Embodied Spatial Cognition in Tangible Computing

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1. INTRODUCTION

Cognition can be embodied – it can be embedded in the body and based on bodily experience. Higher cognitive processes, the traditional realm of cognitive science, can rely on lower level processes such as emotion and sensorimotor processes that link perception and action. Thus feeling, action, and perception can be functionally integral to thought [Hardy-Vallée and Payette 2008]. We can for example physically simulate cognitive processes, offloading cognition onto action to functionally 'think with our bodies' [Kirsh 2013]. We can cognitively grasp objects, temporarily, contingently incorporating tools into our body schema [Kirsh 2013].

In embodied cognition the mind is embedded in the body. It is based on bodily experience. Higher cognitive processes, the traditional realm of cognitive science, rely on lower level processes such as emotion and sensorimotor processes that link perception and action [Hardy-Vallée and Payette 2008]. Thus our bodies and actions mediate how we think. We can for example physically simulate cognitive processes, offloading cognition onto action to functionally 'think with our bodies' [Kirsh 2013]. We can cognitively grasp objects, temporarily, contingently incorporating tools into our body schema [Kirsh 2013]. This view of cognition considers feeling, action, and perception to be functionally integral to thought.

Many conceptions and studies of spatial thinking focus on a visual, semantic understanding of space. Embodied cognition, however, highlights the importance of a kinaesthetic, pragmatic understanding of space and the enaction of spatial transfor-

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mation – for the act of transforming an object changes how we think about space. As [Kirsh 2013] argues, sometimes 'we know more by doing than by seeing' [Kirsh 2013].

[Uttal et al. 2013b] defined spatial thinking as 'the mental processes of representing, analyzing, and drawing inferences from spatial relations' [Uttal et al. 2013b]. This definition is based on a semantic rather than pragmatic understanding of space, an understanding based on visual rather haptic, kinaesthetic feedback. In this paradigm space is imagined rather than felt and spatial transformation is imagined rather than enacted. Psychometric tests of spatial ability – the application of spatial thinking – for example study spatial visualization and mental rotation [Uttal et al. 2013b; Uttal et al. 2013a; Ormand et al. 2014]. We, however, do not just see space – we also feel it; we use our bodies to feel size, shape, and volume. Space need not be imagined to be transformed – haptic feedback about space informs subconscious pragmatic representations that rapidly generate action [Jeannerod 1997]. Spatial thinking can be embodied.

Spatial thinking is malleable and can be improved with training. The effects of spatial training can be durable – persisting for months – and transferable – training in a given spatial task improves performance in other untrained spatial tasks [Uttal et al. 2013b]. How can spatial training integrate domain specific knowledge? And could such applied training more effectively improve performance in a given discipline? [Uttal et al. 2013b]

Embodied spatial thinking may lead to improvements in performance by reducing cognitive loads with pragmatic representations and physical simulation and by enhancing perception with visual and haptic feedback.

Since spatial thinking is mediated by technology the effectiveness of training methods will depend upon their implementation, upon the technology used. Computer gaming has been shown to improve spatial thinking and technologies like geographic information systems (GIS) can be used to integrate domain specific knowledge [Uttal et al. 2013b]. Unintuitive human-computer interaction, however, may constrain spatial thinking and add cognitive costs thus reducing the effectiveness of digitally implemented training methods. Embodied and computationally enriched cognition may enhance spatial thinking in novel ways enabling and encouraging coupled creative and analytic thinking.

Tangible computing aims to embody computing by coupling physical and digital data [Dourish 2001] – by physically manifesting digital data so that we can cognitively grasp and absorb it, so that we can think with it rather than about it [Kirsh 2013]. [Ishii and Ullmer 1997] envisioned that TUIs would 'take advantage of natural physical affordances to achieve a heightened legibility and seamlessness of interaction between people and information' [Ishii and Ullmer 1997].

To understand how computing transforms cognition we need to study 'the complex coordination between external and internal simulation, between doing things internally and doing things externally' [Kirsh 2013].

Theoretically tangible interaction should offload cognitive processes through bodily action, physical simulation, and digital computation.

Should improve spatial performance.

Research questions: Can tangible interfaces improve spatial performance? Which tangible analytics improve spatial performance the most?

Aim: Improve spatial performance

A comparative study of 3D spatial performance with hand modeling, digital modeling, and tangible interaction.

Two experiments.

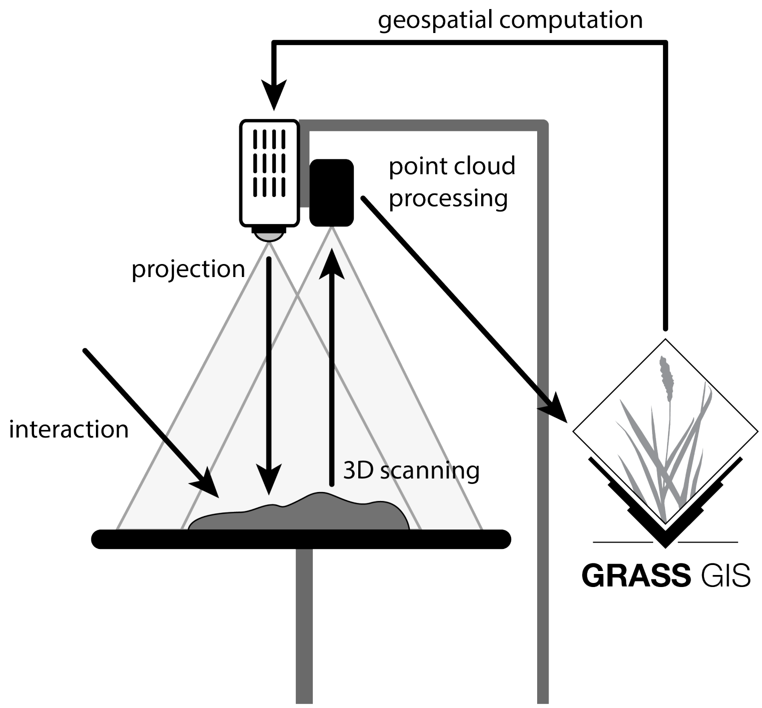

Fig. 1. Caption.

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

2.5. Coupling experiment

2.6. Analytics experiment

2.7. Case studies

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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