Revisiting Haptic Issues for Virtual Manipulation

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POSITION STATEMENT

In efforts to develop interaction techniques for virtual environments which are extremely flexible and versatile, manipulation in virtual reality has focused heavily on visual feedback techniques (such as highlighting objects when the selection cursor passes through them) and generic input devices (such as the glove).

Such virtual manipulations lack many qualities of physical manipulation of objects in the real world which users might expect or which users might unconsciously depend upon. For example, in the case of selecting a virtual object using a glove, the user must visually attend to the object (watch for it to become highlighted) before selecting it. But what if the user's attention is needed elsewhere? What if the user is monitoring an animation and is just trying to pick up a tool?

We believe that designers of virtual environments can take better advantage of human motor, proprioceptive, and haptic capabilities without necessarily giving up flexibility and versatility. In support of this statement, we present our experiences with two systems, the two-handed props interface for neurosurgical visualization [2] and with the Worlds in Miniature (WIM) metaphor [6].

Mechanics of Manipulation: Props

In conjunction with the Department of Neurosurgery, we have designed a 3D user interface based on the two-handed physical manipulation of hand-held tools, which we call "props" [2]. This interface allows neurosurgeons to explore a 3D scan of a patient's brain during presurgical planning.

From the neurosurgeon's perspective, the interface is analogous to holding a miniature head in one hand which can be "sliced open" or "pointed to" using a cross-sectioning plane or a stylus tool, respectively, held in the other hand. Cross-sectioning a 3D volume, for example, simply requires the surgeon to hold a plastic plate (held in the preferred hand) up to the miniature head (held in the nonpreferred hand) to demonstrate the desired cross-section (*fig. 1*).

Our informal evaluation of over fifty neurosurgeons, and of hundreds of non-physicians, has demonstrated that these interface props facilitate transfer of the user's skills for manipulating tools with two hands to the operation of an interface for visualizing volume data, without training.

For this system, we have clearly chosen props which are tailored to the specific tasks and demands of our user community, that of neurosurgeons. While such application-specific tailoring limits "flexibility" in an academic sense, from a practical standpoint it makes the interface accessible to our users.

The use of props raises many interesting research issues. What features or qualities would a general purpose interaction prop need to be effective, or, alternatively, what would be the minimum set of "props" to span the set of tasks commonly required in virtual manipulation? To what extent must a prop match its visual counterpart? In the worst case, are 3D and virtual environment interfaces prone to be highly task and user-specific?

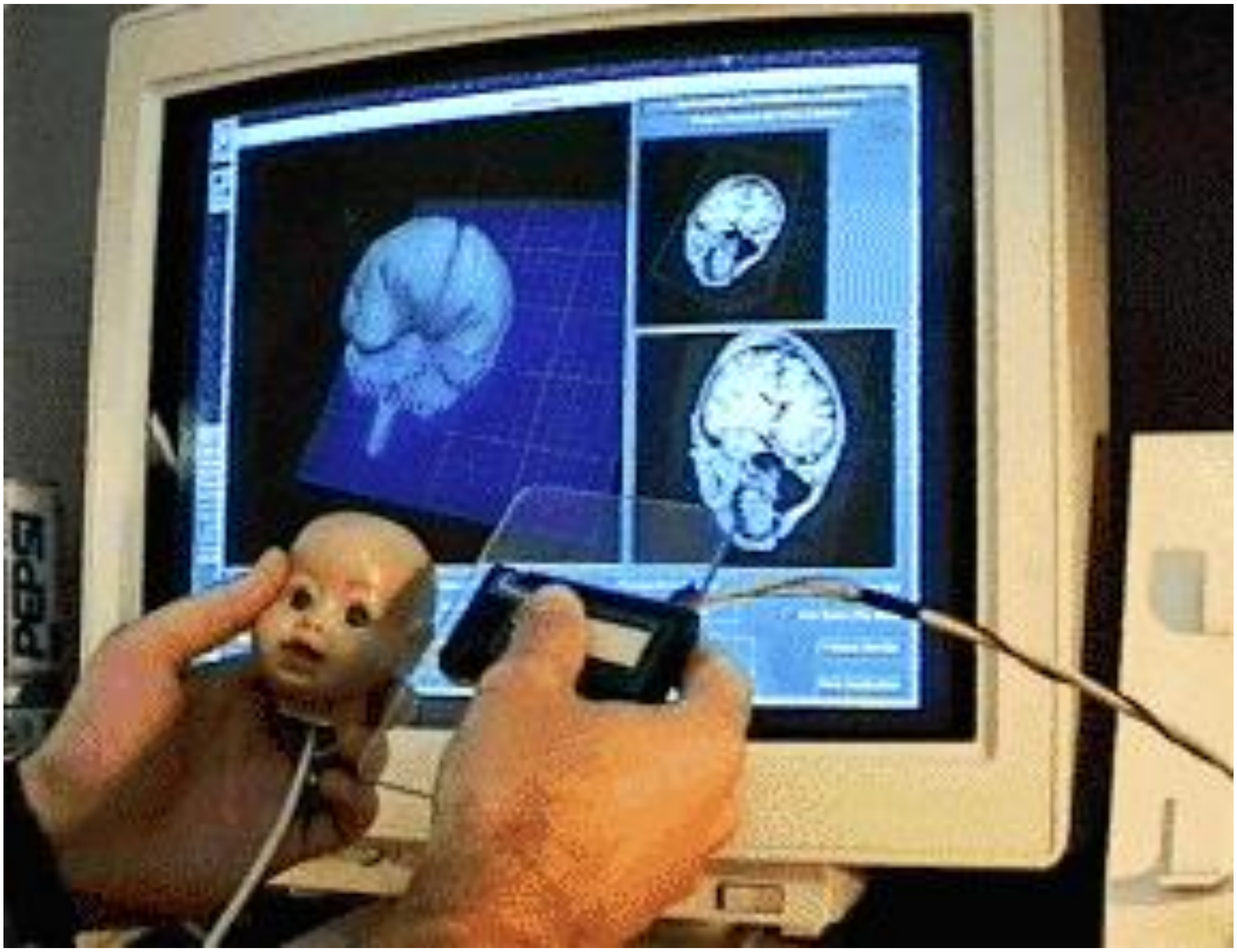

Figure 1: User selecting a cross-sectioning plane using the two-handed props interface for neurosurgical visualization.

Two-handed Interaction

Two-handed input is commonly viewed as a technique which saves time by allowing the user to perform two sub-tasks in parallel. For 3D input, however, we believe two-handed interaction is of far greater importance and has a number of distinct advantages:

- Users can effortlessly move their hands relative to one another, but it requires a conscious effort to move a single hand relative to an abstract 3D space.
- The user can express complex spatial relations as a single cognitive chunk. Users can manipulate our interface props with two hands to specify a cut relative to a particular brain orientation in a single gesture.
- Using both hands takes advantage of the user's existing skills. Most tasks we perform in our everyday lives involve using both hands in asymmetric roles, not one hand in isolation [1]. Guiard's analysis of human skilled bimanual action [1] provides an insightful theoretical model for reasoning about the processes involved in two-handed coordination of motor acts. A key concept of Guiard's model is that the preferred and nonpreferred hands effect an *asymmetric division of labor*. This division of labor allows the hands to perform tasks in unison, with results *superior to that which either hand could achieve by itself*. For example, Guiard reports that "the writing speed of adults is reduced by some 20% when instructions prevent the nonpreferred hand from manipulating the page" [1].

Overcoming Scale: The Worlds in Miniature Metaphor

The literature has claimed many benefits for immersive 3D displays. While VE technology has the potential to give the user a better understanding of the space he or she inhabits, and can improve performance in some tasks [4], it can easily present a virtual world to the user that is just as confusing, limiting and ambiguous as the real world. We have grown accustomed to these real world constraints: things we cannot reach, things hidden from view, and things beyond our sight or behind us. Our VE's need to address these constraints and with respect to these issues be "better" than the real world.

In particular, many VE implementations only give the user one point of view (an all-encompassing, immersive view from within the head mounted display) and a single scale (1:1) at which to operate. A single point of view prohibits the user from gaining a larger context of the environment, and the 1:1 scale in which the user operates puts most of the world out of the user's immediate reach.

We have introduced a user interface technique which augments an immersive head tracked display with a hand-held miniature copy of the virtual environment. We call this the Worlds in Miniature (WIM) metaphor [6]. In addition to the first-person perspective offered by a virtual reality system, a World in Miniature offers a second dynamic viewport onto the virtual environment. Objects may be directly manipulated either through the immersive viewport or through the 3D viewport offered by the WIM.

The WIM interface metaphor provides the user with a hand-held miniature representation of the life-size world (*fig. 2*). The user can now interact with the environment by direct manipulation through either the WIM or the life-size world. Moving an object on the model moves the corresponding life-size representation of that object and vice versa.

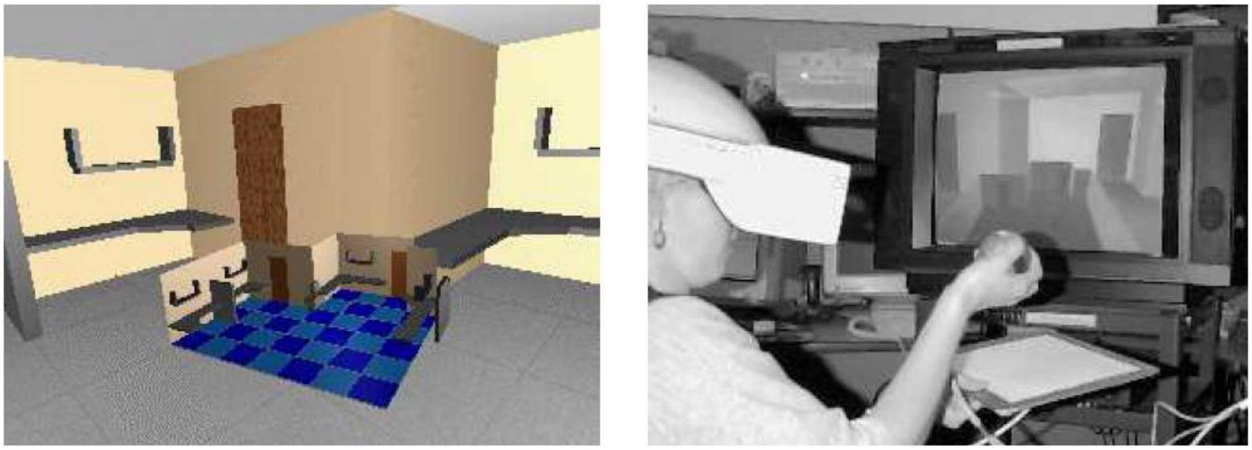

Figure 2: The World-in-Miniature as seen in the head mounted display (LEFT) and a user manipulating the WIM using the clipboard and button ball (RIGHT).

Users interact with the WIM using props and two-handed interaction. The user's non-preferred hand holds a clipboard while the preferred hand holds a ball instrumented with some buttons. By turning the clipboard, the user can view parts of the environment that are obscured from the current line of sight. The ball is used to manipulate objects. Reaching into the WIM with the ball allows manipulation of objects at a distance, while reaching out into the space within arm's reach allows manipulation at 1:1 scale.

We find that the Worlds in Miniature metaphor not only addresses issues of scale and manipulation at a distance, but also acts as a single unifying metaphor for techniques such as object selection, navigation, path planning, and visualization. For example, we have found that by allowing the user to move an iconic representation of himself, the WIM provides an effective technique for navigation while maintaining perceptual and cognitive constancy [5].

Informal observations of hundreds of user trials indicates that users adapt to the Worlds in Miniature metaphor quickly and that physical props are helpful in manipulating the WIM and other objects in the environment.

The WIM raises more questions than it answers. We presently have worked with WIM's for room-sized environments, but how can one extend the functionality of a WIM to building, city, or even larger sized environments? Can WIM's facilitate collaborative work on a shared virtual environment? Can multiple WIM's be used to help switch between disparate working contexts?

The WIM is an excellent example of an interaction technique which employs human motor, proprioceptive, and haptic capabilities to its advantage without giving up versatility. We have even observed users manipulating objects in the WIM without looking at it (that is, users have manipulated objects while holding the clipboard below the field-of-view seen in the immersive display).

This is perhaps the strongest qualitative evidence that interaction techniques based on hand-relative-to-hand manipulation of physical objects allows users to focus attention on their tasks without becoming distracted by the interfacing technology.

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BIOGRAPHICAL SKETCH

The User Interface Group at the University of Virginia is based in the Computer Science department, and is composed of faculty, staff, graduate and undergraduate students.

Our high-level mission is to explore and develop the mechanisms by which humans can more effectively and enjoyably interact with technology. As computers and other technology become pervasive, the challenge of providing appropriate, effective, and pleasant interfaces to technology will require talents drawn from a wide variety of disciplines. By surrounding open-minded technologists/engineers with diverse influences, we can most effectively guide the design and development of future human-technology interfaces. Our research includes collaboration with the Departments of Psychology, Neurosurgery, Architecture, Art, and various engineering disciplines.

Active areas of research include:

- *Infrastructure:* The Alice rapid prototyping system provides easy to learn 3D graphics, allowing users to quickly experiment with programmed real-time behavior of objects.
- *Fundamental knowledge:* Working with perceptual and cognitive psychologists, we are addressing the question "When is Immersion Useful, and Why?" This work focuses on performing user studies to determine which aspects of immersion affect task performance, with the ultimate goal of extracting HCI design principles and predictive theories.
- *Interaction techniques:* Virtural Reality is a new medium, just as film, radio, and graphical user interfaces are media. In the case of film and GUIs, there are well-acknowledged idioms of the medium (for film, flashback, crosscut, fade, etc., and for GUIs, scroll bars, pulldown menus, and the like). We are attempting to develop the lexicon of interaction techniques for VR.

Position statement for CHI'96 Workshop on Virtual Manipulation.
