Embodied Spatial Cognition in Tangible Computing

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Additional Key Words and Phrases: Human-computer interaction, tangible interfaces, interaction design, physical computation, embodied cognition, spatial thinking, geospatial modeling

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1. INTRODUCTION

We have designed Tangible Landscape – a tangible interface powered by a geographic information system (GIS) – that gives spatial data an interactive, physical form so that users can naturally feel it, see it, and shape it. Our aim was to iteratively design and empirically test a tangible interface that augments spatial thinking and improves spatial performance. Spatial thinking can be embodied – people can functionally think about space with their bodies by cognitively grasping objects and physically simulating it [Kirsh 2013]. Theoretically tangible interfaces should improve spatial performance through embodied cognition by enabling natural modes of interaction [Dourish 2001], offloading cognitive processes onto the body [Kirsh 2013], and computationally augmenting spatial thinking [Dror and Harnad 2008]. We designed Tangible Landscape to physically manifest digital data so that users can cognitively grasp the data as an extension of their bodies and automatically, immediately, and subconsciously interact with it. We conducted a series of experiments using quantitative methods including geospatial modeling, analysis, simulation, and statistics and qualitative methods including semi-structured interviews and direct observation to test whether tangible interfaces can improve spatial performance. We also explored how users approached spatial problem solving using Tangible Landscape in a serious gaming event.

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1.1. Spatial thinking

Spatial thinking – 'the mental processes of representing, analyzing, and drawing inferences from spatial relations' [Uttal et al. 2013] – is used pervasively in everyday life for tasks like recognizing things, manipulating things, interacting with others, and wayfinding. Spatial thinking is also used extensively in science, technology, engineering, the arts, and math for tasks like simulating physical processes, mapping and manipulating molecules, designing circuits, designing buildings, shaping sculpture, and studying topology. Given the importance of spatial thinking – personally, academically, and professionally – how can we effectively improve our spatial performance, our ability to perform tasks that require spatial thinking?

Many spatial tasks can be performed computationally enabling us to efficiently store, model, and analyze large sets of spatial data and solve complex spatiotemporal problems. In engineering, design, and the arts computer-aided design (CAD) and 3D modeling software are used to interactively, computationally model, analyze, and animate complex spatial forms. In scientific computing spatial patterns and processes can be mathematically modeled, simulated, and optimized. Geographic information systems, for example, can be used to computationally store, model, analyze, simulate, and represent geospatial patterns and processes. The open source project GRASS GIS for example supports 'geospatial data management and analysis, image processing, graphics and maps production, spatial modeling, and visualization' [GRASS Development Team 2016].

Computing mediates and transforms spatial thinking, expanding, but also constraining what is possible. While spatial computing can augment spatial thinking – distributing or offloading cognitive processes through digital computation – the logic of implementation, the limits of what is computationally possible, and the modes of input and output constrain how we reason. Furthermore, when it is difficult to interact with a computer, to input commands and parse the resulting output, one has to think harder and risks frustration and demotivation.

Unintuitive modes of human-computer interaction constrain how we think and add cognitive and emotional costs. The paradigmatic modes for interacting with computers today – command line interfaces (CLI) and graphical user interfaces (GUI) – require physical input from devices like mice, keyboards, digitizing pens, and touch screens, but output data visually as text or graphics.

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... presented graphically using a graphical user interface (GUI) and require sophisticated spatial thinking to parse and understand. Furthermore it can be challenging to interact with these computational models using a GUI due to the high cognitive load of visualizing multidimensional space (and time) and the disconnect between intention, action, and feedback – the disjunction between ones idea, it expression constrained by the input device (such as a mouse and keyboard, a touch screen, or a digitizing pen), and the graphical representation [Dourish 2001; Ishii 2008].

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1.2. Tangible interaction

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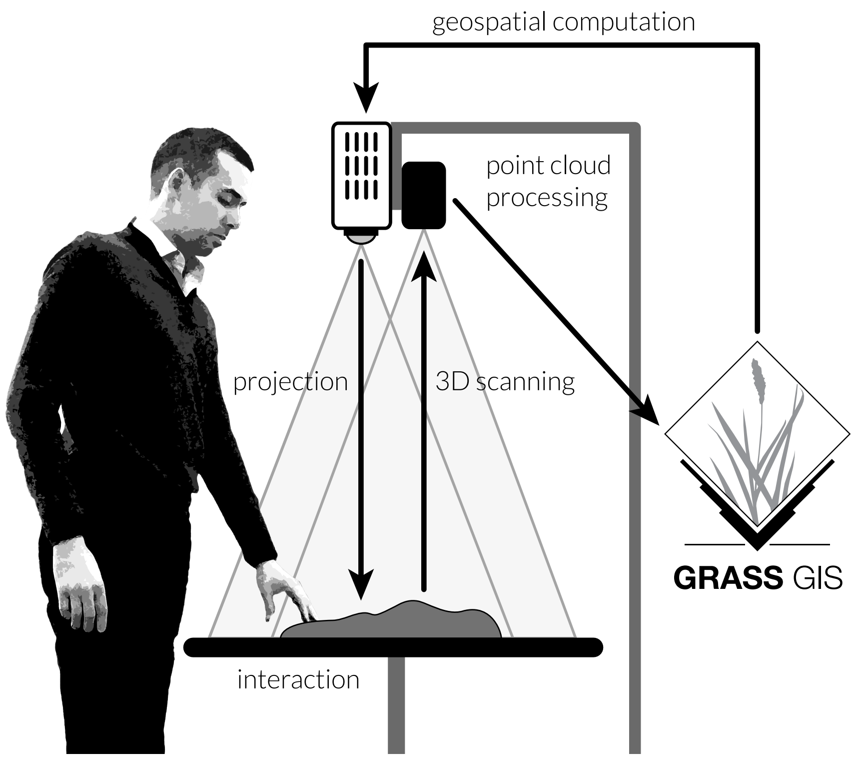

Fig. 1. Caption.

2. METHODOLOGY

2.1. Tangible Landscape

Concept. A tangible user interface powered by open source GIS. Coupling a digital and physical model of a landscape so that you can intuitively feel and shape it with your hands. Near-real time interaction.

Evolution. An evolution of Illuminating Clay and the Tangible Geospatial Modeling System.

Design. Tangible Landscape couples a digital and a physical model through a continuous cycle of 3D scanning, geospatial modeling, and projection. Intuitive scientific modeling with Tangible Landscape. Tangible Landscape is designed to make scientific data, models, and simulations exploratory, engaging, and fun.
Figure 1 . . .

Modes of interaction.

Applications.

2.2. Coupling experiment

2.3. Analytics experiment

2.4. Case studies

Coffee & Viz. Scientific gaming: Structured problem solving with rules, challenging objectives, and scoring

3. RESULTS

4. DISCUSSION

5. FUTURE WORK

6. CONCLUSION

APPENDIX

In this appendix ...

ELECTRONIC APPENDIX

The electronic appendix for this article can be accessed in the ACM Digital Library.

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Online Appendix to: Embodied Spatial Cognition in Tangible Computing

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