Beyond – Collapsible Tools and Gestures for Computational Design

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Abstract
Since the invention of the personal computer, digital media has remained separate from the physical world, blocked by a rigid screen. In this paper, we present Beyond, an interface for 3-D design where users can directly manipulate digital media with physically retractable tools and hand gestures. When pushed onto the screen, these tools physically collapse and project themselves onto the screen, letting users perceive as if they were inserting the tools into the digital space beyond the screen. The aim of Beyond is to make the digital 3-D design process straightforward, and more accessible to general users by extending physical affordances to the digital space beyond the computer screen.

Keywords
3D Interaction, Augmented Reality and Tangible UI, Pen and Tactile Input, Tactile & Haptic UIs, Pen-based UIs, Tangible UIs

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): H.5.2. Input Devices and Strategies.

General Terms
Design, Human Factors, Experimentation

Introduction

Recent developments in computer technologies have made the design process much more precise, and scalable. Despite this powerful role the computation plays in design, many designers and architects prefer to build physical models using physical tools and hands, employing their versatile senses and bodily expressions in their early stage of design [17]. There has been no straightforward way to sketch and model 3D forms on the computer screen.

Tangible User Interfaces have appeared as a strong concept to leverage the traditional ways of design with digital power, while preserving physical affordances, by blurring the boundary between the physical environment and cyberspace [1]. In an attempt to diminish the separations between visual and tactile senses, which are critical for the design process, researchers of Augmented Reality (AR) have suggested several input devices and ways of displaying digital information in more realistic ways [8][9][10][11]. Despite these efforts, a flat monitor and a mouse remain our standard interfaces for design, leaving digital media apart from the physical world blocked by a rigid screen. It is extremely hard for users to select a certain 3-dimensional coordinate in virtual space and sense the volume without wearing special display glasses and using complicated mechanical equipments.

A parallel trend in CAD, development in gestural interfaces, has allowed users to employ bodily expressions in data manipulation [4][14]. However, simple combinations of mouse and gestures on 2D surface does not take full advantage of gestures as bodily expressions and can hardly cover the large number of the commands necessary in design.

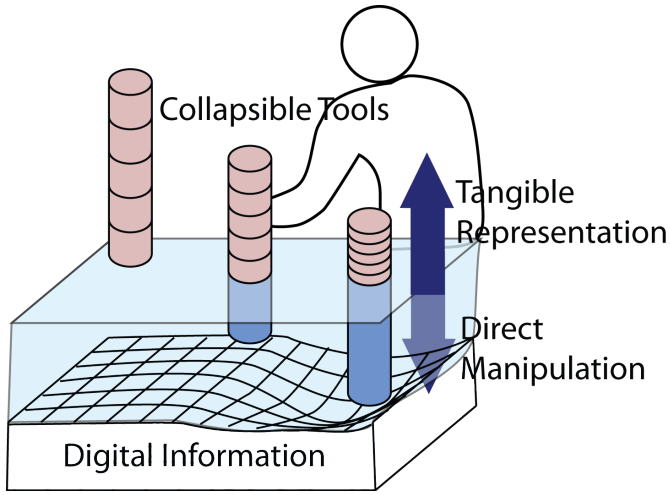

figure 1. Direct manipulation of digital information beyond the screen with collapsible tools

In this paper, we present Beyond, an interface for 3-dimensional design where users can directly manipulate 3-D digital media with physically retractable tools and natural hand gestures. When pushed onto the screen, these tools can physically retract and project themselves onto the screen, letting users perceive as if they were inserting tools into the digital space beyond the screen. Our research goal is to enable users to design by simply sketching and cutting digital medium using tools, supported by gestures, without having to look at multiple planes at the same time. We believe this effort will make digital 3-D design process straightforward, scalable and more accessible to general users.

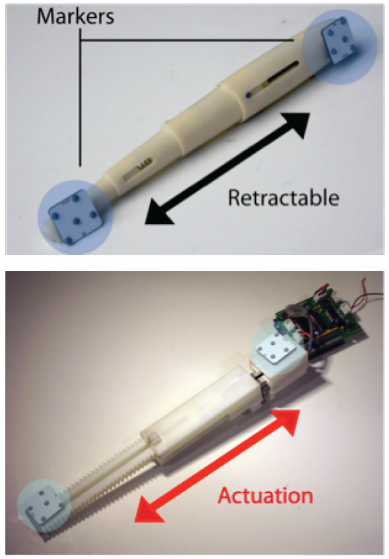

figure 2. Collapsible pen (Top) and saw (bottom).

Related Work

Various approaches have been taken to enable users to design in 3D in with more straightforward and intuitive manners by integrating input and output, and by providing users with tangible representations of digital media [1].

The concept of WYSIWYF – "what you see is what you feel" – has been suggested in the domain of Augmented Reality in an attempt to integrate haptic and visual feedback [8]. Technologies like stereoscopic glasses for 3-D display, holograms and wearable mechanical devices such as phantom that provide precise haptic feedbacks are invented and experimented within this context [18][15]. However, many of these systems require users to wear devices, which are often heavy and cumbersome, intervening natural views and limiting behaviors of the users. Sand-like beads or actuated pin-displays are examples of deformable physical materials built in an attempt to diminish the separation between input and output [18]. However, they are often not scalable because solid forms embedded in physical materials are less malleable than pixels.

In an effort to convey users' intentions more intuitively, gesture based interactive sketch tools have been suggested [2][13]. Most of the systems are based on pen-stroke gesture input, whose functions are limited to simple instant ones such as changing the plane and erasing objects. Oblong's g-speak is a novel gestural interface platform that supports varieties of gestures and applications including 3-D drawings [3]. However it is still a hard task to select a certain coordinate in arbitrary space with these systems.

What is Beyond?

Beyond is a design platform that allows users to employ their gestures and physical tools beyond the screen in 3-D computational design. Collapsible tools are used in Beyond so that those can retract and project itself onto the screen, letting users perceive as if they were inserting the tools into the screen. This design enables users to perceive workspace in the screen as 3-D space within their physical reach, where computational parametric operation and human direct manipulation can occur together. As a result, this interface helps users design and manipulate digital media, with affordances they have with physical tools (figure 1).

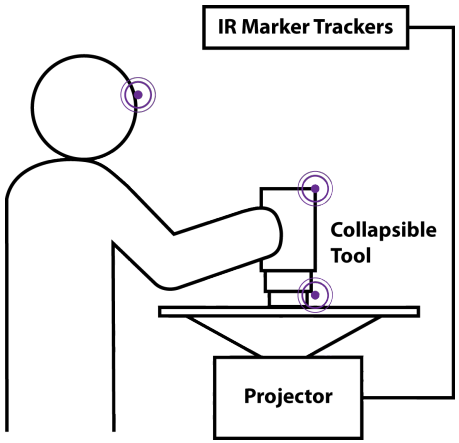

figure 3. Mechanism for tracking users' head and tools' positions.

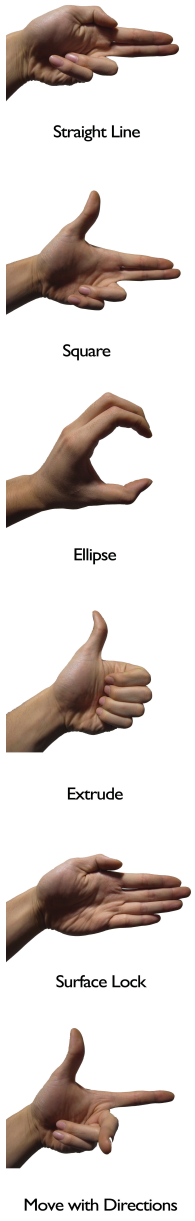

figure 4. Gestures used in Beyond Prototype.

Another significant design decision was use of 3-D gestures. We came to the conclusion that gestures in 3D effectively helps users to convey their intentions that are abstract but at the same time related to spatial or shape-related senses. Types of gestural commands used in the Beyond are discussed more in details in the interaction section.

Beyond Prototype

The current Beyond prototype consists of retractable tools, a table-top display and an infrared position tracking system. The tools are designed to retract and stretch with two IR retro-reflective markers attached on both tips. As illustrated in figure 3, Vicon system composed of IR emitters and cameras is used to track these markers, letting the system obtain information about the location, length and tilt of the tools. An additional marker is attached to the users' head for real time 3D rendering [16]. We implemented two kinds of collapsible tools for the first prototype of Beyond: Pen and Saw (figure 2).

Pen

The pen serves as a tool for drawing. This passive tool can specify any 3D coordinate in virtual space within its reach and draw shapes and lines.

Saw

The saw serves as a tool for cutting and sculpting. It is designed to provide several different forms of physical actuation when users touched virtual objects.

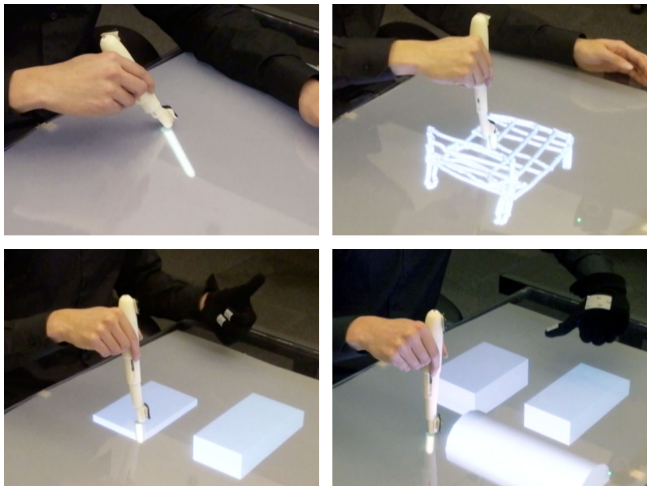

figure 5. Rough 3D sketch (top) and abstract shape drawing (bottom) using gestures.

Gestures

Beyond uses several gestural interaction techniques mediated by gloves tagged with IR reflective markers tracked by Vicon tracking technologies, which are developed by oblong industries.

3-D rendering techniques based on users' head position

In order to render the scene where phsysical and digital portions are seamlessly connected, we implemented a software to rerender 3D scenes based on users' head position in real-time. This helps users perceive the objects rendered on the flat screen as 3-D object put behind the screen.

Interaction with Beyond

Direct Selection and Drawing

Beyond allows users to directly select certain 3D specific coordinates within its physical reach of physical tools in virtual 3D space without looking at multiple planes or wearing head mounted display. By doing so it allows users to sketch in 3D shapes in a straightforward manner, help them externalizing their 3D images in their minds.

Touching and Cutting

Using Beyond-Saw, users can cut and trim any surface or shape by simply inserting the saw tool into the virtual space. When virtual objects are touched or cut by a tool, a slide actuator installed inside the saw tool creates force feedbacks, preventing the tool from retracting. By doing so users can interact with digital media with better sense of volume and material properties of virtual objects.

Gestural Interactions with Beyond

Gestural commands effectively complement tools-mediated direct manipulation by conveying users' intention to the system in intuitive manners. Users can define several different abstract shapes and operate functions while directly specifying coordinates with the collapsible tools. Figure 4 shows a few examples among several types of gestures. The current Beyond prototype provides shape-related gestural commands such as straight line, square, ellipse and function-related gestural commands including extrude, lock the drawing surface and move objects. For example users can do "straight " gestures to make lines they draw straight, and "extrude" gestures to extrude certain surfaces (Figure 5).

New Work flow for 3-D Design

Several interaction techniques illustrated in the previous sections can be merged and weaved together to create a new workflow for 3-D computer-aided design as followings. First, users can sketch rough design in 3D with free-line drawing techniques. The next step is to define discreet shape on top of its quick-sketch by specifying locations and other critical parameters with tools and to operate the functions with gestures. In the middle of the design process users can always modify its design by using other types of tools.

User Evaluations

Since the project is currently at its initial stage, we are planning to conduct comprehensive user evaluations in the future. However, overall feedback we have received for several weeks have been that the Beyond platform helps users sketch and model the 3D shape they have in mind and that gestural commands complement directness of tools-based interactions decreasing ambiguities.

Discussion and Future Work

In this paper, we introduced Beyond, a design platform that enables users to interact with 3D digital media using physically collapsible tools that seamlessly go into the virtual domain by simple mechanism of collapse, projection, and actuation. Initial user evaluations showed that applying natural hand gestures to convey abstract intention of users greatly complements tools-mediated direct manipulation. We presented the design and implementation of the first Beyond prototype that used Vicon location tracking system and the physically collapsible pen and saw.

figure 6. A more portable version of Beyond prototype, using camera based tracking and a touch screen.

The Beyond allows users to directly select certain 3-dimensional coordinate in virtual space. We believe this challenge will help more diverse range of users to access to the technology. While many of the AR or TUI approaches to leverage computational design do not scale up well or too application specific due to inherent rigidity of physical handles, the Beyond platform shows potentials to be a more scalable and generalizable user interfaces by seamlessly transforming rigid physical parts to flexible pixels.

Since the Beyond is at its initial stage of developments, we foresee several improvements to Beyond. First, the entire system can be more portable and low-cost by using simple touch screen and camera based tracking technologies. Secondly, we plan to develop more comprehensive gestural languages applicable to design process combined with direct pointing tools. We also plan to improve the force feedback of the active tools by using series elastic actuator, which can create more precise and varieties of force profiles allowing the system to express tactile feedback of various material properties. Finally, we are planning to conduct extensive user evaluations on the system in the near future.

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