Subcell erosion for terrain generation

(Masters-level internship)

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Figure 1: Physically-based simulations of erosion allow us to generate believable terrains at the scale of the mountain ranges (left), but cannot produce small-scale details because of the underlying discretization, for instance, the small gullies and ravines common in Alpine slopes (right, Google Earth, Swiss Alps). In this project, we will learn sub-cell dynamics to increase the accuracy of the erosion simulation and generate a detailed texture on the final terrain.

Context and goal

Digital terrains are used by many industries, from entertainment to construction or marketing. They are also fundamental in a variety of educational of vulgarization tasks, and this need is nowadays brought to the forefront by the tragic impact of climate change on the mountains.

In this context, the generation of large-scale terrains is of critical importance. It allows creating educational material, better understanding the subsurface geology, and simulating possible futures for our landscapes. Inspired by laws commonly used in geomorphology [6], we can now efficiently generate mountains at the scale of the mountain range [1,2]. However, these approaches are limited by the special resolution, where the smallest elements are around 20-100m large. Our goal is to model the physical effects that occur bellow this scale, and to use machine learning to 1) feed this information back into the large-scale simulation, and 2) produce highly detailed, yet physically accurate terrain texture.

Approach

Most of the large-scale landscape models in geomorphology only consider the action of water as the main erosion factor. This is sound when the objective is to understand the evolution of the mountain ranges at gigantic spatial and temporal scales, but less when the goal is to generate finer-scale, visually plausible landscapes. Indeed, recent work [3] shows that other processes dominate at low drainage (close to the ridges of the mountain), and steep slopes.

In these locations, the accumulation of rock falls and a mixture of rock and mud called *debris flow* have significant erosive power.

Fortunately, the above-cited study shows that debris flow can be modeled as a power law similar to the classical fluvial case. We believe, however, that the discretization used to model large scales terrain (with cell sizes of around 20-100m), is too large to capture accurately the complex patterns shaped by this process (see Fig. 1, right).

Our first step will be therefore to produce high-resolution, small-scales simulations, to validate that a simple debris-flow model produces the desired patterns. For instance, we can use a classical erosion simulation to generate a large-scale landscape, and then couple the simulation to the debris-flow model only in a small part of the generated terrain.

In a second step, we will use neural networks to learn the statistics of the high-resolution simulations, for two complementary applications. The first one is to propagate the effect of debris flow to the original large-scale model, without the cost of a fine-drained simulation. Learning sub-cell dynamics is already explored in fluid simulations [4] but will lead to additional challenges, for instance, because our erosion model processes the cells by order of elevation. A second application will be to generate a high-definition texture of the terrain after erosion, to recover all the fine details below cell size, thanks to data-driven supper-resolution [5]. Here again, the challenge will be to preserve the geological consistency of the generated texture, and in particular the connectivity of the drainage pattern.

Work environment and requirements

The internship will take place at Inria Sophia Antipolis in the GRAPHDECO group (http://team.inria.fr/graphdeco). Inria will provide a monthly stipend of around 1100 euros for EU citizens in their final year of masters, and ~600 euros for other candidates.

Candidates should have strong programming and mathematical skills with knowledge in computer graphics and experience in Python data science libraries. Interest in geology/mountaineering/outdoors activities is a plus. The project might extend to a Ph.D. position on a topic that relates terrain generation to machine learning, and for which experience in optimization and machine learning is required.

References

[1] Jean Braun and Sean Willett. 2013. A very efficient O (n), implicit and parallel method to solve the stream power equation governing fluvial incision and landscape evolution. *Geomorphology* 180, (2013), 170–179.

[2] Guillaume Cordonnier, Jean Braun, Marie-Paule Cani, Bedrich Benes, Eric Galin, Adrien Peytavie, and Eric Guérin. 2016. Large scale terrain generation from tectonic uplift and fluvial erosion. *Computer Graphics Forum* 35, 2 (2016), 165–175.

[3] Luke A Mcguire, Scott W Mccoy, Odin Marc, William Struble, and Katherine R Barnhart. 2022. Steady-state forms of channel profiles shaped by debris-flow and fluvial processes. *Earth Surface Dynamics Discussions* (August 2022), 1–33.

[4] Kiwon Um, Robert Brand, Yun (Raymond) Fei, Philipp Holl, and Nils Thuerey. 2020. Solver-in-the-Loop: Learning from Differentiable Physics to Interact with Iterative PDE-Solvers. *Adv Neural Inf Process Syst* 33, (2020), 6111–6122.

[5] Zhihao Wang, Jian Chen, and Steven C.H. Hoi. 2021. Deep Learning for Image Super-Resolution: A Survey. *IEEE Trans Pattern Anal Mach Intell* 43, 10 (October 2021), 3365–3387.

[6] Kelin X Whipple and Gregory E Tucker. 1999. Dynamics of the stream-power river incision model: Implications for height limits of mountain ranges, landscape response timescales, and research needs. *Journal of Geophysical Research: Solid Earth (1978–2012)* 104, B8 (1999), 17661–17674.