

**REACHing**  
Exploring Bimanual Spatial Interfaces

**Alina Podkolinska**  
BFA Sculpture  
University of Calgary, Canada  
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*The reasonable man adapts himself to the world: the unreasonable one persists in trying to adapt the world to himself. Therefore all progress depends on the unreasonable man.*

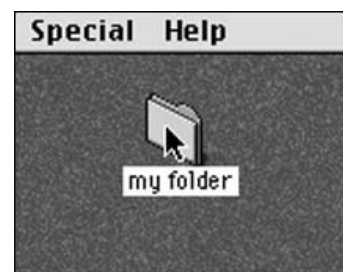
George Bernard Shaw

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## INTRODUCTION

Computers do not know that users have two hands, nor that users can produce two continuous actions at the same time. The current paradigm for GUI (graphical user interface) design has been called the WIMP (Windows, Icons, Menus, Pointer) interface. These techniques of interacting with the system were necessary due to the natural limitations present during the early stages of this evolving technology. Considering the current acceleration in computer technology, it is hard to ignore that while our computers are getting faster, interaction techniques have not evolved in over 50 years. To get past this *plateau* of the WIMP interface, it is necessary to not just deliver a new metaphor for interactivity, but to break through the current constraints of the input devices and take advantage of the natural human capability to interact with the computer. With this paper, I intend to define current interaction techniques by focusing on spatial input through bimanual input devices.



## MOTIVATION

The impetus for this paper is my interest in constructing a device that would follow, and hopefully expand on, the thinking of notable contributors in this profession. As a first step towards constructing this device, I need to compile a comprehensive listing of related ideas in this field. Through this research I plan to develop a manifesto that will serve as a set of principles in the development of my thesis project. While it is absolutely necessary to admit that all devices have their strengths and weaknesses, it is necessary to acknowledge that anything that I create as a departure point from findings in this paper will also exhibit

such constraints. Nevertheless, I believe the bigger issue is in the identification of the application demands and the tailoring of the relevant dimensions within which the user might benefit the most.

## **RESEARCH AND CONTEXT**

This research is broken up into two sections. Section one focuses on two-handed interfaces and section two looks more broadly at current examples of what has been developed across the industry. Although one may seem a subset of another, it was necessary to make this division to allow us to focus on certain empirical studies and theories versus practical applications of this topic. This paper draws information from a large body of work, of which the primary contributors are Bill Buxton, Scott MacKenzie and Yves Guiard. The focus of this paper is to identify key issues and amalgamate information from this ever expanding manifest of design considerations in the development of two-handed spatial apparatuses.

In researching input devices, one must confine the survey to a limited scope of human interaction. Two-handed input is certainly not a new topic. While two hands are used in typing, this is a single task made up of discrete actions and it does not reflect more continuous actions in everyday life. A good example of two-handed interaction is the use of function keys that are depressed during the continuous input of a mouse; this is now often seen in CAD related activities. Some of the most prevalent examples of two-handed interaction are joysticks and other video game controllers that require, just like the mouse and function keys, continuous and discrete actions. Those actions are broken down to the left hand having the control of a character on the screen and its orientation, while the right hand is in charge of more complicated tasks such as: switching weapons, focusing on enemies, and coordinating with other characters on screen. Such tasks require good coordination between the two hands. Unfortunately this is where the venture ends in mainstream products.

Spatial interfaces are not sought out, or even known of, by everyday users. One reason has to do with the high cost of such devices, with some designs starting at two-thousand dollars. Other issues related to this paucity of options for the general consumer, include the lack of well developed application, the lack of

knowledge in software development regarding when such attributes might provide necessary or desirable benefits to end-users.

When discussing input, we must also touch upon output. By output, we refer to the sensations and forces that the device applies to the user. This output can be observed through the physical sensations a user is experiencing during the use of the device. Its shape, material it is made from, weight, and ergonomics must not be undervalued in design. Additional to the passive characteristics of the design of the device, some devices offer an extended feedback, such as forced-feedback on special joysticks and gloves. As a general rule it is the suitability of the device to the designated output that makes the experience a rich event. It is important for this paper to study human behavior and learning patterns, rather the technology behind the interfaces.

## TWO-HANDED INTERFACES

To study two-handed input, one can analyze the tasks performed everyday. Looking at a painting, reading, writing, and driving a car, are examples of the human ability to coordinate actions of their hands in different situations.

All manual hand activities can be classified in one of three categories (Guiard, 1987):

- *Asymmetric (or unimanual)*. For example brushing one's teeth or throwing a dart.
- *Symmetric bimanual*. Both hands playing the same role, either in phase or out of phase. For example weightlifting and swimming.
- *Asymmetric bimanual*. Hands playing different roles in the same task. For example playing a guitar or shooting an arrow.



In 1986, Buxton and Myers experimented to show benefits of two-handed interactions. They performed two experiments. One experiment involved position-scaling and the other on a navigation-selection task. Both took advantage of two hands involved in continuous motion during the task, either parallel or sequentially. The position-scaling experiment involved the left

hand in scaling an object and the right hand was employed in moving the object. Although the users where

not told that the actions could be performed in parallel, the results showed that all subjects except one did perform certain aspects of the task simultaneously. This led the team to conclude that the additional cognitive load was not hindered by the application of the two-handed input. The second experiment involved scrolling a simple piece of text while selecting passages from it. The experiments were performed with both unimanual and bimanual techniques. In the bimanual trials, a custom, one-dimensional, mouse was placed in the left hand while the right hand used a two-dimensional mouse to highlight text on screen. The results showed that the bimanual results were faster as there was no switching of task required of the user to attain the goal (Buxton and Myers, 1986).

Dillion, Edey and Tombaugh published a similar paper in 1990 regarding their experiments in two-handed interaction. The study used the standard GUI as they compared a single cursor method of menu and task manipulation to a method involving dual cursors. The team found no significant improvement in bimanual action in this setup (Dillion et al., 1990).



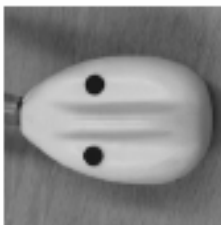
From the contradictory views presented in these studies; one must conclude that the direct task to input is dependent for successful interaction. Nevertheless, Buxton and Myers made the most significant contribution in proving that bimanual interaction does not significantly affect cognitive load. Dillion et al. were faced with the classic bimanual conflict: rub your stomach while tapping your head. Leganchuk et al. in 1998, describe that the difficulty lies in the polyrhythm of the two tasks, where the rhythms are not multiples of one another. Only a skilled musician, such as a violinist, may reproduce rhythms with the ratio of 5:3 with rigorous training. The complexity is only intensified when the actions are parallel (8).

The most comprehensive study into bimanual skill as applied to HCI has been by Guiard in 1987 with his definition of the *kinematic chain theory* (KC). According to this model, both the left and the right hand act

as links in a chain, where the left is the base and the right is the terminal point in the chain. This theory fundamentally stems from the assumption that hands are cooperative and asymmetrical in nature. His four basic properties follow (5):

1. *The non-dominant hand determines the frame of action of the dominant hand.* Two examples are holding a piece of paper you are writing on, holding a bowl of soup you are eating.
2. *The sequence of action is non-dominant, then dominant.* An example is moving dirt in the potting planter before you place the plant.
3. *The action of the non-dominant is coarse, relative to the fine action of the dominant hand.* This can be seen in all the examples, as the accuracy of the non-dominant hand does not have to be as accurate as the right hand.
4. *Right-hand is dominant.* Because the right hand is the terminal link in the chain it has controls over finer and concluding functions.

If we are to truly exploit all the possibilities of asymmetrical, bimanual actions, we must utilize these characteristics as a guide to designing input interfaces. One such example can be seen in Buxton's *MacPaint*, where a user wants to continue painting beyond the scope of the screen. Here Buxton repeats his previous experiment with Myers by adding a second dimension. While the task sequence in the current system requires a user to change the tool to the "hand" cursor and scroll the virtual paper, the proposed system allows the user to utilize both hands. Instead of interrupting the paint action, she can use a trackball in the non-dominant hand to scroll to the wanted area without the interruption of the creative flow.



Another such example can be found in 3D interfaces with an experimental device called the *Frog*, by Maarten W. Gribnau and James M. Hennessey. It is composed of two symmetrical hand-held devices (Frogs) that can manipulate objects in space through the 6 degrees-of-freedom sensor that is embedded in the device.

The test program of this input device presents itself with a 3D cursor. The dominant hand manipulates the cursor on the screen and the non-dominant hand manipulates the screen's pan, zoom and rotation. Pressing any of the small buttons on the dominant Frog makes a single selection, while pressing and moving, the *Frog* allows creation of a bounding box for the selection of multiple

objects. The experiment in this paper tested whether a one-handed versus a two-handed interface improved the speed of object movement within the test area. Their findings were that the speed of the task was only improved by 17.5% with bimanual input (Gribnau and Hennessey, 1997).

The validity of bimanual tasks within any environment can only be measured if the bimanual action of the non-dominant hand can be defined to encompass the action of the dominant hand or somehow scaled. To relate their experiment to a real-life situation, we can imagine a piece of paper with a cube positioned in the center. If we were to peel the stickers from each side of the cube, it is naturally implied that we would pick up the cube to do so rather than moving the paper around to reposition the cube in our environment.

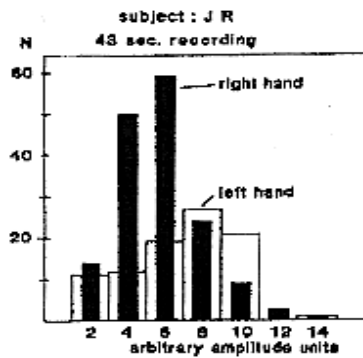


While Guiard talks about the spatial reference, he also successfully redefines our idea of hand dominance by breaking down the understanding of preference. It is accepted that the right hand, in a right-handed person, is capable of producing



finer tasks in both accuracy and timing, but that the left maintains a postural role. Guiard defines those roles as *micrometric* and *macrometric*, rather than dominant and non-dominant, respectively. The global view of hand preference is triggered by the fact that there is an assumption of specializations and that hands are completely complimentary. Guiard therefore concludes that there is no necessity to assume the superiority of a micrometric device over a macrometric device just like one would never conclude that a microscope is superior to a telescope. The conclusion is that this inequality of action enables function that is superior to an individual performance (15).

To support this view a simple experiment was conducted that was unpublished during the writing of Guiard's paper. All right-handed subjects were requested to produce a square on a monitor with a cursor by the use of an unusual input device. The device consisted of two potentiometers, one controlling the x-



axis and the other one controlling the y-axis of the cursor. The subjects moved the cursor on the screen in unpredictable manners while a polygraph served to record the motion produced by the two knobs. It is worth noting in the graph that the right hand generally produced smaller movements than did the left and that the common working period was greater for the right than left hand. Therefore it can

not be disputed that the right hand tended to produce oscillations that were not only faster than the right hand but also covered less space which supports the theory that the hands are used to moving at different scales (18).

It is the view of Leganchuk et al. that while Guiard's KC theory of bimanual action offers a helpful framework for the design of two-handed interfaces; it does not touch upon the benefits of bimanual input. They propose that the idea of chunking is the reason for the ease of cognitive skill acquisition. Chunking was well defined in the study by Card et al. in 1980, "Composed of highly integrated submethods (or subroutines) that show up over and over again in different methods" (2). A common example in the GUI is when the user wants to access the menu and knows to press on the menu bar over the item and then moves the cursor down to the desired submenu item and clicks again. Such a task is repeated for accessing any menu item. In response, Buxton claims that the key to success in learning a motion language in any interaction must be followed and reinforced at the cognitive chunking level. He suggests that those two notions act as adhesive between muscular tension and the continuity of motion. Therefore all tasks that are cognitively chunked should also be physically chunked into one motion, or physical phrase (Buxton and Myers, 1987).

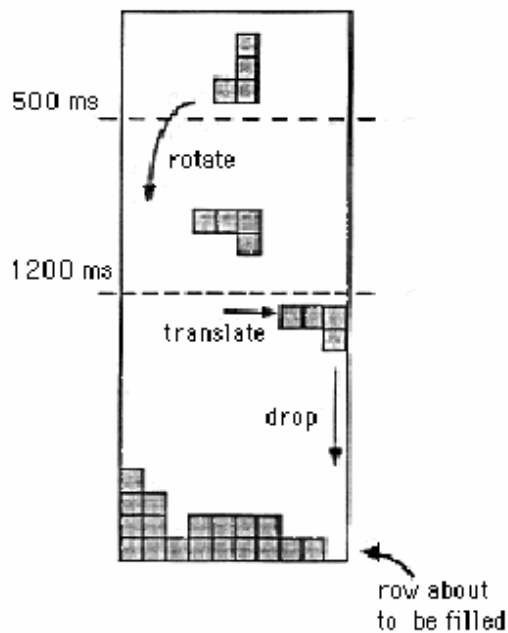
Owen et al. in 1998, made the following observations related to chunking that may allow bimanual interfaces to correspond more with familiar, everyday activities resulting in higher interrelated cognitive advantages (5):

1. *Reduce and externalize the load of planning/visualization in unimanual input. Because two-handed input allows the user to treat the task as a larger and more natural gestalt, the user no longer needs to compose, “think”, and plan the elemental steps of a task.*
2. *Rapid feedback of manipulation results in a higher level of task: the user immediately sees the result of action in relation to the goal state.*
3. *Support epistemic action: the user may take advantage of the two-handed input and perform action of an epistemic nature in addition to those of a pragmatic nature*

As the action of chunking reduces our interaction with segments, it is also necessary to look at how promoting the active epistemic nature of our brain, increases our ability to comprehend certain actions. Kirsh and Maglio in 1994 emphasized that motor activity can be classified as either epistemic or pragmatic action. Epistemic actions are performed to uncover information that is hidden or hard to compute mentally. Such actions may include looking at our fingers when we count or, when playing checkers, moving a piece to evaluate its action on the playing board. Fitzmaurice (1996) concluded that epistemic actions could improve cognition by (12):

- *reducing the memory involved in mental computation (space complexity)*
- *reducing the number of steps in mental computation (time complexity)*
- *reducing the probability of error of mental computation (unreliability)*

In contrast, pragmatic actions are physical movements that ultimately allow us to reach our goal. While it can be argued that all actions can be considered pragmatic as they serve a means to an end, it has been shown that novice users benefit from moving checkers on the board, and while this activity may be wasteful from a motor perspective; from a cognitive perspective, it can be very useful.



An experiment by Kirsh and Maglio in 1994 shows a rigorous distinction between the epistemic and pragmatic actions during the game of Tetris. It was revealed in the trials that the participants would prefer to physically rotate the falling pieces during game play by pressing a button, which took less than 150 ms, rather than computing mentally the rotation of the piece which took 800 to 1200 ms. In addition, this epistemic action revealed information that would not be otherwise available to the player such as: (1) reveal new information early in the game, (2) save mental effort, (3) facilitate retrieval of shapes of pieces from memory, (4) make it easier to identify a piece's type, and (5) simplify the matching process of the falling piece with the contour below. It is a concluding remark by the researchers that, "it takes effort to physically modify and re-perceive the external world than it does to compute and retain the new information state internally" (Kirsh and Maglio, 1994).

Kirsh has also said that how we manage the special arrangement of items around us is not an afterthought; it is an integral part of the way we think, plan and behave (Kirsh, 1995). Therefore an intelligent use of space comes into play in bimanual functions. He has also defined the most basic rules in special arrangement: (1) simplify choice, (2) simplify perception and (3) simplify internal computation. He also states that people constantly rearrange items to make it easier to: (1) track the state of the task, (2) figure out, remember, or notice the properties signaling what to do next, and (3) predict the effects of actions. This can be illustrated in any situation where many things must be executed at the same time while they are in different stages of the same process. For example a while cooking different parts of a meal, we may gather all the groceries together for each dish. As we continue to cook we may take out other necessary things such as stencils or machines to mark their order of use (7).

Gibson defines *affordances* as how to use something. It is imperative that we consider affordances related to objects, such as how a large hole at the tip of a bottle opener promotes how it can be used. Yet it is also necessary to talk about affordances as relating to situations. Just like chunking can aid in the relations to situations, spatial arrangement can contribute or hinder the operations of any design. Gibson relates spatial arrangement to three possible outcomes: (1) constraining affordances by hiding, (2) cueing the user by highlighting affordances, or (3) providing a setup of order in the action.

There are a variety of strategies for the spatial arrangement of control devices in the workspace (Sanders and McCormick, 1987). Such arrangements include:

- *importance* – arrange items based on the degree to which the activity of using the item is essential to the overall goal of the user.
- *frequency of use* – arrange items which are more commonly used together near each other.
- *functional* – group items base on their function.
- *sequence-of-use* – arrange items based on the pattern of usage so that the user can take advantage of it.

Whether our goal is to limit or enhance our involvement with the computer, we must carefully tailor our needs to our possibilities in tune with what our bodies and minds can achieve. The exploration of what our bodies are capable of runs parallel with learning how we, as humans, learn and solve problems. Posing a solution to these problems can elevate our possibilities above the shallow understanding of ourselves within the field of human-computer interaction.

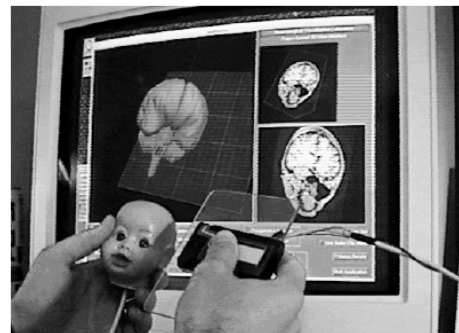
## **SPATIAL INPUT**

The term *spatial input* refers to interface devices that operate in free space such as camera-based or magnetic trackers, as opposed to desktop devices such as 3D mice or the Spaceball. Previous work done in this field had been classified into two categories: Application specific tasks for users with specialized needs and generic research into isolated tasks. It is not yet known how to start bridging the gap between these two acts, but Ken Hinckey, Randy Pausch, John Goble, and Neal Kassell have put together a document outlining the most critical points in general spatial development:

1. *Understanding three-dimensional space vs. experiencing three-dimensional space*
  - *Spatial reference*
  - *Relative gesture vs. absolute gesture*
  - *Two-handed interaction*
  - *Multi-sensory feedback*
  - *Physical constraints*
  - *Head tracking techniques*
2. *User perception of multidimensional tasks: related vs. independent input dimension*
  - *Extraneous degrees of freedom*
3. *Control metaphors*
  - *Eyeball-in-hand*
  - *Scene-in-hand*
  - *Flying vehicle control*
  - *Ray casting metaphor*
5. *Issues in dynamic target acquisition*
  - *Use of transparency*
  - *Ray casting vs. direct positioning in 3D*
  - *Cone casting vs. Ray Casting*
6. *Recalibration mechanisms*
  - *Command-based*
  - *Ratcheting*
  - *Continuous*
7. *Multiple degrees of freedom input in coarse positioning tasks vs. precise positioning tasks*
8. *Dynamics and size of the working volume of the user's hands*
9. *Use of mice and keyboards in combination with the free-space input devices*
10. *Clutching mechanism*
11. *Importance of ergonomics in special interfaces*

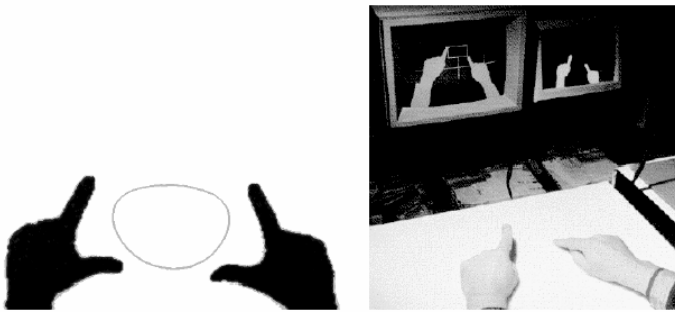
While this is not an exhaustive list, the following examples can be observed through what can only be guidelines in such an extensive field. Understanding why interaction techniques do or do not work requires the observation of numerous techniques, processes, and methodologies. While many designs have surfaced as the new post-WIMP interface, non have, so far, been a successful solution to all the challenges we face, but have often been targeted towards specialized interfaces and devices.

Hinckley et al., in 1994, designed a 3D, two-handed input system using *props* with embedded sensors. In order for neurosurgeons to specify a slice of the brain data to view, the user controlled two props, a doll's head and a cutting plane made of plexiglass. The computer could sense the position and orientation of the props. By placing the plastic sheet on



the doll's head, the surgeon could control what "slice" of the brain was displayed (4).

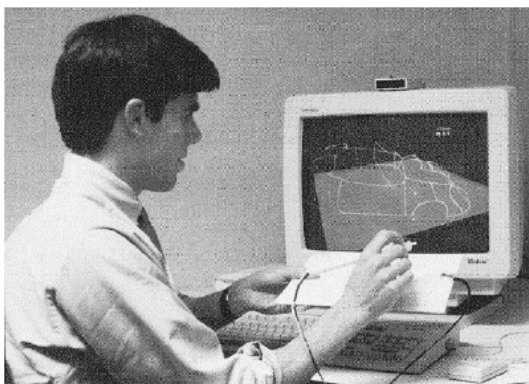
The VIDEODESK system by Krueger (1991) uses video cameras and image processing to track 2D hand position and to detect image features such as hand, finger, and thumb orientation. This approach leads to a



rich vocabulary of simple, self-revealing gestures (such as pointing, dragging, or pinching) that do not require any explicit input device (Krueger 1993). For example, the index finger and thumb of both hands

can be used to simultaneously manipulate four control points along a spline curve, or the fingertips can be used to sweep out a rectangle.

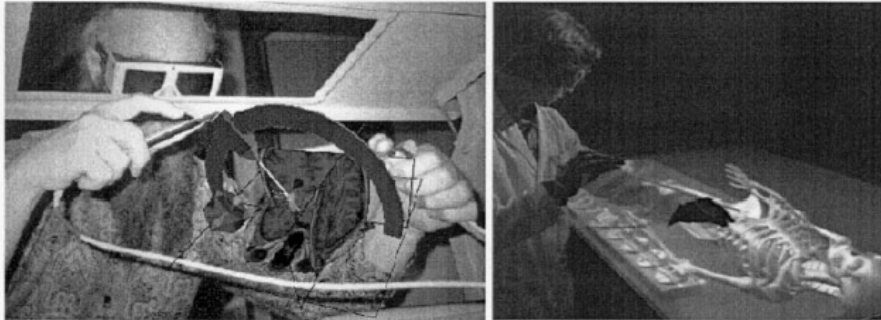
The ToolGlass and Magic Lenses metaphor by Bier et al. (1993) consists of a semitransparent menu that the user superimposes upon a target using a trackball in the non-dominant hand. The dominant hand then moves the mouse cursor to the mark and clicks through the menu to apply an operation to the object. Note that this integrates the task of selecting a command from the menu and the task of applying that command to objects being edited.



The 3-Draw system is a computer-aided design tool which facilitates the drawing of 3D curves by Sachs et al. (1991). In 3-Draw the user holds a stylus in one hand and a custom tablet in the other. The user is able to move, pan, and rotate the view of the object being sketched. The tablet represents a 3D floor of the designed 3D model which is seen on a desktop

monitor. The tablet is used to view the object, while motion of the stylus is used to draw and edit the curves making up the object.

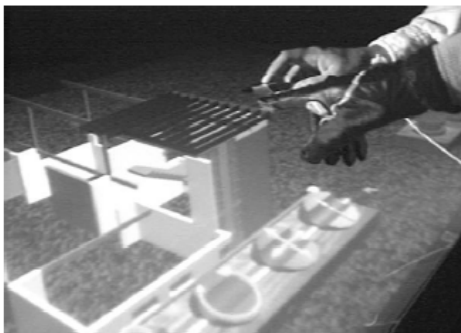
The Virtual Workbench by Poston and Serra (1996) displays 3D images on an opaque mirror in front of the user's face. Since the mirror is opaque, the images are completely computer generated, allowing correct occlusion cues to be maintained. The Virtual Workbench employs both hands to move physical tool



handles which can have different virtual effectors attached to them, depending on the current mode.

The Virtual

Workbench has been developed with medical applications in mind (such as Hinkley), including support for tasks of interest in neurosurgical visualization, such as cross-sectioning a volume. Poston and Serra have not, however, performed any formal experimental evaluation of the design issues raised by the Virtual Workbench.



The Responsive Workbench by Cutler et al. (1997) provides two-handed manipulation on a stereoscopic, rear-projected tabletop VR display. The tabletop provides a natural working surface. Examples of two-handed interaction techniques supported by the system include two-handed zooming, where the non-dominant hand sets a focus point, while the dominant

hand moves back and forth to zoom; rotation about an axis, where the non-dominant hand specifies the axis of rotation, while the preferred hand performs the rotation; and “steering wheel” rotation, where both hands grab the model and twirl it.

Two-handed input seems to be suitable for a wide range of tasks in both 2D and 3D interaction, although it is not clear what tasks are suitable for two-handed input, what input devices are required, or what advantages or limitations two-handed input might offer to the user. Using two hands for three-dimensional interaction is not in itself a new idea, but there are so few examples of such systems that the implementation and user interface design issues are still not well understood. While a handful of experimental studies have been performed, to my knowledge no studies prior to this work specifically address two-handed interaction in spatial 3D. Such studies are needed to identify when and why two-handed interaction techniques should be considered, as well as to quantify human two-handed abilities, so that user interfaces that do incorporate two-handed interaction can be designed to match the underlying human skill.

## **CONCLUSION**

The current design of the dominant input method is over half a century old. The limitations of this method of input are needlessly limiting the development of new methods of user interface design. Much research has been conducted regarding how human beings manually interact with the world; some of this research has been reviewed in this paper. Theories and designs related to hand dominance, three dimensional space representation, and task classification will all come into play in designing a superior method of input to the currently ubiquitous mouse. Areas requiring further experimental analysis include the affect of bimanual interaction with three dimensional spatial representations.

While this paper outlines certain considerations one must consider as it is extremely hard to formulate a method for successful interaction. It is the in pure balance of human needs and wants; we can search for the true appreciation of an immersive experience. Both input and output must be considered in all cases. There is no such thing as a tool for every need.

The following is a list of things that should be considered, studies and carefully tested in the wake of creating bimanual spatial interfaces:

Unimanual vs. Bimanual  
Symmetrical vs. Asymmetrical  
Polyrhythm  
Sequential/Parallel Actions  
Kinematic Chain Theory  
Dominant vs. Non-Dominant  
Micrometric vs. Macrometric  
Chunking  
Epistemic vs. Pragmatic Action  
Affordances

The list by Hinckley et al. should also be consulted as a way to identify essential tasks with input and output scenarios.

Before I continue with my current thesis project I would like to explore how these facts affect my design. While I believe that I have all the necessary information to start development on the device itself, how it will be used still requires careful planning and consideration. I will be looking into gaming and game design to further my work.

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