Real time Erosion simulation

River erosion computer simulation

OpenGL river

Shallow water computer simulation

Navier-Stokes Equations (to do with water simulating)

Lit review sections:

Real world example

Water simulation methods

Terrain generation

Erosion methods

Physics based erosion methods use different types of fluid simulations. Most of them are expensive to run and contain data dependencies that make it hard to execute on parallel hardware.

The first method was a partial simulation of valleys and rivers. Another one uses Navier stokes equation on a 3D regular grid that simulates the erosion and another used a simplified Newtonian physics model for velocity computation on a 2D grid.

Some methods were found to help make this process a lot less expensive and able to be ran in real time. these include, 2D Navier-Stokes equations, a shallow water simulation which allows for a simulation with real time erosion**[2]** and a method that uses virtual pipes which is key for executing in parallel.

Erosion model uses 2D uniform grid where each cell holds – terrain height, water height, suspended sediment amount, water outflow (being the pipes to adjacent cells), velocity vector, thermal erosion outflow flux.

They also use a scale that dampers the erosion equation the deeper the water gets because water moves slower the deep down you go which means the sediment is less disturbed.

**Notes from [1]**

Different types of erosion – weathering is a small scale type of erosion that usually affects stones and rocks. It creates rifts on their surface in a thermal or chemical way. Thermal weathering causes disintegration of material by thermal shocks in the presence of moisture that has bigger dilatations that the rock. Chemical weathering is caused by a chemical reaction between a liquid on the surface and the material itself.

Denudation is another type of erosion. The first type of denudation is gravity-conditioned mass movement where gravity pulls pieces of sand and gravel down the slope. The next type of denudation it splash erosion which is caused by raindrops falling onto a material causing an elliptical footprint. The last type of denudation is fluvial. This is the most important for this project as it is when water flows down a surface picking up different materials as it moves.

Full 3D hydraulic erosion was a paper that uses Navier-Stokes equations which are coupled with material transportation and solved on a 3D grid. This simulation is able to simulate receding waterfalls, river bed and river bank erosion, meander break, etc. this model provides high quality results but is also very expensive to run which makes it impossible to run in real time.

**Notes from [2]**

This paper talks about 2 different methods for simulating water. Grid based and particle based. The best grid based method to use is the pipe model. This is where a cells in a 2D grid are connected via pipes. This can be 4 pipes or 8 pipes per cell. 4 pipes is best to use as its faster while still allowing for a realistic simulation. Although 8 pipes would be more realistic it is much slower to compute. The most commonly used particle based simulation is smooth particle hydrodynamics. This method tracks particles in varying locations instead of using a fixed grid. Each particle represents a quantity and mass. The quantity is calculated by a weighted sum of the neighbouring particles. An advantage of using particle based methods over a grid based method is that the only area that is simulated is where there are particles rather than the entire scene needing to be simulated like with a grid based method. This only becomes a problem when simulating larger bodies of water like rivers or lakes as a lot of the particles will be sitting at the bed of the river or lake taking up processing power whilst not doing anything. This problem has been worked on though with the shallow water equation which limits the amount of particles to a certain depth.

**Notes from [6]**

This paper improves on the shallow water equations and implements a way of using a 2D grid and particle method of simulating water. Not all of this paper will help as its mostly with large bodies of water like the ocean and simulating waves.

**Notes from [7]**

simplifies the 3D Navier Stokes equations to get simulation in real time.

**Notes from [8]**

Uses velocity field to simulate erosion. They use a 2d arrays that holds water quantity, velocity vector, collision energy and elevation. They obtain the velocity field by arranging water particles on each grid point of the terrain model and examine the flow of each individual water particle. They then use this information to obtain the collision energy which is then used for the erosion. This method is quite slow as the program ran a 128x128 array with 50 steps in 5697s.

**Notes from [9]**

Video on unreal engine 4 water physics. Could be used as a comparison for looks and performance.

**Notes from [10]**

Uses a fast method for animating rivers but has very limited interactivity.

**Notes from [11]**

[1] <https://diglib.eg.org/bitstream/handle/10.2312/EG2011.short.057-060/057-060.pdf?sequence=1>

[2] <https://www.cs.purdue.edu/cgvlab/www/resources/papers/Benes-2007-Real-Time_Erosion_Using_Shallow_Water_Simulation.pdf>

[4]<https://data.exppad.com/public/papers/Layered_data_representation_for_Visual_Simulation_of_Terrain_Erosion.pdf>

[6] <https://www.modeemi.fi/~daemou/mindtrek12.pdf>

[7] <https://matthias-research.github.io/pages/publications/hfFluid.pdf>

[8] <http://graphics.uni-konstanz.de/publikationen/Neidhold2005InteractivePhysicallyBased/Neidhold2005InteractivePhysicallyBased.pdf>

[9]<https://static.aminer.org/pdf/PDF/000/593/535/terrain_simulation_using_a_model_of_stream_erosion.pdf>

[10] <https://www.youtube.com/watch?app=desktop&v=EfzhMqZyilI&ab_channel=ImaginaryBlend>

[11] <https://artis.inrialpes.fr/Publications/2009/YNBH09/riversEG09.pdf>

EROSION PAPERS AND STUFF

<http://wscg.zcu.cz/wscg2002/Papers_2002/F23.pdf> - visual simulation od Hydraulic erosion.

<https://www.engr.colostate.edu/~pierre/ce_old/Projects/Paperspdf/Julien-Simons-ASAE85.pdf> - sediment transport capacity of overland flow

<https://www.youtube.com/watch?v=MoRHdk5mX0Q&ab_channel=FancyFennec> – guiding post

<https://jobtalle.com/simulating_hydraulic_erosion.html#:~:text=Hydraulic%20erosion%20is%20the%20process,and%20the%20flow%20of%20rivers>. – particle based erosion simulation

<https://cgg.mff.cuni.cz/~jaroslav/papers/2008-sca-erosim/2008-sca-erosiom-fin.pdf> - pipe model erosion

<https://dl.acm.org/doi/pdf/10.1145/311535.311548> - some with sediment transport

-------------------------

WATER SIMULATION PAPERS

<https://empslocal.ex.ac.uk/people/staff/gv219/ecmm719/ess-ecmm719.pdf> - chapter for shallow water equations

<https://gfd.whoi.edu/wp-content/uploads/sites/18/2018/03/lecture8-harvey_136564.pdf> - lecture on shallow water equations

<https://dl.acm.org/doi/pdf/10.1145/97880.97884> - shallow wave equations?

-----------------------

PROGRAMMING RESOURCES

<http://kylehalladay.com/blog/tutorial/2014/06/27/Compute-Shaders-Are-Nifty.html>

<https://stackoverflow.com/questions/74489139/generating-a-normal-map-from-a-height-map-in-compute-shader>

----------------------

<https://www.researchgate.net/publication/259398063_Level_of_Detail_for_Real-Time_Volumetric_Terrain_Rendering> - volumetric data

<https://perso.liris.cnrs.fr/eric.galin/Articles/2009-arches.pdf> - more volumetric stuff

<https://diglib.eg.org/bitstream/handle/10.2312/conf.EG2013.stars.155-173/155-173.pdf?sequence=1&isAllowed=y> – something on multiple methods

<https://graphics.tudelft.nl/~rafa/myPapers/bidarra.3AMIGAS.RS.pdf> - talks about procedural generation

<https://onlinelibrary.wiley.com/doi/epdf/10.1111/cgf.12530?saml_referrer> – Terrain modelling from feature primitives

<https://dl.acm.org/doi/pdf/10.1145/2461912.2461996> - Terrain Generation Using Procedural Models Based on Hydrology

<https://core.ac.uk/download/pdf/34480918.pdf> - pdf version^

<https://reader.elsevier.com/reader/sd/pii/S1569190X07000111?token=84D28D08B34808D6170A48E5C23B134AC777FACD5FAF7CA919E51C533C7269862CFED2FC981AB99E7281699BDE3346A0&originRegion=eu-west-1&originCreation=20230301223630>

<https://www.sciencedirect.com/science/article/pii/S1569190X07000111>

<https://static.aminer.org/pdf/PDF/000/593/535/terrain_simulation_using_a_model_of_stream_erosion.pdf>

<https://core.ac.uk/download/pdf/38910806.pdf>

<https://scholarworks.calstate.edu/downloads/m900nt80d>