# PhD Proposal

3D Tabletop Display Interaction

by Mark Hancock

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**Abstract**

On traditional tables, people frequently use the third dimension to pile, sort and store objects. People also use the third dimension to communicate through artifacts across the table by orienting them "toward" other people. However, this interaction usually does not extend far above the table. I focus on the interaction space of shallow-depth 3D — 3D interaction with limited depth — to enrich collaboration on digital tables. Research in tabletop display environments has largely been limited to two dimensions, perhaps due to the 2D nature of the surface itself. Research in 3D virtual environments has typically been explored in vertical displays and involves 6DOF (or more) of input. Furthermore, little consideration has been paid to collaboration in these 3D environments — neither what effect 3D has on collaboration nor what benefit 3D could provide to collaborative activities. In the specific domain of 3D tabletop interfaces, it is not yet understood (1) whether multiple people can share the same 3D display without inconsistencies interfering with collaboration, (2) whether interaction on the table's surface can provide sufficient freedom for people to adequately manipulate 3D objects, nor (3) whether these 3D visuals can be integrated with an interaction technique in an application domain. In this proposal, I will describe these problems in more detail and present a plan for how to address them. In my research I will provide several alternative designs for how the 3D information will be projected on the 2D surface, as well as several interaction techniques for manipulating 3D objects on this 2D surface. I will provide an empirical evaluation of both as well as an interface that integrates one or more of these techniques with appropriate visual feedback.

# Contents

# Research Proposal

On traditional tables, people frequently make use of the third dimension, despite its two-dimensional nature. They make piles for storage, flip paper to make use of its backside, vertically stack books to save space, and reorient objects in a multitude of ways to achieve comprehension, coordination and communication (Kruger et al., 2003). My research will focus on leveraging the interactions already ubiquitous with traditional tables in the digital realm, thus combining the power offered by technology with these freedoms.

Specifically, I will focus on enabling many people to simultaneously interact with 3D artifacts on a digital table. Instead of the artifacts that are represented on the table being merely objects of interest intended only for observation and understanding, I intend to allow people to become embodied with them in such a way that the digital representations themselves can be used as tools within the 3D virtual environment. Furthermore, I intend to allow this type of interaction to specifically allow for coordination and communication in a collaborative tabletop environment. This embodiment not only allows digital artifacts to be used as tools, but it allows others in the environment to recognize this usage and therefore would afford mutual understanding between collaborators.

In Section 1.1, I describe some of the background work relevant to my research and how it can inform my dissertation. In Section 1.2, I draw a picture for how my research fits in a broader scope. In Section 1.3, I describe three specific problems that I intend to address and, in Section 1.4, I describe my specific objectives for this dissertation. I discuss the current status of my research in Section 1.5 and present a timeline for completion of my objectives in Section 1.6.

## 1.1 Background

Computing technology has had a large impact on how people do work together. Because a large amount of work is now done on a personal computer (intended specifically for individual use), it can be more difficult to collaborate and share work. Tabletop displays offer a promising medium for multiple people to simultaneously interact with a computer, while maintaining some of the abilities to communicate and coordinate that have been lost in this transfer. Tabletop display input technology has been rapidly improving (Dietz and Leigh, 2001; Han, 2005) and it may soon be possible for many people to seamlessly and simultaneously control digital artifacts on these tables.

In this section, I will describe how several areas of research are relevant to my dissertation. These areas include embodied interaction, interaction in 3D virtual environments, collaboration & awareness, and existing 3D tabletop interfaces.

### 1.1.1 Embodied Interaction

Dourish (2001) discusses the idea of *embodied interaction* – "the creation, manipulation, and sharing of meaning through engaged interaction with artifacts" (p. 126). Specifically, he addresses how meaning, understood from a phenomenological perspective, requires embodiment. That is, the meaning of an artifact in terms of its existence (ontology), a person's ability to affect change to that artifact (intentionality), and the ability of two or more people to achieve a mutual understanding (intersubjectivity) can only happen through action in the world. He also discusses the idea of *coupling* – interaction with an artifact as a tool instead of as an object of enquiry. That is, objects can have a dual role. For example, a hammer can be used as a tool to hit a nail into a board or one can observe the hammer and its properties (e.g. a wooden shaft with a metallic head that has both a blunt end for hitting nails and a forked end for removing them). A person can thus couple with a hammer so that they are embodied and act as one in the world. Dourish also describes Urp (Underkoffler and Ishii, 1999), a tangible interface for urban planning, as a successful example of how embodied interaction can be made possible using physical artifacts in combination with technology.

One of the objectives of this dissertation is to support embodied interaction with completely virtual 3D artifacts on a tabletop display. I intend to show that people can couple with 3D virtual artifacts in the same way that they can couple with physical ones. For example, a person could couple with a 3D representation of a hammer to hit a 3D virtual nail into a 3D virtual board.

### 1.1.2 Interaction in 3D Virtual Environments

There have been many attempts to leverage the freedoms available in manipulation of physical artifacts in virtual environments. Virtual environments typically offer some method(s) for selection and manipulation of objects, as well as navigation in the 3D world. For full control of both the 3D artifacts and the 3D environment requires a minimum of 12 degrees of freedom (6DOF artifact position & orientation + 6DOF camera position & orientation). These 12 DOF can be integrated into one device (Huckauf et al., 2005) or can be separated into a 6DOF device for manipulation and 6DOF head tracking for navigation (Bowman et al., 2005). Jacob et al. (1994) describe how input can be further decomposed and suggest that careful attention should be paid to what parameters can be integrated and which should be separated in an input device. For example, they show that a person can easily control both the position and size of an object in a single integrated motion, but that when controlling both position and colour, they tend to use separate motions for each. Fröhlich et al. (2006) describe an elegant solution for indirect 6DOF input to a 3D virtual environment that combines isotonic[1] rotational input with elastic[2] translational input into one input device. Some techniques have been suggested that use multiple 2DOF input devices (e.g. mice) to control 6DOF (Zeleznik et al., 1997; Bowman et al., 2005), but little attention has been paid to how these techniques might transfer to control of artifacts on a digital table.

In my research, I will explore several alternatives for interacting with artifacts on a digital table using only surface interactions. In order to provide a technique that allows for true direct input – a superimposed display space and control space – I will limit interaction to 5DOF instead of 6DOF (i.e. provide no movement in or out of the table). Appendix A describes the first steps of this exploration.

### 1.1.3 Collaboration & Awareness

In distributed groups, workspace awareness – "the up-to-the-moment understanding of another persons interaction with the shared workspace" (Gutwin and Greenberg, 2002, p. 417) – has been the subject of many discussions. This awareness information is typically described as being an issue for design due to the lack of support for this awareness in most distributed groupware. However, this awareness information is also an important aspect to consider when designing technology in a co-located setting. Because it is possible (and sometimes recommended) to use "magical" behaviour with technology, such as teleporting, x-ray, and reaching from a distance (Shneiderman, 2003), providing awareness to others does not come for free at tabletop displays either. For example, if one person at a table is able to move an object by moving a mouse in his or her lap, another person observing that motion may be confused about its cause. In designing appropriate interfaces for 3D on a digital table, my work will largely consider how multiple people can interact in a way that supports awareness within the co-located group.

Gutwin and Greenberg (2000) also describe the mechanics of collaboration – the low-level elements required to support coordination and communication in groups. Rodden (1996) describes awareness as the intersection of the focus (the area where attention is being paid) and nimbus (the area where information is being provided) of two or more members of a group and thus describes a mathematical model of awareness. Scott et al. (2003) also provide specific guidelines for the support of co-located collaboration at tabletop displays. This background work will help to inform my designs and to evaluate their viability in the tabletop domain.

[1] Isotonic devices require a constant (usually small) force (e.g. a mouse or trackball).
[2] Elastic devices require a force that increases with distance.

### 1.1.4 Existing 3D Tabletop Interfaces

There are some examples of applications that attempt to provide 3D visuals in the co-located setting of a tabletop display. Ståhl et al. (2002) created a music browsing system that uses a pond metaphor to have objects float to the surface or sink to the bottom. However, the third dimension of movement and rotations about the x- or y-axes are not controllable by users. The IllusionHole (Nakashima et al., 2005; Kitamura et al., 2001) and the two-user responsive workbench (Agrawala et al., 1997) allow for 3D stereoscopic viewing of artifacts at a tabletop display by two or more users. However, these systems all require the use of a head tracker or head-mounted display and so impede the ability to establish eye contact and thus tend to inhibit collaboration. The Lumisight table (Matsushita et al., 2004) also provides the ability to present four unique images to four different people at the same table without the need for headwear, and so could provide a consistent 3D projection for multiple people at a table. However, they did not specifically explore the use of 3D and issues such as pointing inconsistencies may arise in such a system.

In my research, I will explore the use of various 3D projections onto the 2D table surface and evaluate whether multiple people can establish a common understanding of the 3D virtual environment presented to them. My work differs from the use of 3D simply as a metaphor (such as in the Pond system) in that full 3D rotations of the artifacts will be provided. I will focus specifically on whether this interaction in combination with various visual feedback alternatives can allow embodied interaction and what effect this will have on collaboration.

## 1.2 Research Context

The specific area of research that this dissertation will address is *3D tabletop display interaction*. Figure 1 shows how this research fits across the boundary of two broader areas: human-computer interaction and graphics & perception. The area inside human-computer interaction can be narrowed down from computer-supported cooperative work into co-located collaboration. More specifically, my focus is on tabletop display environments. The broad area of graphics & perception can be further narrowed to 3D graphics & depth cues.

My research will attempt to bridge these two areas of research with specific consideration to the idea of *embodied interaction* (Dourish, 2001). I will demonstrate my work by developing an interface specifically targeted to address the needs of planning on a tabletop display.

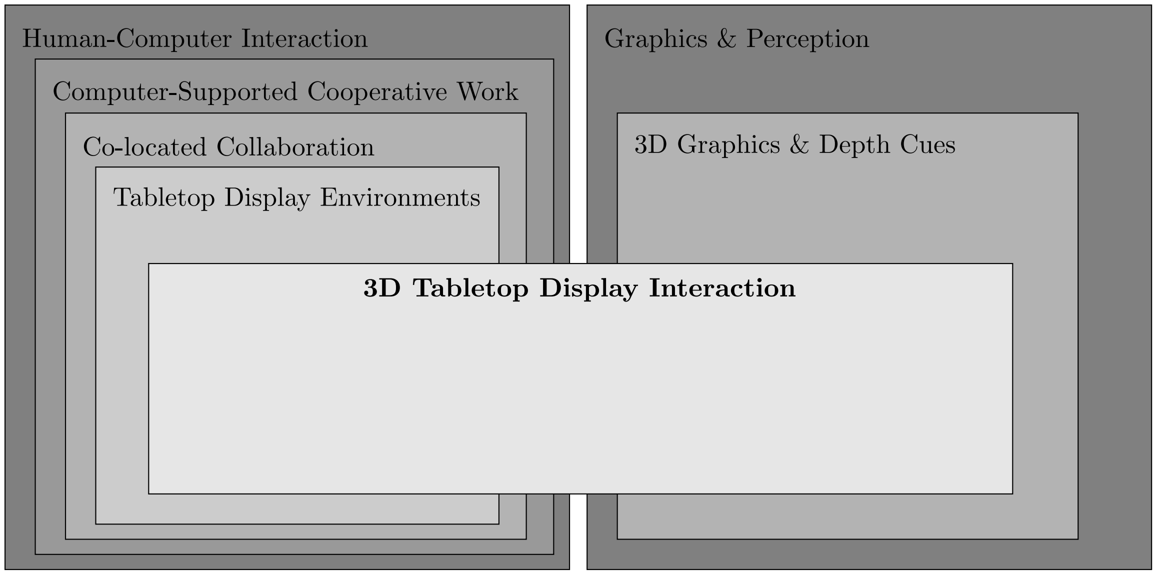


Figure 1: The context of my research.

## 1.3 Problems

**Can multiple people share the same 3D display, despite having different viewing angles?**

Tabletop displays afford walking around and viewing from multiple different locations. When many people are collaborating around the same shared display, different people will each have a unique viewpoint. Because 3D projections onto a 2D surface typically require an assumption about the location of the viewer's eye, there may be a consistency problem when the same display is used for multiple viewers.

It has been noted that 3D perspective projections are particularly robust to off-axis viewing (e.g. Zeeman's Paradox (Dixon, 1991, p. 82)). Thus, it is likely that multiple viewers would be able to each make sense of such a projection, despite their unique viewpoint, however, the image that each viewer sees may be inconsistent with that of their collaborators. Pointing may become more difficult and expectations about (for example) which side of an artifact other people can see may be confusing. This confusion may lead to difficulties in coordinating actions and communicating intention. It is an open question whether or not it would be possible to create a 3D tabletop interface that can overcome this inconsistency.

### Can the freedoms of 3D interaction be made available through only surface interactions on the table?

When people collaborate around traditional tables, they have the freedom to pick objects up, rotate them around and manipulate them in ways limited only by the laws of physics. The use of these freedoms has a wide variety of purposes. People frequently stack objects to store or save space, people flip objects to observe other features or to make use of the flipside (e.g. of paper), and they often use the orientation of objects to coordinate and communicate with others in the environment (Kruger et al., 2003).

When moving to a digital world, artifacts that are displayed on the 2D surface do not inherently have the same freedom of movement. Typically, input devices only allow interaction at the surface of the table and usually with a limited number of contact points (e.g. (Dietz and Leigh, 2001)). The design of how to map these limited surface interactions to artifact manipulation in the virtual environment, therefore, has a long way to go before reaching the complexity of interaction available with physical objects. It is an open question whether or not the freedoms normally available to people can be leveraged in the virtual world.

### Can an environment be built that allows embodied interaction with 3D virtual objects on a table?

It has been shown that a tabletop environment can enrich interaction when tangible media is used (Underkoffler and Ishii, 1999). Dourish (2001) argues that this system is particularly successful because it enables embodied interaction. With physical objects and tangible media, people are able to establish physical contact and make use of artifacts as tools, instead of as objects of enquiry.

On tables with a projected digital display, it is possible to create virtual renditions of artifacts that are perceptually similar to physical objects. If it is possible to control 3D artifacts with surface interactions (discussed in the previous problem), it may be possible to make such virtual artifacts interactive. It is an open question as to whether this combination of realistic visuals with realistic interaction would allow embodied interaction with virtual objects on a digital table.

## 1.4 Objectives

**Design and evaluate various 3D projections suitable for multiple people around a tabletop display.**

In order to address the problem of each person around the table having a different and possibly inconsistent perspective of the 3D projection, I will design various projection solutions and run an empirical study to determine the efficacy of each. The projections that will be compared include (but are not necessarily limited to):

*Standard Perspective* – As a baseline, I will include the standard perspective projection used in most 3D applications and games.

*Orthographic* – Studies have shown that the skew introduced by off-axis viewing can be somewhat alleviated by using a "near-orthographic" projection (Ware, 2004). I will include a fully orthographic case to verify this result and explore how this benefit might affect inconsistency between different viewpoints.

*Stitched Perspective* – I will explore the use of a stitched perspective rendering (Singh, 2002) to see if a "correct" perspective for closer digital artifacts with a greater skew as proximity decreases might benefit a person's ability to recognize the inconsistency and to perhaps better cope with it.

*Perspective Lenses* – I will explore the use of a user-controlled perspective rendering. That is, each person at the table will be able to specify camera locations and degrees of influence of these cameras to provide (multiple) perspective cues under their control.

I will also explore the presence or absence of various other 3D depth cues, including shading and shadows. Thus the factors in my study will be:

- *Projection* - perspective, orthographic, stitched, lenses
- *Shadows* - present, absent
- *Shading* - present, absent

The tasks in this study are not yet defined, but will likely involve multiple simultaneous participants performing one or more tasks that require interaction with several 3D artifacts on the table. Dependent measures of time, accuracy, and preference will be analyzed and video analysis will be performed to determine more difficult-to-measure elements, such as communication and coordination.

**Design and evaluate a usable interaction technique for manipulating 3D objects on the table's surface.**

I am already nearing completion of this objective. I have conducted and analysed a user study, details of which are provided in Appendix A. In this study, I designed several alternatives for manipulating 3D digital artifacts on a tabletop display and provided an empirical evaluation to compare these techniques. The techniques allow interaction with one, two, or three points of contact on the surface of a DiamondTouch input device (Dietz and Leigh, 2001) with a top-projected display. Participants performed three tasks designed to explore the use of these techniques in a simulated collaborative task, a precise docking task, and a semi-realistic puzzle task. I analyzed task completion times, incomplete trials, and preference. I also collected data about how the techniques are used, including where the participants tended to "touch" the artifacts.

The results of this study indicated the superiority of the two- and three-touch techniques, which I now intend to compare to a tangible alternative. That is, I intend to create a task that can be completed with both virtual and physical artifacts to compare performance. I expect that the results will indicate that physical artifact manipulation is easier and faster, but that virtual artifact manipulation is a viable alternative. Specifically, this study will illustrate and quantify the gap between the two.

**Integrate the 3D manipulation and the appropriate projection for a specific task case.**

Once the above two objectives have been completed, I will attempt to integrate appropriate 3D interaction with appropriate 3D visuals on a digital table to demonstrate the viability of 3D in this domain. In particular, I intend to demonstrate that tangible media can be simulated in a 3D virtual tabletop environment by creating a system equivalent to Urp (Underkoffler and Ishii, 1999). In particular, I will create a system that allows 3D virtual buildings to be manipulated using the iteratively designed interaction techniques within a projection that is determined to be suitable for collaborative viewing. These buildings can be placed in an urban planning environment to create shadows and demonstrate effects of wind. With this system, I intend to demonstrate that embodied interaction is possible with virtual artifacts and that careful design of both interaction and feedback is key to enabling embodied interaction.

## 1.5 Current Status

At this point, I have completed the empirical study described in my second objective. This evaluation has been submitted to the premiere Human-Computer Interaction conference (see Appendix A). I have already had a chance to see the reviews during a rebuttal period, all of which were highly positive and I would say that it is extremely likely that this paper will be accepted. I have also done an extensive literature review in preparation for the other two objectives and have begun the design of the experiment described in the first objective.

## 1.6 Timeline

The following timeline shows my current plan for completion of each objective and includes time required for the writing of my dissertation. I have already completed the 3D technique study and the in-depth literature review. In the Winter 2007 semester, I will design and implement projection alternatives and evaluate these alternatives in a user study the following summer. I will likely submit a paper to *CHI 2008* in September of 2007 that includes this user study and the results of the analysis. In the Fall 2007 semester, I will develop a complete 3D tabletop environment to demonstrate embodied interaction in this domain. I will then write my dissertation in the following two semesters, with the intention of defending my thesis in August of 2008.

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| **Summer 2006** | 3D Technique Study |
| **Oct/Nov 2006** | In-Depth Literature Review |
| **Winter 2007** | Design & Implement Projection Alternatives |
| **Summer 2007** | Projection Comparison Study |
| **Fall 2007** | Build 3D Environment (e.g. “Virtual Urp”) |
| **Winter/Summer 2008** | Thesis Writing |
| **Aug 2008** | Thesis Defense |

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# Appendix A CHI 2007 Submission

Hancock, M., Carpendale S., Cockburn, A. (2007). Shallow-depth 3D interaction: Design and evaluation of one-, two- and three-touch techniques. Submitted to *CHI 2007*.