Hydrology-guided underground model for realistic terrains

(Masters-level internship)

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In collaboration with BRGM – http://www.brgm.fr

Figure 1: Captured or generated terrain (Google Earth, left) does not embed underground geological information necessary to model, for instance, the resurgence of underground rivers (right).

Context and goal

Digital terrains are used in many industries, from entertainment to construction and training. They also play a crucial role in education and public outreach, a need increasingly highlighted by the devastating effects of climate change on mountain environments and water resources.

A large range of methods allow the digitalization of landscapes, from the scan of real landforms with lidar or satellite imagery to the simulation of the underlying geological processes [1]. But these methods focus mostly on the representation of the *terrain surface*, not the subsurface geology, because this subsurface is hidden and not readily accessible. This is a strong limitation, as the knowledge of the underground rock properties and their spatial distribution have the potential to guide a variety of applications both on the usage of real terrains (construction planning, underground resource management, hazard assessments), and on the generation of realistically-eroded virtual landscapes.

In this internship, we will explore a new data structure for terrains, which naturally exposes the surface and subsurface geometries along with their physical properties. From the observation that most terrains are naturally shaped by water processes, both at the surface [2] and underground [3], we will design this data structure to enable the efficient computation of water transfers. This new structure will open the road to novel terrain generation technics, as well as to assist field geologists in the mapping of subsurface geology and water resources.

Approach

We will start by developing a simple physically-based simulation for water transfers above and below ground, able to run over long time spans, for instance with steady-state approximations [4]. We will use this model to constrain the most important physical and geometrical properties of the subsurface, which will in turn inform the construction of an adapted geometric data-structure. We expect that this data structure will hybrid a mesh (or heightmap) representation of the water surface with a multi-scale graph structure underground, to enable the efficient modeling of underground water transfers, potentially accelerated on the GPU by extending our previous approach on GPU-based flow routing [5]. We will progressively adapt our water model to the construction of this new data-structure. We will then develop the simulation model and the associated data-structure toward two types of applications:

- Surface and subsurface erosion for physically-based terrain generation: our new model will provide a detailed distribution of below- and above-ground water resources, key to the realistic generation of landscapes especially in mountainous locations where rivers emerge.
- Inversion: we will study the links between our hydrological model and surface characteristics captured by lidar, satellite imagery, drillings, or field measurements from geologists. In particular, we will explore to which extent, when coupled to geological knowledge, our model can be used to infer underground properties from surface data.

This project will be conducted in collaboration with BRGM, the French geology survey, who will bring a strong expertise in sub-surface geology and hydrology modeling, as well as different application use-cases in field geology.

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 1400 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. The project might extend to a Ph.D. position.

References

[1] E Galin, E Guérin, A Peytavie, G Cordonnier, MP Cani, B Benes, J Gain, A review of digital terrain modeling, Computer Graphics Forum 38 (2), 553-577, 2019

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[3] A Paris, E Guérin, A Peytavie, P Collon, E Galin, Synthesizing geologically coherent cave networks, Computer Graphics Forum 40 (7), 277-287, 2021

[4] KL Callaghan, AD Wickert, R Barnes, J Austermann, The Water Table Model (WTM) v2. 0.1: Coupled groundwater and dynamic lake modelling, Geoscientific Model Development Discussions, 1-42, 2024

[5] A Jain, B Kerbl, J Gain, B Finley, G Cordonnier, FastFlow: GPU Acceleration of Flow and Depression Routing for Landscape Simulation, Computer Graphics Forum, 2024