

3D Computer Interaction Using Physical Objects:

Exploration of Tangible User Interfaces

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Abstract

Why is computer interaction using a 3D CAD (Computer Aided Design) tool such a hard task while an untrained child can easily build 3D buildings out of a LegoTM set? We believe that the reason lies in the current Human Computer interface (HCI). TUIs (Tangible User Interfaces) offer natural means of interaction with computers and have already been shown to simplify existing computerized applications and offer solutions for tasks that were considered to be “out of the scope” of human-computer interaction. We are currently pursuing new applications for 3D geometry defining TUIs that can better exploit our innate abilities. In this paper we attempt to provide the reader with a brief overview of the underlying paradigms and research in this emerging domain. We also describe a TUI, the Segal Model, created by John Frazer and his colleagues 20 years ago and our current work in reviving this interface. We briefly present some of the initial results of building physical 3D worlds on top of the Segal Model and then rendering them into fully active 3D virtual worlds. Practical ways of enhancing the expressiveness of the interface and some of our future research plans are briefly presented.

Introduction

When we interact with the world we rely on several natural abilities, among them our tangible manipulation ability. We can move, manipulate, assemble and disassemble a seemingly endless variety of physical objects with very little cognitive effort. Yet, current Human-Computer Interfaces (HCI) use only a limited

range of our abilities and rely on a very limited variety of physical objects. The thirty year old Keyboard-Mouse-Monitor interface and the Window-Icon-Menu-Pointer (WIMP) interaction metaphor prevail as the major or even sole HCI, used for anything from word processing to 3D graphical design and modeling. We believe that many of our natural abilities are blocked by this standard HCI, forcing complexity on what could otherwise become a simple, even natural HCI task. More specifically, we believe that providing new and original tangible 3D-shape based HCI tools might change dramatically the way in which we perform 3D modeling and construction oriented HCI tasks and open the way for other applications that are not currently supported by computers.

What can be learned from the ease of building models or manipulating objects in the real world as opposed to the hardship involved in performing similar tasks in a digital environment? Three concepts that are taken from our “natural” interaction with physical tasks can be borrowed as themes for the design of new HCI paradigms and TUIs [11]. The **affordances** or transparency of the interface is the expression of its functionality through its physical qualities. The **synchronization of perception and action space** is the "natural" coincidence in time and space of our hands and fingers (termed as parts of our action space) with the position of the objects we are manipulating (termed as part of our perception space). Last, **the support of both pragmatic and epistemic maneuvers** is the natural inclusion of both straightforward and trial and error procedures in the set of possible actions we can perform with physical objects.

Related Work

The term "Tangible User Interface" should be credited to Hiroshi Ishii from the Tangible Media Group at the MIT Media Lab. Many TUIs technologies and applications are emerging as more natural HCI alternatives to the standard mouse and keyboard interface. To mention a few, the toy industry has several examples of tangible interaction tools between children and computerized applications [21] or ‘huggable interfaces’ [1,18]). TUIs were introduced as simple and natural methods to support animation keyframing [6,7]. Tangible curve and surface inputting tools were introduced in the ShapeTape [4] and the Haptic Lens [22] respectively. Tangible 3D-shape manipulation was suggested in DO-IT [20]. Topological (though limited) tangible inputting for educational purposes was introduced in Triangles [15] and AlgoBlocks [25]. Planar, physical desktop tangible interaction was introduced in several studies [5,10,11,16,17,26]. For a thorough discussion of this emerging field and its potential see [8,9].

Several research groups have developed various tangible interfaces for 3D modeling and design over the last 20 years for a variety of applications. The impetus for the practical aspects of our current work originated in pioneering HCI tools developed by John Frazer and his colleagues as early as 1980 [12-14]. Frazer developed working prototypes of 3D Input Devices (he also used the terms “Machine Readable Models” or “Intelligent Modeling Systems”) in order to support new design approaches in architecture. The models were intelligent, in that they were able to extract their geometry automatically. The supporting design software enabled implementation of feedback concepts such that a model (via its supporting software running on a host computer) can advise the designer on design errors or insights interactively. It is important to note that side by side with the development of 3D Input Devices by John Frazer and his colleagues, Robert Aish published and developed tools along similar lines. Figures 1 - 4 show a sample of Frazer’s 3D input devices (sadly, the HCI community largely did not refer to these models, and many of them were ‘reinvented’).

Geometry Defining Processors (GDP) were introduced [2] along similar themes for physically defining a 3D-geometry problem and solving it digitally. Two impressive, very recent efforts, MERL’s Lego-like blocks [3] and Yoshifumi Kitamura’s ActiveCubes [19] enable the user to define, in an easy-to-use manner, a 3D structure and extract it to a host computer (in real-time in the ActiveCube case). A new effort - ‘Digital Clay’ – at Xerox PARC seems to follow the same ideas, but might also enable direct (without human intervention) shape output as well as input [27].



Figure 1. The Universal Constructor [12]



Figure 2. Flexible Intelligent Modeling System [12]

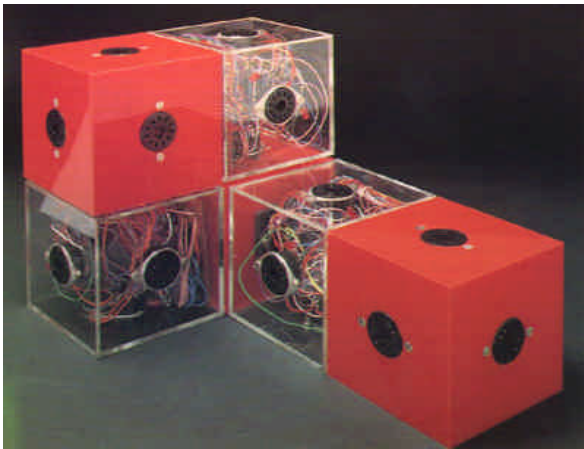


Figure 3. Three - Dimensional Intelligent Modeling System [12]

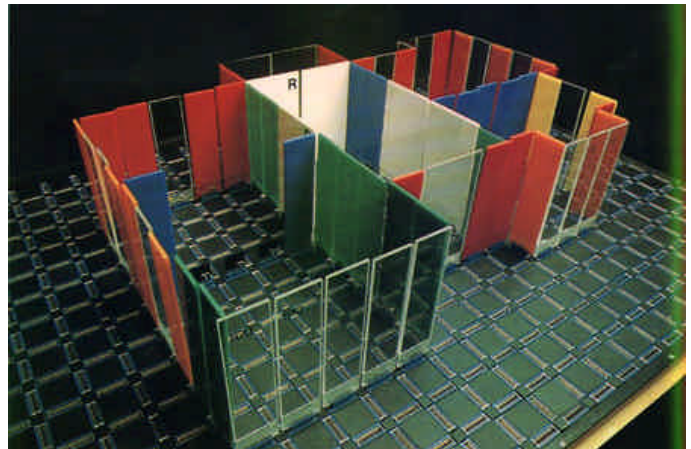


Figure 4. The Segal Model [12]

Reviving the Segal Model

We believe that new geometry inputting TUIs, can not only change dramatically several interaction paradigms, but also make completely new interaction paradigms feasible. We have decided to focus our efforts on developing new applications that can benefit from existing TUIs. We are currently researching three main applied domains for new tangible interfaces: new design tools, tools for the visually impaired and neuropsychological assessment tools, using the Segal model (figure 4) as the test bed for our work.

The Segal model originally allowed the user to construct various home plans, on top of a large grid (the base) using 127 different physical entities, each with a different electronic identification. The entities can range from colored plastic panels to any other small-scale object. While the user places the physical objects on top of the model, the position and identification of these objects is sampled electronically in real-time. In the original use of the model the output was used as input to wire-frame rendering software and a design feedback tool, which produced design advice, such as house area and cost, to interactively help the designer (and in a way, imitate some of the expertise of an experienced architect [12]). The board was scanned electronically, in real-time with very low processing demands from the hosting system (i.e., no real-time image processing, etc). The Segal model is a one-of-a-kind device - a single copy was constructed for the research, and there are no known copies. The model was used with an early 80's, now obsolete, computer [12,13]. Our initial goal was to 'make the Segal Model work' with a standard, modern PC using a generic as possible interface. We have revised the Segal Model hardware and software interface so that the model is scanned now using the parallel port of a standard PC. The new interface to the Segal model is able to read out the entire board 500 times a second (this effort is detailed elsewhere [24]).

A Sample Crossing from the Physical to the Virtual

A simple, preliminary demonstration of the power of the Segal model as a design tool was achieved by rendering a tangibly constructed world via a “Half-Life” graphical engine [23]. The user starts by building a world using physical-tangible objects on top of the Segal model base (figure 5). The physical model is sampled and transferred automatically to a virtual model in a “Half-Life” based 3D environment, with full control of the appearance of the world (texture, lighting, etc.) and full ability to take a virtual walkthrough in the former physical model (figure 6). Furthermore, the virtual world can now be populated with dynamic virtual entities and characters, either by physical-tangible means or by software editing (figure 7). The physical model can then become a fully interactive, fully active virtual world (figure 8).

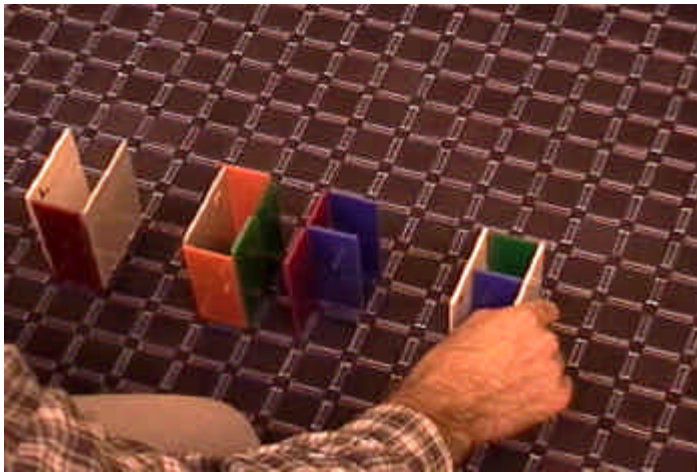


Figure 5. Building a world tangibly. The user builds the letters ‘U OF A’.

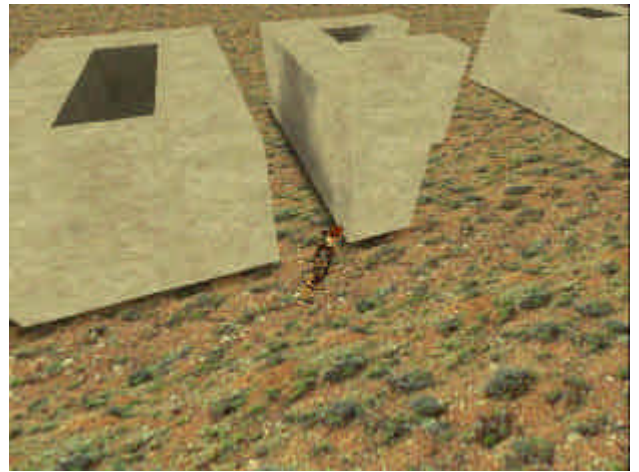


Figure 6. Gordon Freeman (“Half-Life”’s avatar) running below the virtual ‘OF’ structure.



Figure 7. Gordon Freeman meets two fellow scientists inside the ‘U’ structure.



Figure 8. A fierce battle takes place around the letters structures.

Adding New Meaning

In order to support a wider range of activities, mostly for cognitive assessment tasks, we are designing a variety of couples of virtual and physical objects that will enrich the expressiveness of the Segal model interaction. Practically, all these objects are TUIs: they can be manipulated and positioned by the user on top of the Segal model base, while their position and identification is being sampled. Such sample house interface is presented in figure 9. In order to keep a close link between the physical and the virtual characteristics of the objects added to the Segal model's "vocabulary", a 3D printer is used to print the virtual objects we design. A sample house interface is presented in its printed, physical form and as a virtual model in figure 10 and 11, respectively. This design approach enables us to effectively "print out" interfaces, keeping their form identical in both domains: the virtual and the physical. This enables us to maintain a very high level of interface affordances.



Figure 9. A house interface for the Segal model. Keeping close coupling of the physical and virtual forms.



Figure 10. Physical interface - the 3D printed two stories residential house.

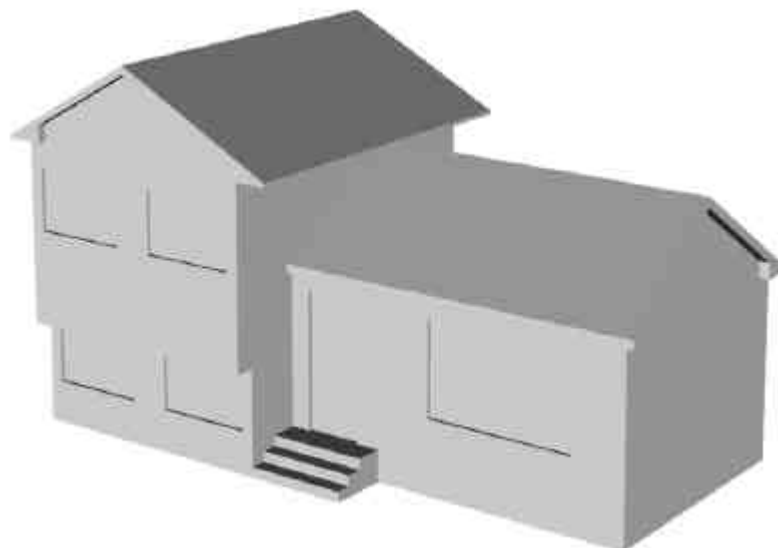


Figure 11. Virtual interface - the 3D graphics two stories residential house.

Conclusion

In this paper we briefly explored several of the key issues that motivated our work in the field of TUIs and presented some initial results and insights into our current efforts. The scope of past and current research in the TUIs domain and the paradigms underlying it were concisely described. We briefly discussed geometry inputting tangible user interfaces and our research motivations and goals in this field. We described the revival of a pioneering tangible user interface called the Segal Model and an initial demonstration of its power by tangibly designing 3D virtual “Half-Life”TM worlds. We concluded by presenting our current efforts towards enlarging the expressiveness and affordances of the Segal model interface.

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