TANGIBLE LANDSCAPE: COGNITIVELY GRASPING THE FLOW OF WATER

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ABSTRACT:

Complex spatial forms like topography can be challenging to understand, much less intentionally shape, given the heavy cognitive load of visualizing and manipulating 3D form. Spatiotemporal process like the flow of water over a landscape are even more challenging to understand and intentionally direct as they as dependent upon their context and require the simulation of forces like gravity and momentum. This cognitive work can be offloaded onto computers through 3D geospatial modeling, analysis, and simulation. Interacting with computers, however, can also be challenging requiring training and highly abstract thinking that adds a new cognitive burden. Tangible computing – an emerging paradigm of human-computer interaction in which data is physically manifested so that users can feel it and directly manipulate it – aims to offload this added cognitive work onto the body. We have designed Tangible Landscape, a tangible interface powered by an open source geographic information system (GRASS GIS), so that users can naturally shape topography and interact with simulated processes with their hands in order to make observations, generate and test hypotheses, and make inferences about scientific phenomena in a rapid, iterative process. Conceptually Tangible Landscape couples a malleable physical model with a digital model of a landscape through an continuous cycle of 3D scanning, geospatial modeling, and projection. We ran a flow modeling experiment to test whether tangible interfaces like this can effectively enhance spatial performance by offloading cognitive processes onto computers and our bodies. We used hydrological simulation and spatial statistics to quantitatively assess spatial performance. We found that Tangible Landscape enhanced 3D spatial performance and elucidated the dynamics of water flow.

1. INTRODUCTION

1.1 Understanding physical processes

Complex spatial forms and spatiotemporal processes can be challenging to understand, requiring spatial thinking across multiple scales simultaneously and the simulation of forces like gravity and momentum. Physical processes like the flow and dispersion of water are challenging to understand because they unfold in time and space, are historically contingent, are controlled by their context, and are driven by forces like gravity and momentum. The flow and dispersion of water is controlled by the morphological shape, gradient, and topology of the landscape / topography.

Physical processes like the flow and dispersion of water are challenging to understand because they unfold in time and space, are historically contingent, are controlled by their context, and are driven by forces like gravity and momentum. The flow of water across a landscape is controlled by the morphological shape and gradient of the terrain. It is challenging to understand how water will flow across a landscape because one must not only understand how the shape and gradient of the terrain control the flow and dispersion of water locally, but also how water will flow between shapes and gradients how the morphology is topologically connected. Understanding a physical process requires thinking at and across multiple spatial scales simultaneously.

This cognitive work can be offloaded onto computers through 3D geospatial modeling, analysis, and simulation. Interacting with computers, however, can also be challenging requiring training and highly abstract thinking that adds a new cognitive burden.

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1.2 Tangible interfaces for GIS

Theoretically tangible interfaces for geographic information systems should help users understand environmental processes by giving multidimensional data an interactive, physical form so that users can explore spatiotemporal evolution.

In a seminal paper Ishii and Ullmer envisioned tangible user interfaces that would ‘bridge the gap between cyberspace and the physical environment by making digital information (bits) tangible’ (Ishii and Ullmer, 1997). They described ‘tangible bits’ as ‘the coupling of bits with graspable physical objects’ (Ishii and Ullmer, 1997).

The aim of coupling Illuminating Clay with GRASS GIS was to ‘explore relationships that occur between different terrains, the physical parameters of terrains, and the landscape processes that occur in these terrains’ (Mitasova et al., 2006).

A tangible interface for a GIS that enables intuitive digital sculpting while providing analytical or simulated feedback would allow users to dynamically explore how topographic form influences landscape processes (Mitasova et al., 2006). This should be empirically tested in experiments and case studies so that we can critique and develop the theory grounding Tangible Landscape, identify cognitive challenges, and improve the design.

With a physical model one can feel and cognitively grasp a range, albeit a limited range, of spatial scales – scales ranging from what a fingertip can touch, what a hand can grasp, what a body can reach; the relationships between spatial scales within this range of motion should be naturally, subconsciously understood.

Tangible Landscape (Petrasova et al., 2015)

2. METHODS

2.1 Flow modeling experiment

We ran a terrain and water flow modeling experiment to study how tangible interfaces for geographic information systems mediate spatial performance. In the experiment participants were asked to sculpt a given landscape using different technologies – first using Vue, a triangulated irregular network (TIN)-based 3D modeling program designed for intuitive terrain sculpting, and then using Tangible Landscape. The participants are asked to model a real landscape – a region of Lake Raleigh Woods in Raleigh, North Carolina – from a flat surface using each technology. We selected a region of the landscape with distinctive, clearly defined landforms – a central ridge flanked by two stream valleys.

In the 1st exercise each participant had ten minutes to digitally sculpt the topography of the given landscape in Vue using a physical model as a reference.

In the 2nd exercise each participant had ten minutes to sculpt the given landscape in polymeric sand using Tangible Landscape's water flow simulation as a guide. As participants sculpted they could switch between projected maps of either the 1. simulated water flow across the given landscape that they were trying to replicate 2. or the simulated water flow across the scanned landscape.

2.2 Implementation

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Shallow overland flow Shallow water flow can be approximated by the bivariate form of the St Venant equation:

$$\frac{\partial h(\mathbf{r},t)}{\partial t} = i_e(\mathbf{r},t) - \nabla \cdot \mathbf{q}(\mathbf{r},t) \tag{1}$$

where $\mathbf{r} = (x, y)$ [m] is the position, t [s] is the time, $h(\mathbf{r}, t)$ [m] is the depth of overland flow, $i_e(\mathbf{r}, t)$ [m/s] is the rainfall excess = (rainfall − infiltration − vegetation intercept) [m/s], and $\mathbf{q}(\mathbf{r}, t)$ $[\mathrm{m}^2/\mathrm{s}]$ is the water flow per unit width.

We use the solution of the continuity and momentum equations for steady state water flow with a diffusion term $\propto \nabla^2[h^{5/3}(\mathbf{r})]$ that approximates diffusive wave effects so that water can flow through depressions.

$$-\frac{\varepsilon(\mathbf{r})}{2}\nabla^2[h^{5/3}(\mathbf{r})] + \nabla \cdot [h(\mathbf{r})\mathbf{v}(\mathbf{r})] = i_e(\mathbf{r}) \tag{2}$$

where $\varepsilon(\mathbf{r})$ is a spatially variable diffusion coefficient.

This equation is solved using a Green's function Monte Carlo path sampling method (Mitasova et al., 2004). The overland flow hydrologic simulation using a path sampling method (SIMWE) is implemented in GRASS GIS as the module r.sim.water.

2.3 Analysis

Quantitative

Qualitative The digital models sculpted in the 1st exercise were imported into GRASS GIS as point clouds and interpolated as DEMs using the regularized spline with tension interpolation method (Mitasova et al., 2005).

The physical models sculpted in 2nd exercise were automatically 3D scanned, imported into GRASS GIS as points clouds, and interpolated as DEMs with Tangible Landscape.

The final state of physical models sculpted in 2nd exercise were 3D scanned, imported into GRASS GIS as points clouds, and interpolated as DEMs with Tangible Landscape .

In the 1st-5th exercises the resulting physical models are 3D scanned, imported into GRASS GIS as point clouds, and interpolated as DEMs for analysis.

2.4 Data collection and analysis

In the 1st-5th exercises the resulting physical models are 3D scanned, imported into GRASS GIS as point clouds, and interpolated as DEMs for analysis.

For each model I compute the elevation and its histogram and bivariate scatterplot, the slope, the difference and its histogram, the simulated water flow, and morphology. For each exercise I compute a map of the coefficient of variance of all the of DEMs, bivariate scatterplots of the covariance and correlation matrix of all the of DEMs, and the mean and the absolute value of the mean of the differences between the the reference terrain and the modeled terrain.

3. RESULTS

4. DISCUSSION

5. CONCLUSION

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