Particle systems-based riverbed modelling over a terrain with hardness layer

Korneliusz K. WARSZAWSKI
Faculty of Electrical Engineering,
Computer Science and Telecommunications
University of Zielona Gora
ul. Szafrana 2
65-246 Zielona Gora, Poland
k.warszawski@weit.uz.zgora.pl

Slawomir S. NIKIEL
Institute of Control
and Computation Engineering
University of Zielona Gora
ul. Szafrana 2
65-246 Zielona Gora, Poland
s.nikiel@issi.uz.zgora.pl

ABSTRACT

This paper proposes a method that applies particle systems to simulate results of hydrological erosion caused by spout, like riverbeds. The terrain model is divided into two layers. The first one stores heights data (typical height-field) while the second is reserved for hardness data. This data structure enables fast and simple implementation of terrain deformation. We present the construction of a particle system terrain modifier, its main attributes and how they influence the final product of the modelling process. The proposed technique behaves like in classical particle systems. It uses emitter as element that control starting location, direction and quantity of particles in a given simulation environment. We choose parameters for particles such as: the current position, directional angle, linear velocity, rotation angle, rotation velocity and the size which define its zone of influence for landscape modification processes. Each emitted particle is moving (rolling) over the surface of terrain structure making deformations at its current position. Scale of the modifications depends on particle parameters and landscape structure susceptibility for modifications process under the particle influence zone. The proposed method is not intended to simulate physically erosion process, but focuses on its results for exploitation in virtual environments in real-time simulations and rapid prototyping of virtual terrains.

Keywords

particle systems, terrain surface modelling, riverbed generation, hardness-field, virtual environment.

1 INTRODUCTION

The achievement of an ideal form in a virtual landscape is possible as far as developers, artists and virtual world builders spend a lot of time manually deforming polygon-meshes. Alternatively, an acceptable level can be obtained much faster by automated techniques. Applications of those techniques have been used in electronic systems with elements of virtual environment for military and civilian training courses, digital entertainment and game developing [Ric99a, Bon05a, Sme10a].

The foundations of mostly generation techniques of terrain modelling are based on self similarity fractal algorithms. Traditional method uses Madelbrot's Midpoint Displacement algorithm and was proposed by Fournier, Fussell and Carpenter [Fou82a]. Initial height-field grid has 2x2 resolution and in recursive subdivision, the method increases terrain model precision by calculation of height values of newly generated height-field nodes as the averaged height of the neighbour points displaced by a random offset. The subdivision part of the algorithm faced several modifications. Mandelbrot and Musgrave proposed the Hexagon Subdivision and Miller presented both Diamond-Square and Square-Square subdivisions algorithms. All proposed modifications give alternative models for selection of neighbour points, but the main idea of algorithm still remains unchanged [Mil86a, Mus89a, Koh92a, Sal02a].

Virtual scenery can be simply improved by adding rivers, by simulations of geological structure eroded by flow of spout with use of method based on Computational Fluid Dynamics (CFD). This techniques simulate natural flow of water based on physical model [Fos01a, Cha06a]. Results of simulations are visually acceptable but cost of computations is very high and disqualify this techniques for interactive terrain synthesis.

The real-time method for river-based or rainfall erosion models was presented by Nagashima [Nag97a]. Starting point of the method is put on top of the midpoint

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displacement algorithm, which sets the base edge of erosion. In the following steps the method makes deeper modifications as erosion process proceeds. Teoh [Teo08a] extends procedural method to simulations of coastal erosion, river meanders and river delta formation.

Particle systems are an alternative approach to chaos-based terrain modelling. The technique was originally developed for computer graphics by Reeves [Ree83a] as a fast method for real-time modelling of object with irregular, dynamically changing objects with no defined surface like clouds, fire or explosion. It can be also used for modelling of vegetation and foliage. Proposition of parallel implementation was done Sims [Sim90a] and was adopted by McAllister [McA00a] and Kolb, Latta and Rezk-Salama [Kol04a] for their descriptions of particle systems. Using particle systems for terrain surface modelling, gives us tools to generate complex height-field data, similar to mountains or island-like forms [War08a]. Benes and Roa [Ben04a] uses the technique to simulate sand (or snow) movement and its interaction with other objects in a virtual environment. As shown by research of Benes [Ben08a] and Kristof, Benes, Krivanek and Stava [Kri09a] particle systems can be successfully adopted in simulation of erosion processes. Due to its characteristics the technique can be used as landscape deformer enriched with canyons or riverbeds.

2 TERRAIN MODEL

We use terrain model which is constructed from two layers. The first layer is a standard height-field. The second layer corresponds to the associated hardness-field [War12a]. The resolution, heights and hardness records on both layers are corresponding mutually. The terrain layers initial data can be derived from a file of real landscape data, e.g., Digital Elevation Map (DEM) or Geographic Information System (GIS). It can be also modelled by any automated method, when this information is unavailable or cost of its extraction is unprofitable and procedural results are quite acceptable.

In the Figure 1 we can see the rendered island based on height-field layer, generated by particle downfall algorithm [War09a]. The model was rendered in Terragen. Figure 2 shows artificially generated hardness layer, with use of the Poisson Faulting hardness synthesis algorithm [War12a]. The sample layer is in 6^{th} class, which means that it contains information about distribution of six types of materials with different hardness value (each material is depicted with different shade in greyscale).

3 PARTICLE SYSTEM

The proposed particle system consists of a collection of particles and an emitter, which controls starting location, direction and number of active particles in the system environment. Each particle is described by its position, directional angle, linear velocity, rotational angle, rotational velocity and size.

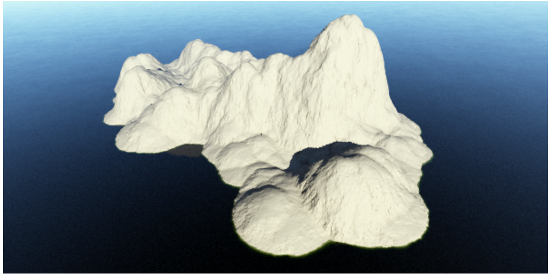


Figure 1: Sample of height-field based island.

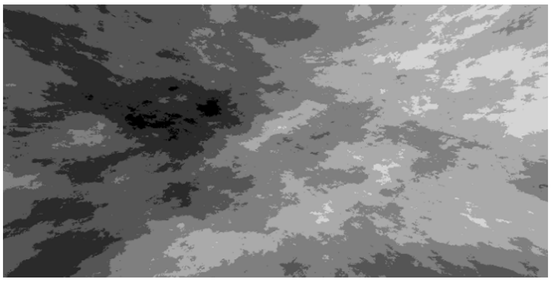


Figure 2: Sample of generated hardness-field.

The particle starting position is selected randomly from area defined by the emitter window. Particle destruction occurs in two cases. Firstly, when its current position exceed bounds of the system workspace. Secondly, as a result of collision with existing terrain fragment. In addition, the collision causes modification (erosion) of the terrain fragment. The erosion zone is related directly to a collided particle size.

4 RIVERBED MODELLING

Setting the emitter position on a side of virtual terrain defines the starting point of the modelled riverbed and its width is defined by the size of the emission window (see Figure 3).

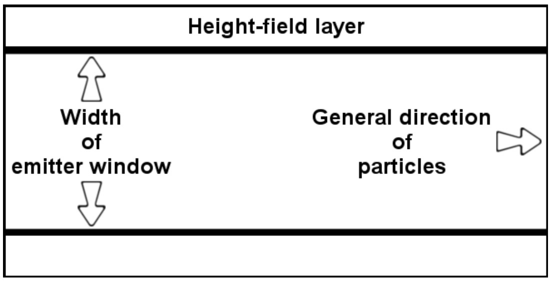


Figure 3: Outline of modelled riverbed.

For our simulation process we supposed that all particles move over the landscape surface. Therefore, we can project their trajectory calculations to a planar equation. Let (x_o, y_o) be a position of point (O) around which given particle (P) rotates. Let (v) be the particle linear velocity and (α) be its current linear angle. Let (r) corresponds to the particle offset to the (O) point and (β) be its current rotational angle. Then new position for the particle (P) defined as pair of coordinates (x,y) can be acquired with use of Equation 1 and its geometric representation is shown in Figure 4.

$$P(x,y) = \begin{cases} x = x_o + v * \cos(\alpha) + r * \cos(\beta) \\ y = y_o + v * \sin(\alpha) + r * \sin(\beta) \end{cases} \tag{1}$$

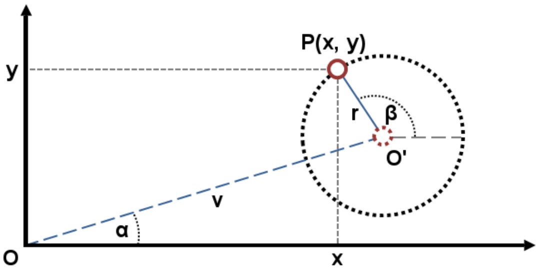


Figure 4: Geometric representation of rotational particle position in $\mathbb{R}^2$ space.

With the particles movement, terrain is deformed. The strength of these modifications depends on particle parameters and landscape erosion resistance. Let (P) be a particle at position defined as (x,y) and (s) be its size. Let (i,j) be a coordinate at height-field layer. Then the decreasing factor (Δh) for this coordinates can be acquired with Equation 2.

$$\Delta h_{i,j} = \sqrt{s^2 - \left((i-x)^2 + (j-y)^2\right)} \tag{2}$$

The main feature of decreasing factor (Δh) is that it has positive value if the height-field cell is inside the particle zone of erosion and it is negative outside. For our research, we assumed that each height-field cell with positive decreasing factor is a subject to erosion procedure. Let (h) be a height-field layer cell at defined position (i,j) and (Δh) be its decreasing factor. Let (d) be a hardness-field layer cell at the same coordinates. Then the new height value (h') can be acquired with Equation 3.

$$h'_{i,j} = \begin{cases} h_{i,j} - \Delta h_{i,j} * d_{i,j}, & \text{if } \Delta h_{i,j} > 0 \\ h_{i,j}, & \text{otherwise} \end{cases} \tag{3}$$

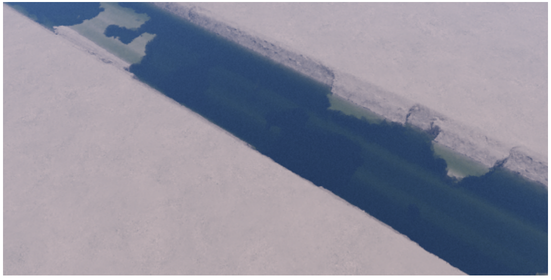
5 CONCLUSIONS

The flow of particles in a virtual environment is similar to spout. The appropriate simulation of interacting particles for virtual terrain scenery makes it possible to use these techniques to model landscape structures subjected to permanent influence of the hydrological erosion process. The parametric algorithm makes it possible to adapt those results for a satisfactory level of the modelled terrain. Selection of suitable system attributes enables us to simulate the effects of liquid dynamics on the basic landscape surface.

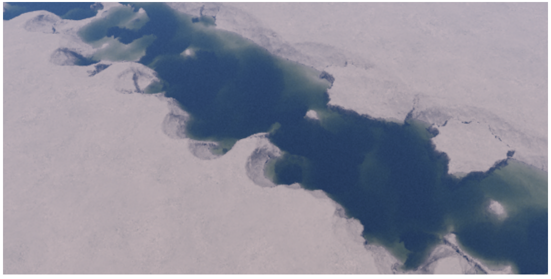
The performance of the proposed technique depends mostly on the number of particles and decreases while this number increases. Computational complexity was estimated as $F(n) = 6n + 4$, where n is a number of particles. This property of the algorithm enables landscape forming in near real-time simulation, thus it offers interactive terrain sculpting.

In Figure 5 we can observe comparison of results of simulation. Top sub-figure shows riverbed achieved without particle rotation. The other two sub-figures presents model were rotational particles were applied (with and without water layer). All simulations were performed with identical pre-generated 5^{th} class hardness-field layer. In Figure 6 we presents other models generated with the method. All samples was rendered in Terragen.

(a) model without particle rotation



(b) model with particle rotation



(c) model with particle rotation and without water layer

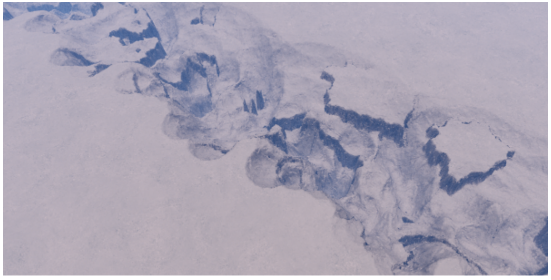


Figure 5: Sample of riverbeds generated over plain height-field with pre-generated hardness records.

Further work will focus on the definition of a fully deterministic method, which could be used to determine flood routes or for optimal regulation of riverbeds. Next, we plan extend this technique to terrain models based on voxel representation.

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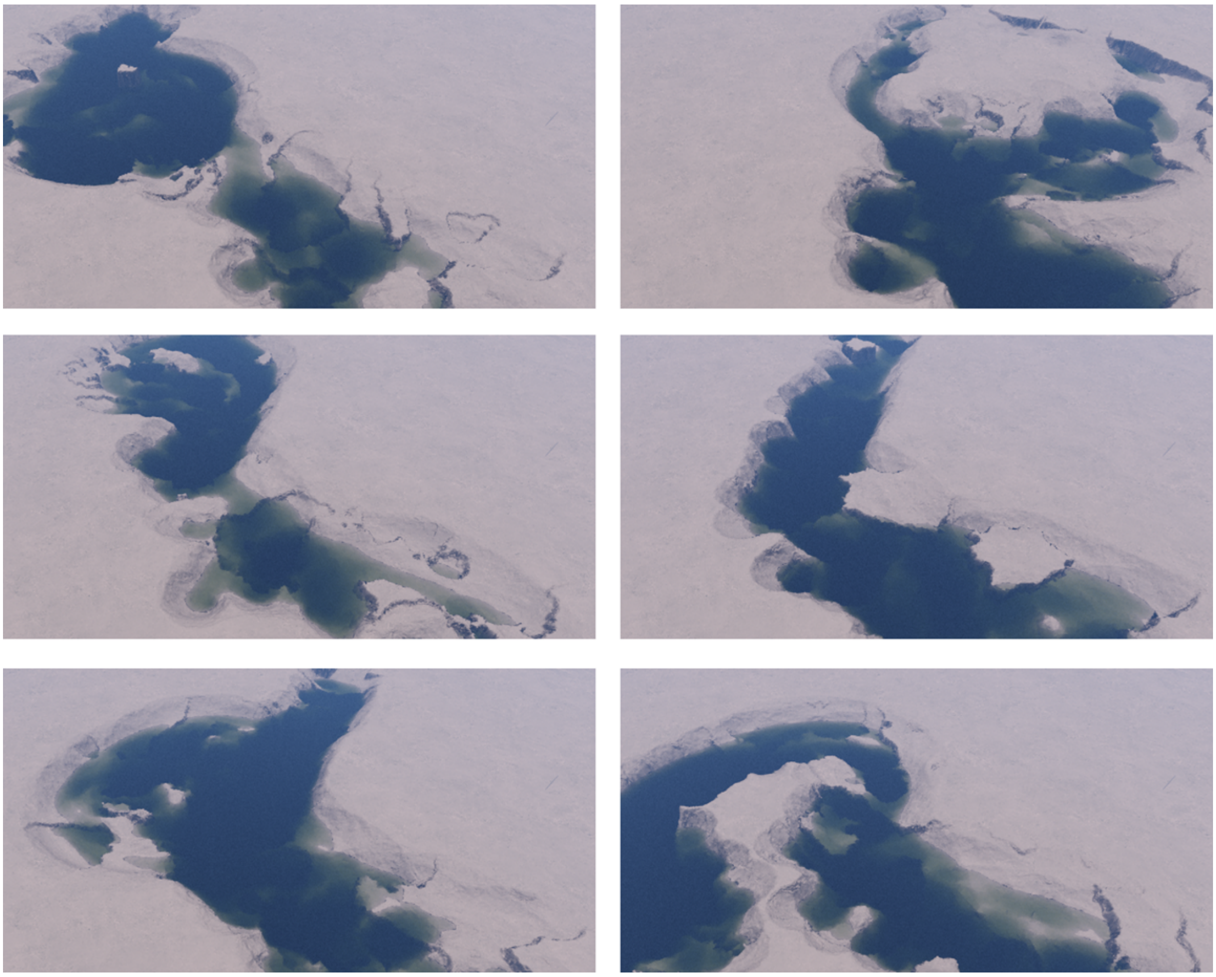

Figure 6: Samples of riverbeds generated with the algorithm.

ACKNOWLEDGEMENTS

HUMAN CAPITAL
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The author is a scholar within Sub-measure 8.2.2 Regional Innovation Strategies, Measure 8.2 Transfer of knowledge, Priority VIII Regional human resources for the economy Human Capital Operational Programme co-financed by European Social Fund and state budget.