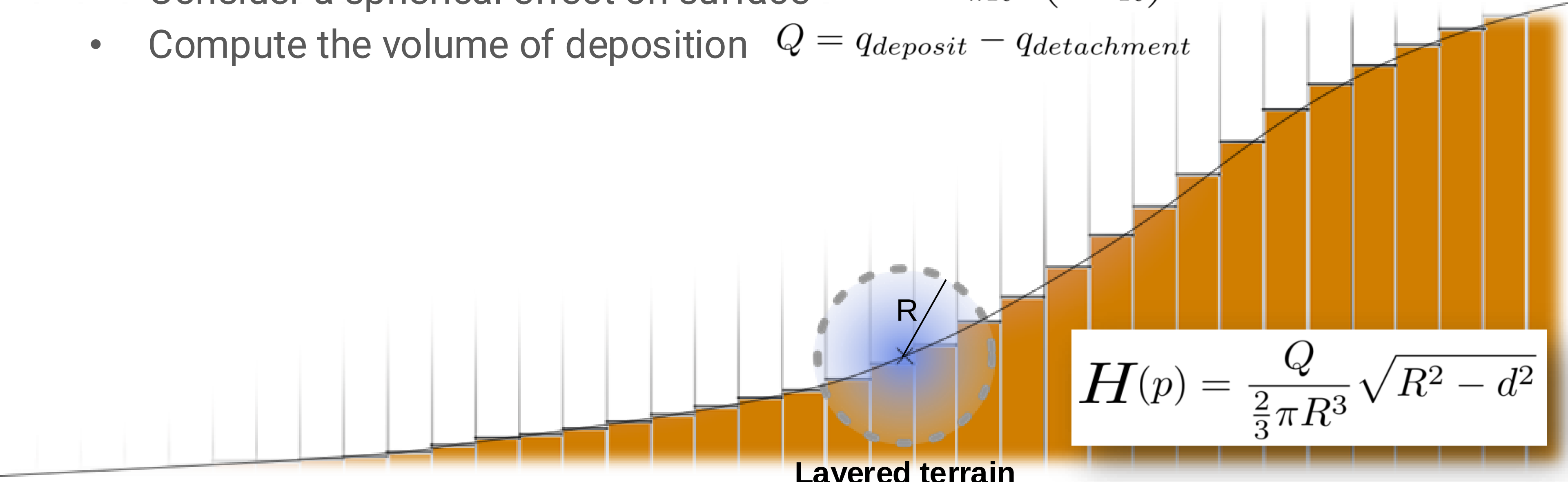
$$\Delta h(p) = \frac{Q}{\frac{2}{3}\pi R^3}\sqrt{R^2 - d^2}$$

Height field

$$h : \mathbb{R}^2 \to \mathbb{R}$$

Terrain alteration

- Consider a spherical effect on surface $\Delta f(p) = \frac{3Q}{\pi R^3}\left(1 - \frac{d}{R}\right)$
- Compute the volume of deposition $Q = q_{deposit} - q_{detachment}$

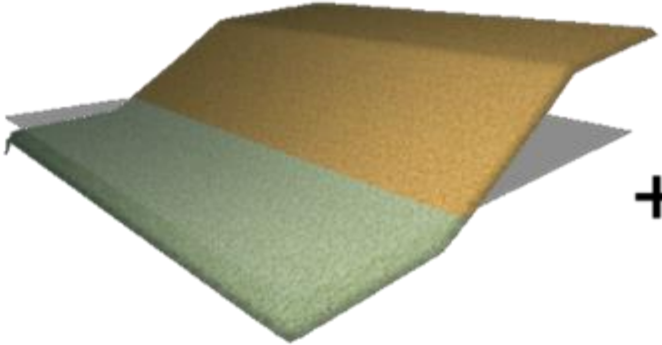


$$H(p) = \frac{Q}{\frac{2}{3}\pi R^3}\sqrt{R^2 - d^2}$$

Layered terrain

$$\mu : \mathbb{R}^3 \to \mathbb{N}$$

Base terrain geometry

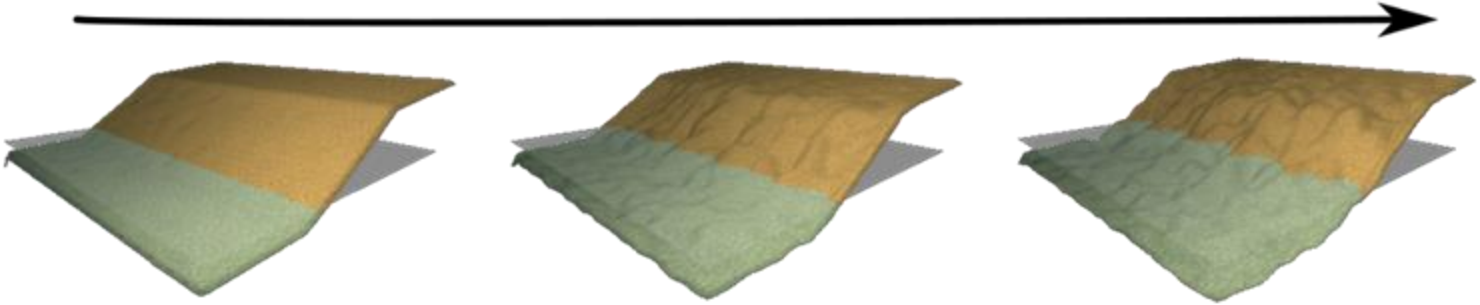


+

Particle properties
- Size
- Density
- Capacity
- Coefficient of restitution (COR)

Medium properties
- Fluid densities
- (Fluid velocities)

Iterative erosion simulation



Results

Rain

Heightmap: 2km x 2km

Particles: 1000

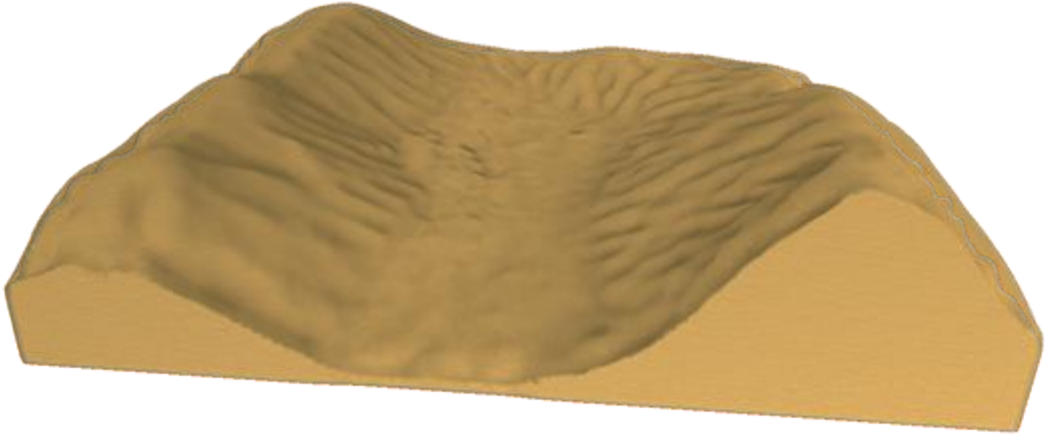
Radius: 20m

Density: 1000 kg/m³

COR: 1.0

Velocity field: None

Time: 4s



Results

Landslide

- Heightmap: 2km x 2km
  - Particles: 2000
  - Radius: 50m
  - Density: 500 kg/m³
  - COR: 0.2
  - Velocity field: None
  - Time: 4s

Results

Coastal erosion

Density voxel grid: 150m x 150m x 50m

Particles: 200

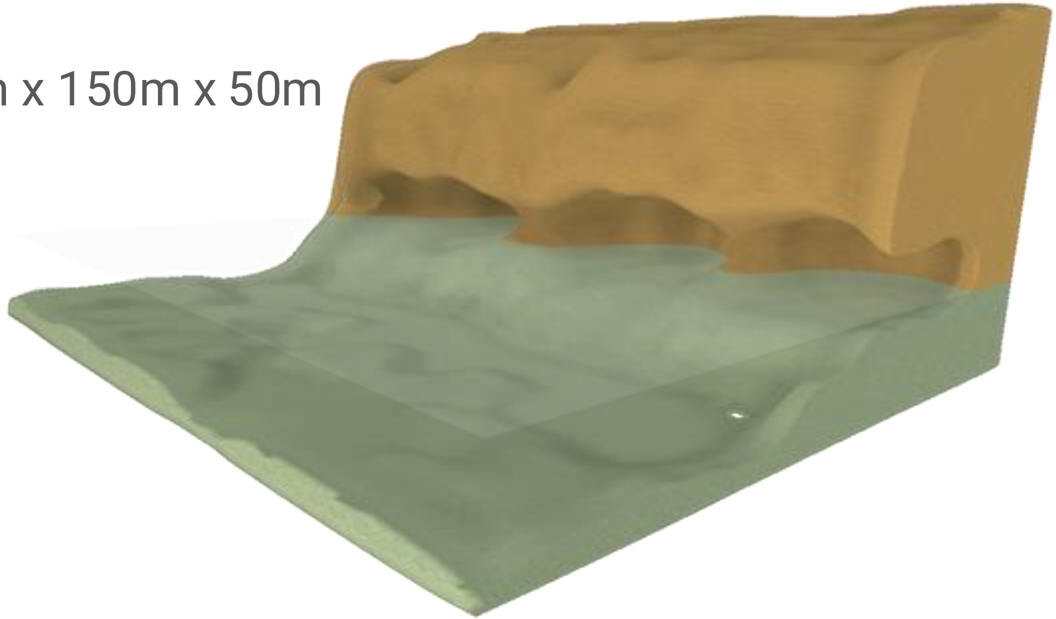
Radius: 5m

Density: 500 kg/m³

COR: 0.1

Velocity field: Uniform

Time: 0.5s



Results

Coastal erosion

SDF: 150m x 150m x 50m

Particles: 200

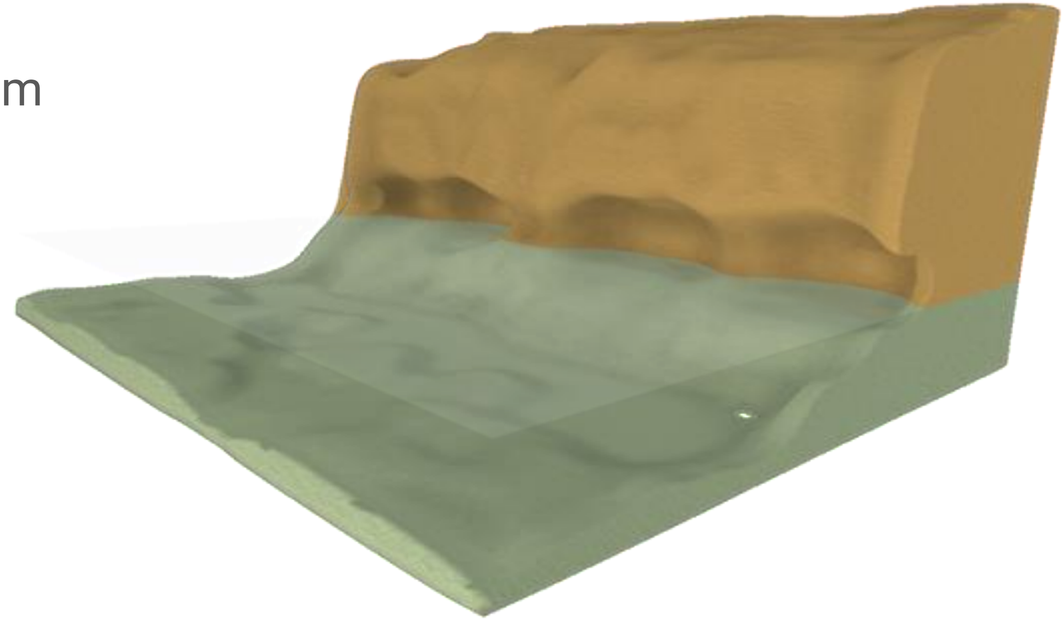
Radius: 5m

Density: 500 kg/m³

COR: 0.1

Velocity field: Uniform

Time: 0.5s



Results

River

Layered terrain: 500m x 500

Particles: 5000

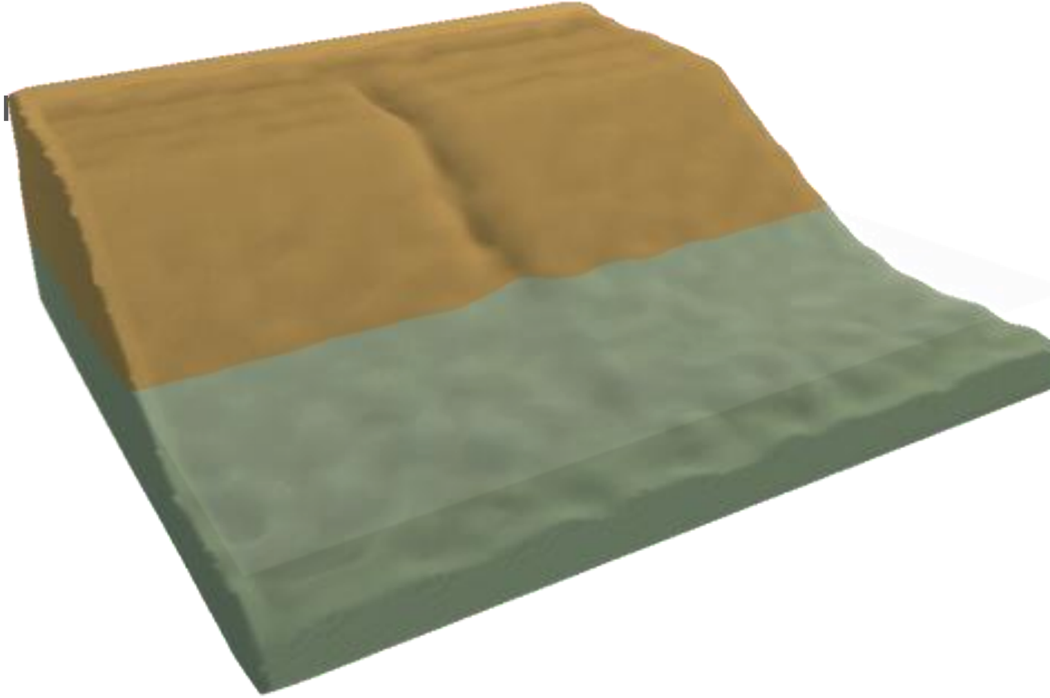
Radius: 8m-30m

Density: 900 kg/m³

COR: 0.5

Velocity field: None

Time: 2.5s



Results

Meanders

SDF: 150m x 150m

Particles: 200

Radius: 20m

Density: 1000 kg/m³

COR: 1.0

Velocity field: User define

Time: 1s

Results

Sand dunes

Heightmap: 150m x 150m

Particles: 200

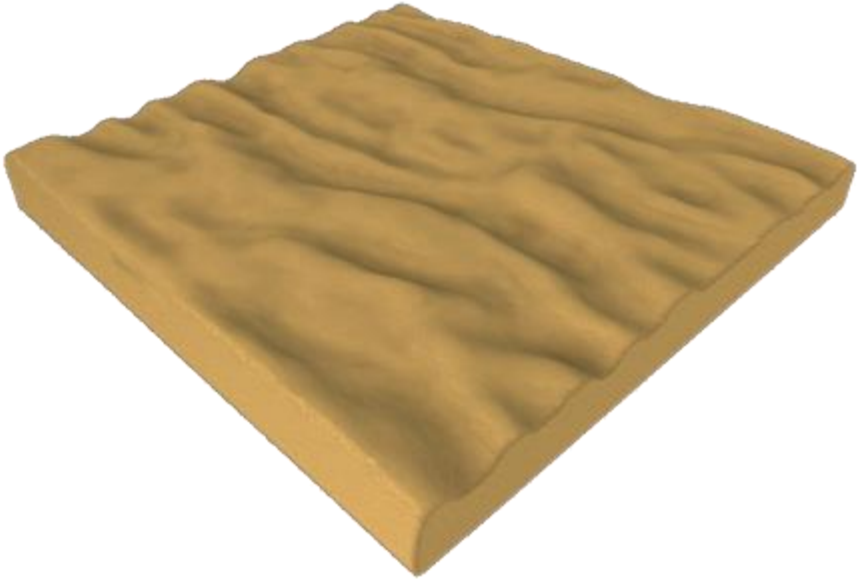
Radius: 20m

Density: 1000 kg/m³

COR: 1.0

Velocity field: None

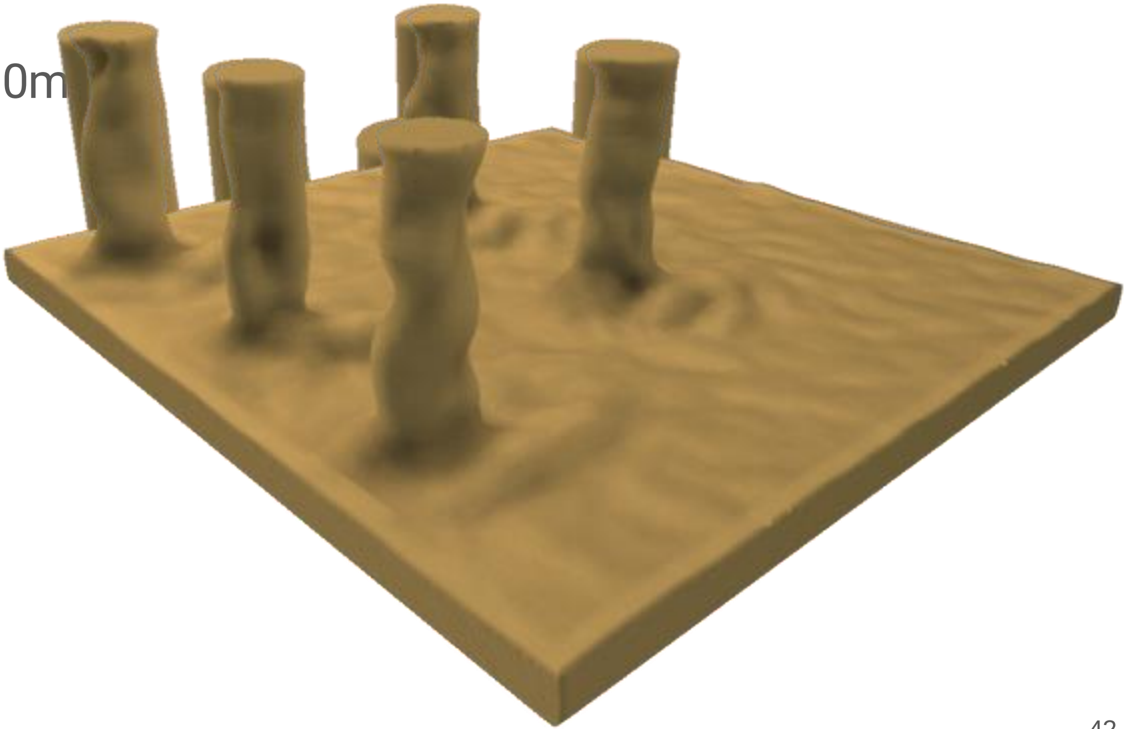
Time: 1s



Results

Wind erosion

- Heightmap: 150m x 150m
- Particles: 200
- Radius: 20m
- Density: 1 kg/m³
- COR: 1.0
- Velocity field: …
- Time: 1s



Results

Water currents

Heightmap: 150m x 150m

Particles: 200

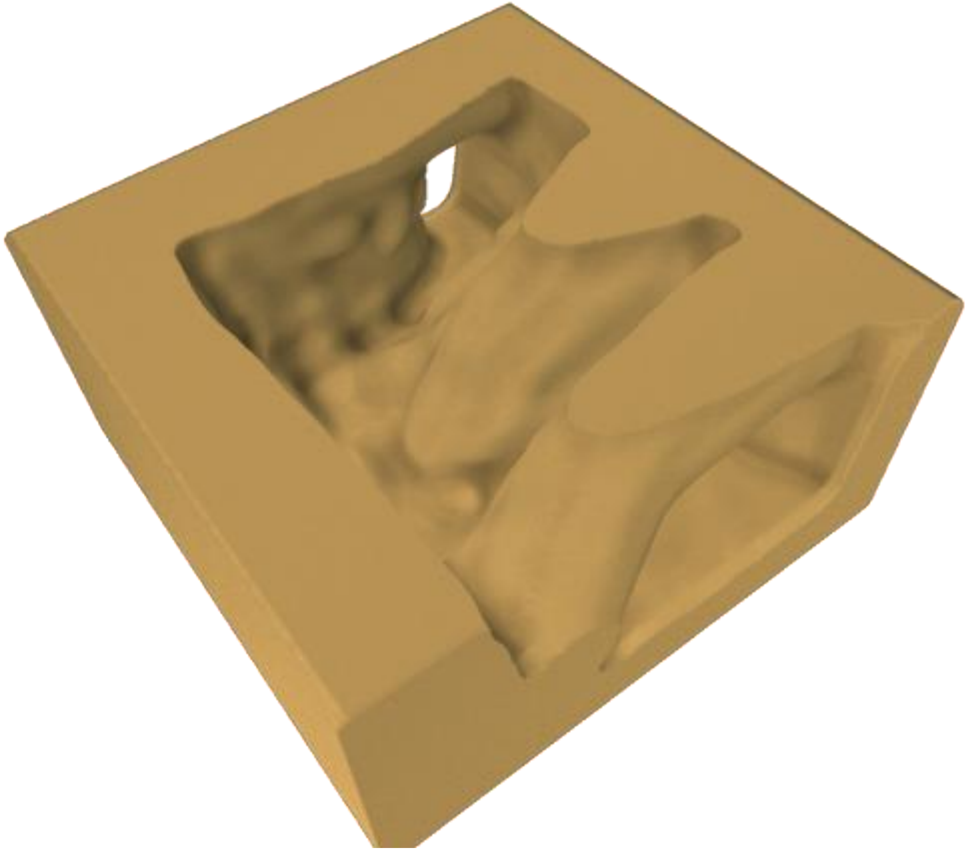
Radius: 20m

Density: 1000 kg/m³

COR: 1.0

Velocity field: OpenFOAM

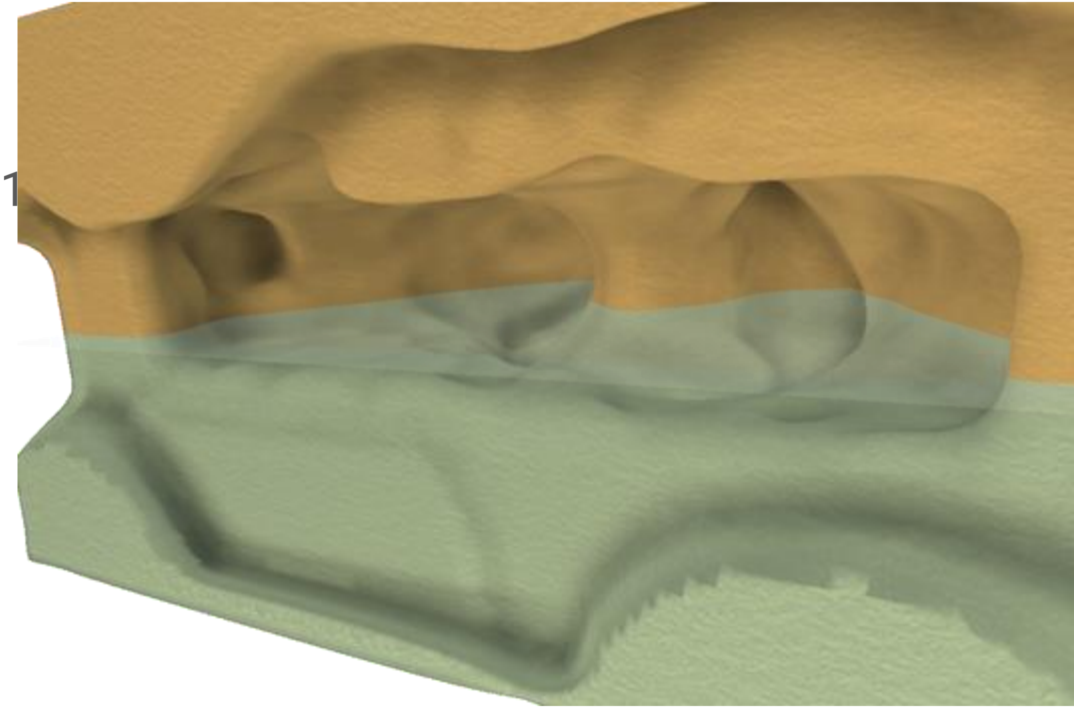
Time: 1s



Results

Karst erosion

- Binary voxels grid: 150m x 1
- Particles: 200
- Radius: 20m
- Density: 1000 kg/m³
- COR: 1.0
- Velocity field: …
- Time: 1s



Results

Volcano

Density voxel grid: 5km x 5km x 0.5km

Particles: 4500

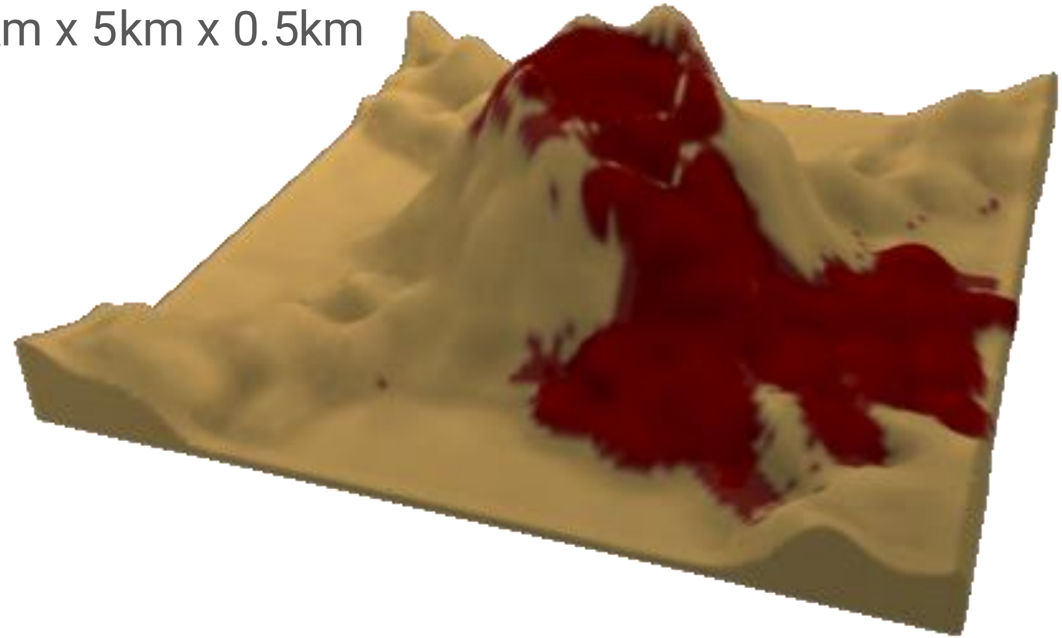
Radius: 50m

Density: 2000 kg/m³

COR: 0.5

Velocity field: None

Time: 0.8s



Contributions

- A generalized particle-based algorithm performing the three stages of erosion on surface and volume representations,
- The decoupling of the erosion system from the fluid simulation

- Providing an algorithm easy to implement,
- with few intuitive parameters,
- inducing a controllable erosion method,
- highly parallelizable

Limitations

- Generalization through simplifications
- Visual quality depends on the particles distribution
- Realism depends on the velocity field provided

CGI2024

Thank you for your attention

Hydraulic erosion on a height field