3D Interfaces and Interaction

CS488 - Computer Graphics

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Introduction

What is a 3D interface? When asking this question we must turn to Bowman [Bowman et al. 2008] who says it is defined as “a UI that involves 3D interaction.” Then what is 3D interaction? The answer is a bit longer with a storied history.

Ivan E. Sutherland demonstrated to the world the first graphical user interface called Sketchpad (Figure 1) in 1963 as part of his PhD thesis [Sutherland 1963] at the Massachusetts Institute of Technology (MIT).

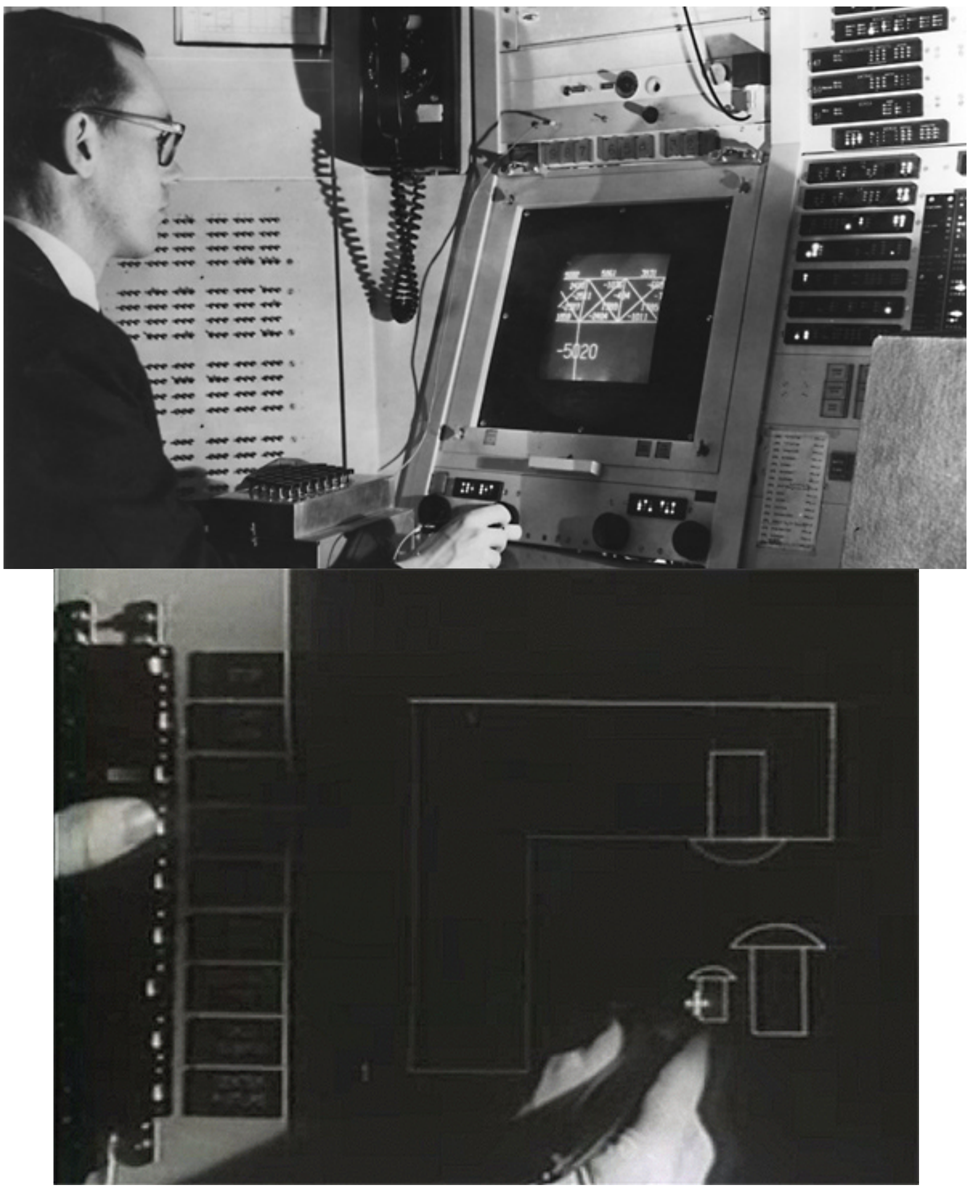

Figure 1, Sutherland demostrating Sketchpad (Top & Bottom), a light pen based drawing system, which esblished itself as the first graphical user inferface in practice [Sutherland 1963].

From Sutherland's Sketchpad, user interfaces have evolved drastically in the past fifty years when the first command line interface allowed users to interact with the computer via screen based terminals rather than stacks of paper based punch cards from the early half of the twentieth century (Figure 2).

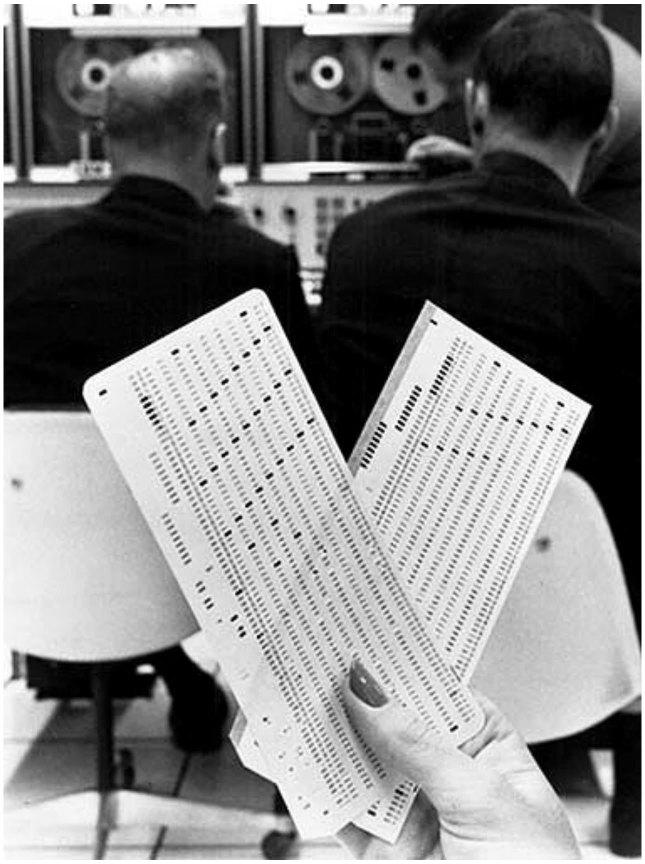

Figure 2, In 1965 IBM computers processed billions of punch cards. These rounded edge punch cards where introduce in 1964, they were all the rage **[Kallal]**

Punch cards to command lines were part of the first major recognized interaction paradigm shift in the newly formed field of Human Computer Interaction (HCI). After command line interfaces (Figure 3), the WIMP (Windows, Icons, Menus and Pointer) (Figure 4) paradigm revolutionized the way people interacted with computers.

Figure 3, With its screen commandline interface, terminals like this VT100 **[]** created an evolutionary step forward from punch card interfaces.

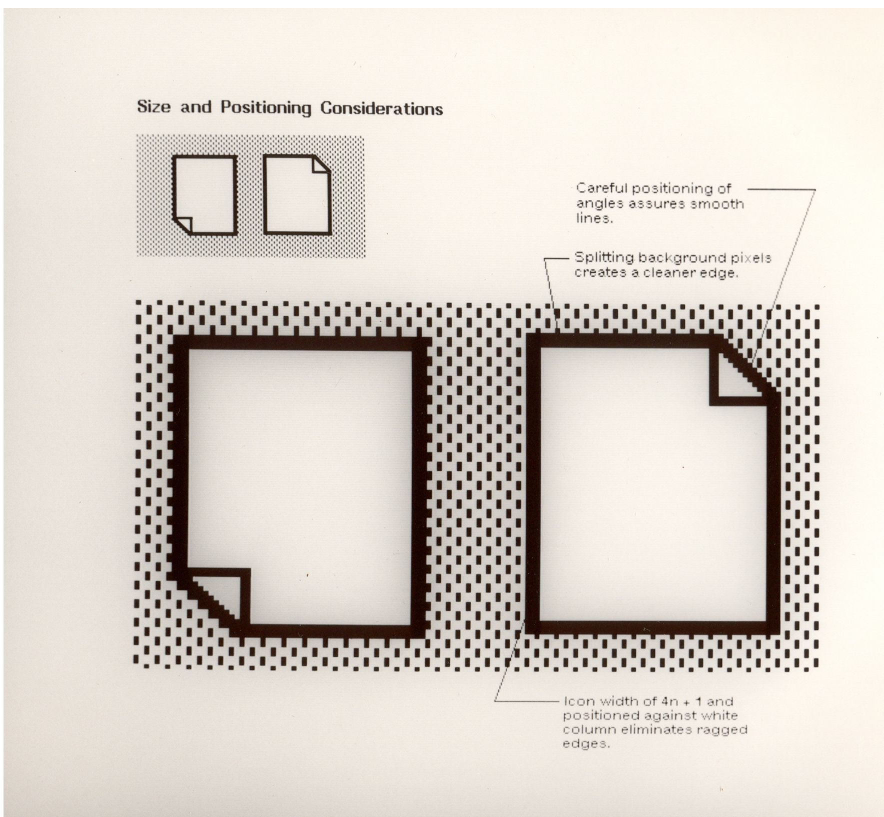

Figure 4, Icon designs for the Xerox Star, the first commerically available computer with a WIMP interface . This icon is legendary and is still used today in modern operating systems to represent a 'file' **[]**.

While that revolution was happening a number of scholars in the field of computer graphics and human computer interaction were investigating ideas beyond the personal computer and in a realm where the user exists in a both in three-dimensional virtual and physical environment. Today as the desktop and the WIMP paradigm slowly fades we are can see the fruits of that scholarship in our everyday lives as we engage with technology that is inherently spatial, physical, and tangible – 3D interfaces and interactions.

Framing

In this paper we are going to briefly give some examples of 3D interfaces (a taxonomy would warrant a study in its own right), highlight some of the main challenges in the space, and discuss some interface technologies and interaction techniques. We will conclude by focusing our attention on interfaces that are glimpses into the future.

3D Interface Examples

Virtual Environment Display System

The Virtual Environment Display System [Fisher et al. 1987] was one of the first realized instances of a Virtual Reality (VR) implementation stemming from the Sutherland's work with head mounted displays (Figure 5).

Figure 5, Sutherland's prototype head mounted display. It was so heavy it had to be secured from the ceiling in order for a person to wear it **[Sutherland 1968]**.

The impetus with the Virtual Environment Display System (Figure 6) was for telerobotics, giving technicians the ability to remotely control robots in a real physical space through interactions in a virtual space.

Figure 6, The Virtual Environment Display System, one of the first Virtual Reality (VR) systems. Seen here, the user is emersed in a virtual world trying to pull the wings off of a butterfly **[Fisher et al. 1987]**.

A discussion about Virtual Reality (VR) warrants its own paper. VR is about total emersion of all 5 physiological senses. Users wear a head mounted display and (data) gloves on their hands for haptic feedback when interacting with the 3D virtual world. In the past VR setups were constructed of bulky components. Today Virtual Reality (VR) is making a come back via the Oculus Rift (Figure 7). Oculus Rift is portable head mounted unit that plugs into any standard personal computer.

Figure 7, Oculus Rift head VR system **[Grubb 2014]**.

A number of manufacturers are developing haptic components for VR to allow users to immerse deep into whatever virtual world they are interacting with. Most notably is this flying simulator (Figure 8).

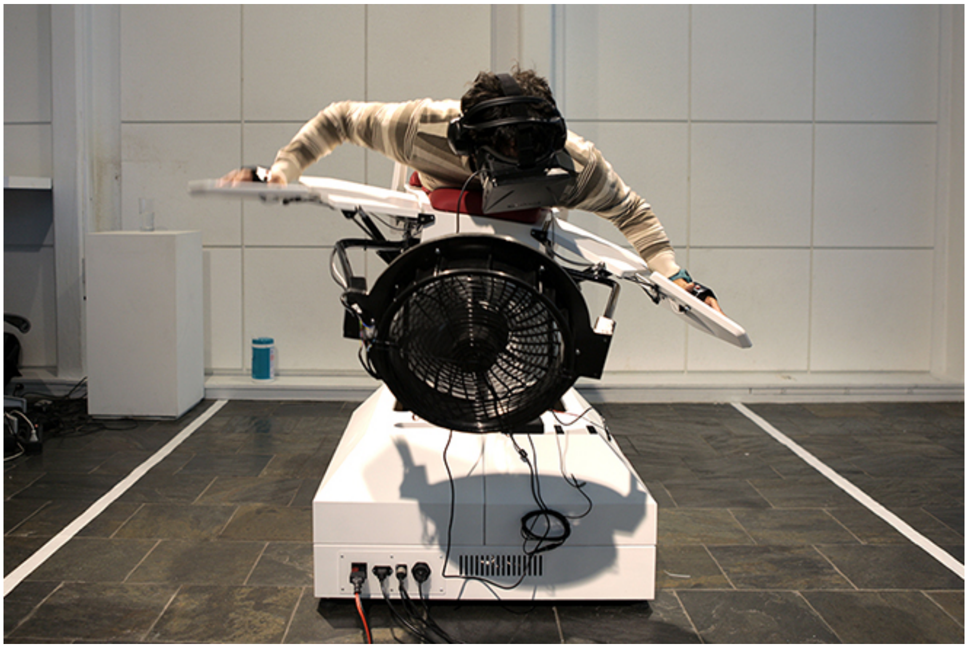

Figure 8, Flying unit for the Oculus Rift VR system **[BATSON]**.

Trackball Mouse

The Royal Canadian Navy invented the trackball mouse (Figure 9) in 1952 as part of a project called DATAR (Digital Automated Tracking and Resolving). The trackball used a standardize bowling ball and was used to input 3D naval logistical information into a remote mainframe [Vardalas 1994].

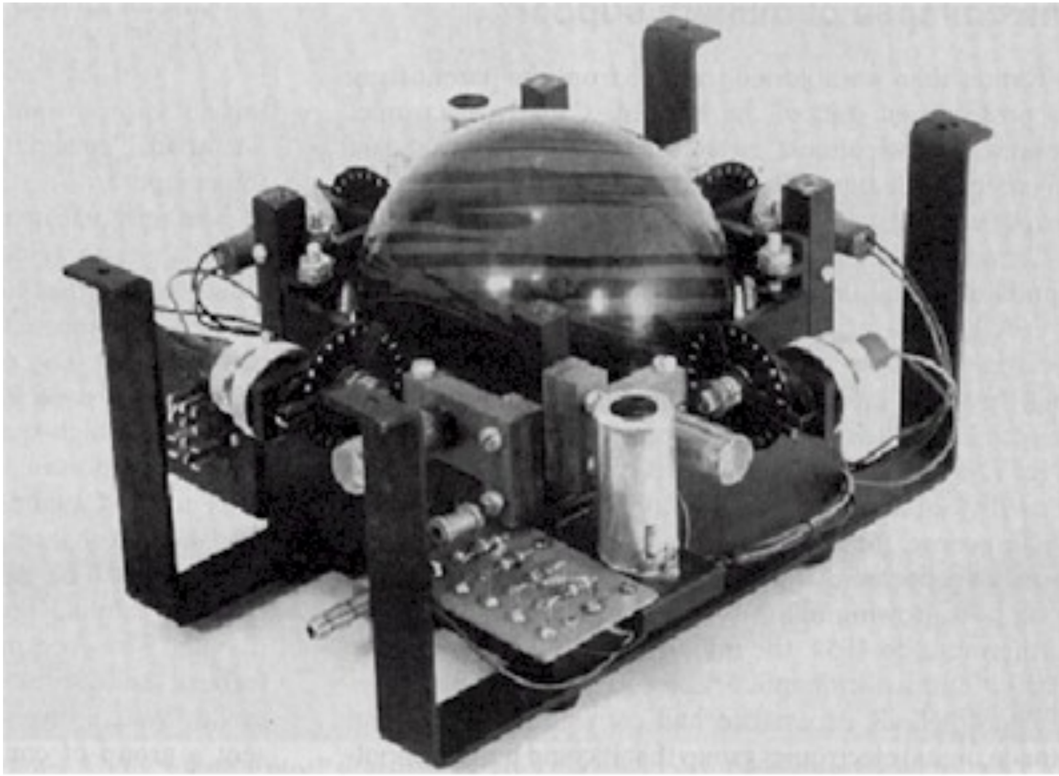

Figure 9, The first trackball mouse invented in 1953 was used for 3D logistical positioning in miltary contexts **[Vardalas 1994]**.

Amazon Fire

While commercially a flop in 2013 and not the first time a mobile device has been labeled with a '3D' interface, the Amazon Fire's distinction is that it includes an array of infrared cameras on its front face to track eye and head movements to dynamically tilt the 3D perspective to match the orientation of the user. This is the first of many perspective-shifting interfaces to come (Figure 10).

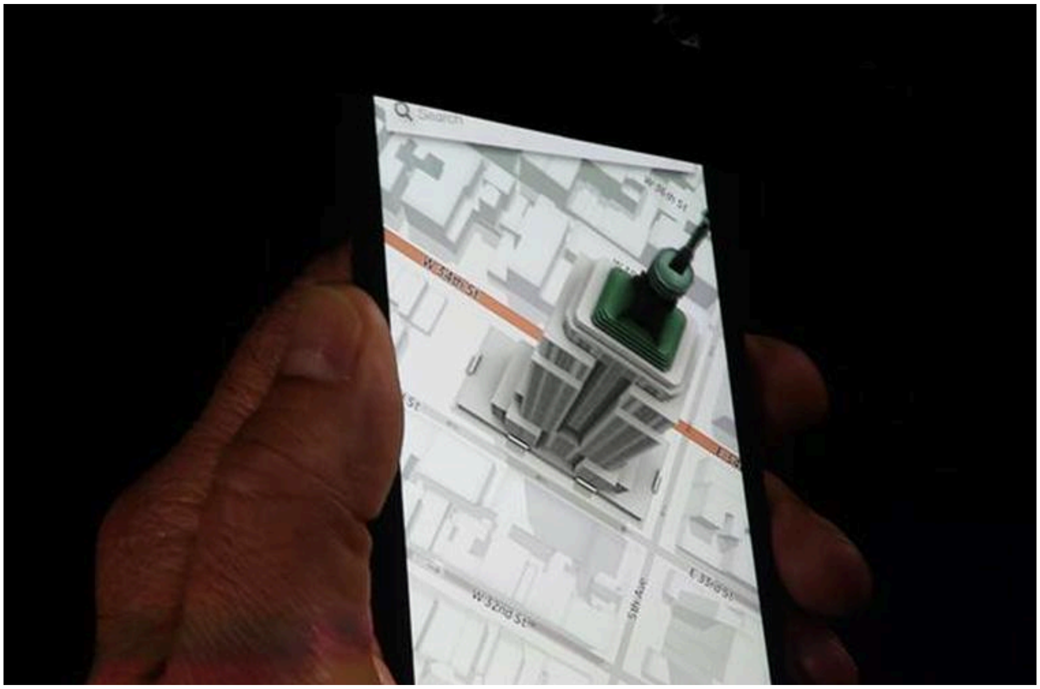

Figure 10, The 3D interface of the Amazon Fire adjusts its perspective dynamically based on head and eye movement **{Ralph:wp}**

Challenges of 3D Interfaces and Interaction

Interaction and Technology Design

There are a number of challenges practitioners and scholars are facing when designing, implementing, and researching 3D interfaces. If we have to quantify the life of 3D interfaces and interaction in the span of human computer interaction and computer graphics it has relatively been short lived. Designers have scores of design principles and reference implementations for tradition interfaces (e.g., web interfaces, desktop interfaces, etc.) on personal computers but have very few of these for 3D interfaces. There are no standard 3D interfaces or established guidelines. For one, in the past it seemed that every new 3D interface brought along its own 3D interaction technology. However, interaction technology taxonomies have been established. Opening the door for scholars and designers to establish interaction and design patterns within individual levels of those taxonomies.

Fidelity

The question of fidelity, both in terms of practices and representations, is a very interesting one, and could merit researching in its own right. It is not necessarily the case that elements of the representations need to be identical to those of the real world – in fact, some exaggerations or simplifications might actually provide benefits to the user, raising saliency of some features and making the deep structure of the environment more accessible to users. How does a designer choose between magic, extending the boundaries of human perception and interaction in a virtual world where it would not be possible in a real world, or realism, interacting with the virtual world with all the constraints of the real physical world? These questions have been investigated by the HCI community for the past twenty years and still are today. The difficulty lies in their complexity, which stems from their inherent nature in cognitive science and psychology.

Embodiment

Can we really talk about 3D interfaces and interaction without talking about embodied interaction? The early years of HCI research were focused largely on tracking people's behavior with mice and keyboards. Today there is a notable shift away from tracking keystrokes and mice pushes to tracking users' full body movement or embodied interactions with many aspects of their physical environment. This directly aligns with 3D interfaces and interaction. In Paul Dourish's groundbreaking text on embodied interaction, he defines embodiment as "possessing and acting through physical manifestation in the world." **(Dourish, 2001, p. 100)** He goes on to say, "Embodied practical action is the source of meaning. We find the world meaningful with respect to the ways in which we act within it**." (Dourish, 2001, p. 125).** In other words, the modality of physical movement and gesture may be one of our primary sources of meaning making. These are many difficult concepts to deal with when investigating or designing 3D interactive systems because the research community is still trying to figure out how to understand them..

3D User Interface Technologies

Today we have a diverse ecology of devices, displays, and technologies. While the 3D interaction is still primitive, it is one step better than the genesis period – where the underlying technology had to be made from scratch. Today designers and developers have off the self-technologies hardware and software types to choose from.

3D Stereoscopic Cameras (Computer Vision)

The Microsoft Kinect (Figure 11) brought computer vision to the main stream. Computer vision is the concept that gives computers the ability to analyze images from the real world in some meaningful way. It uses an array of infrared sensors and cameras to compute a 3D depth map of its space and then uses machine learning to do skeletal tracking [MacCormick 2011]. The Kinect is able to track the movements of multiple skeletons (humans) in its field of view.

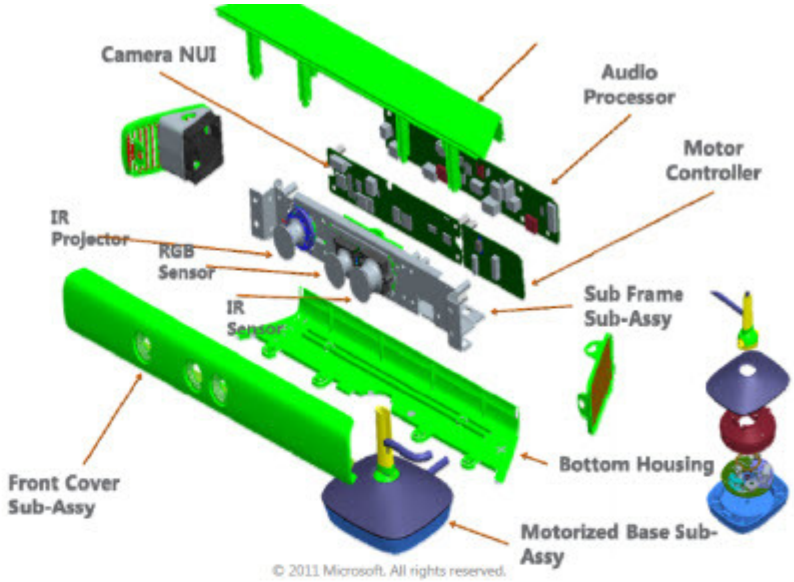

Figure 11, Microsoft Kinect version one assembly **[Takahashi 2011]**.

3D Motion Sensing Devices (Leap Motion)

The leap motion controller is a device (Figure 12) for tracking the 3D movement of the hands in space [2014].

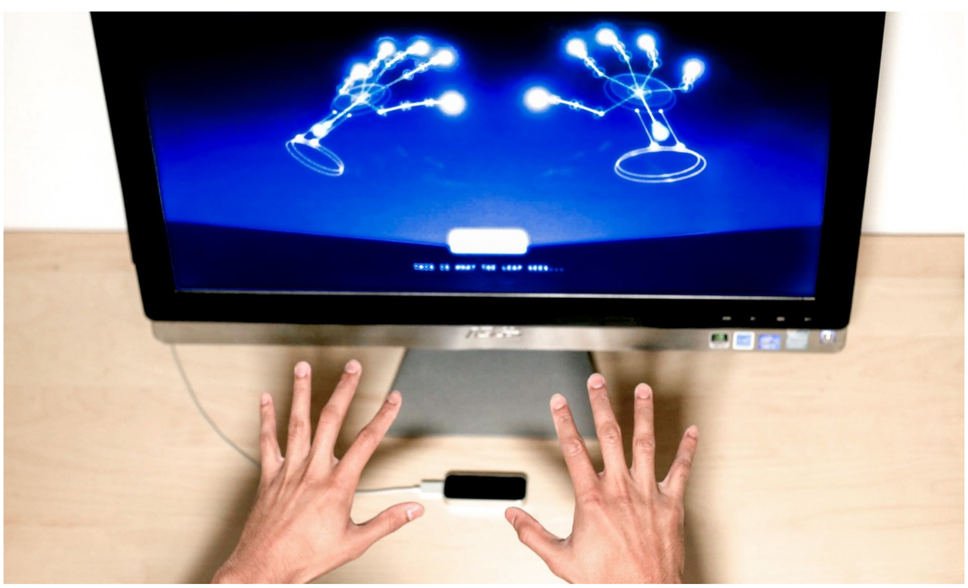

Figure 12, Movement of the hands over the Leap Motion Controller are rendered in real time on the display **[2014]**.

It overlaps with the Kinect in that it uses a stereoscopic method of creating a depth model of the hands over the infrared sensor bar. Infrared light bounces off the users hands creating a virtual model of the hands (Figure 13). The raw data is sent to an application running on the host PC where algorithms will parse it to create the 3D model.

Figure 13, Exploded view of the Leap Motion Controller **[2014]**.

Augmented reality (AR)

Augmented Reality can be defined as integrating virtual objects into real world. Augmented Reality has been very successful and has applications almost in every field, Medical, Gaming, Education, Commercial. A famous survey by Ronald T. Azuma in 1997 about AR in which focused on the AR characteristics and analyzing current challenges faced in building efficient AR systems (Figure 14). It provides a little insight into the future of AR and a starting point for potential researchers [Azuma 1997]
.

Figure 14, Optical and Video see through HMDs in 1997 [Azuma 1997].

An updated survey was published in 2001, [Azu Azuma et al. 2001]. Since our focus is on interfaces in this report, we will discuss about Interfaces and Visualization category of Augmented Reality.

In 2000, an interior design application introduced an interface that enabled users to manipulate (move, grab and drop) the furniture model with the help of a real paddle (Figure 15) [Kato et al. 2000].

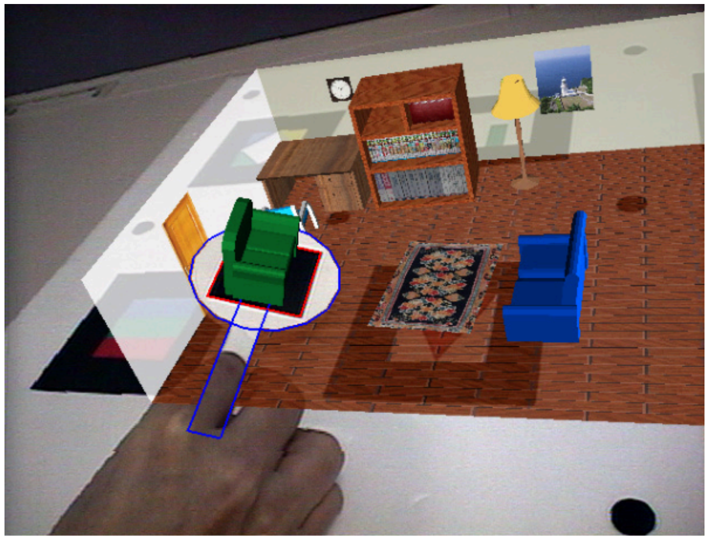

Figure 15, Interface that allows user to manipulate virtual furniture models using real paddle [Kato et al. 2000].

Since then a lot of advancement has been made into this field. One of the famous AR project is: Google Glass (Figure 16). It is an internet connected eyewear. It works like a smartphone, letting you read emails, click photographs, navigate through maps and search the web. It can connect to internet through only Wi-Fi or Bluetooth tethering. Interaction with the glass is done via trackpad on the side of the glass : slide forward, slide backward, slide down and a tap. One of the defining feature of glass that makes it special is that it provides the first person look at what some one is actually doing. It also allows the user to navigate using google maps with a actual real time arrow, Send a message and place a call.

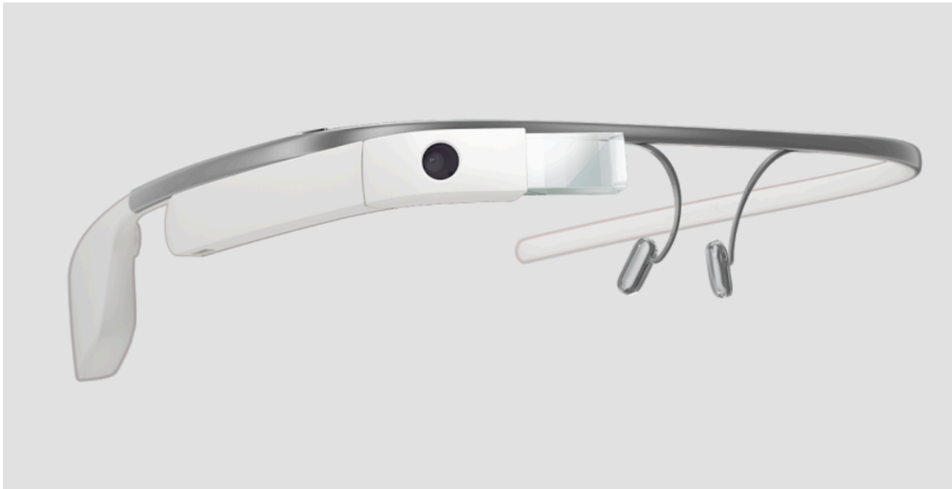

Figure 16, Google Glass **[2013]**

Multi-Touch 3D Interfaces

Touch sensing has been around since mid of 20th century. But it was not until 1980, that multi-touch sensing gained momentum. Multi-touch sensing combined with 3D interfaces into one coherent environment are dominating the entertainment market [Cyborra et al. 2013].These technologies when combined together expands the range of applications as they provide a more intuitive and natural interaction. Multi-touch sensing enables a user to interact with a system using more than one fingers at a time. The sensing devices, such as Interactive walls and tabletops, provide a multi-touch environment. They allow more than one user to work on the device at a time, as they are large in sizes and thus, provide large interaction environment. The gestures for multi-touch include rotation, sliding, selection etc.

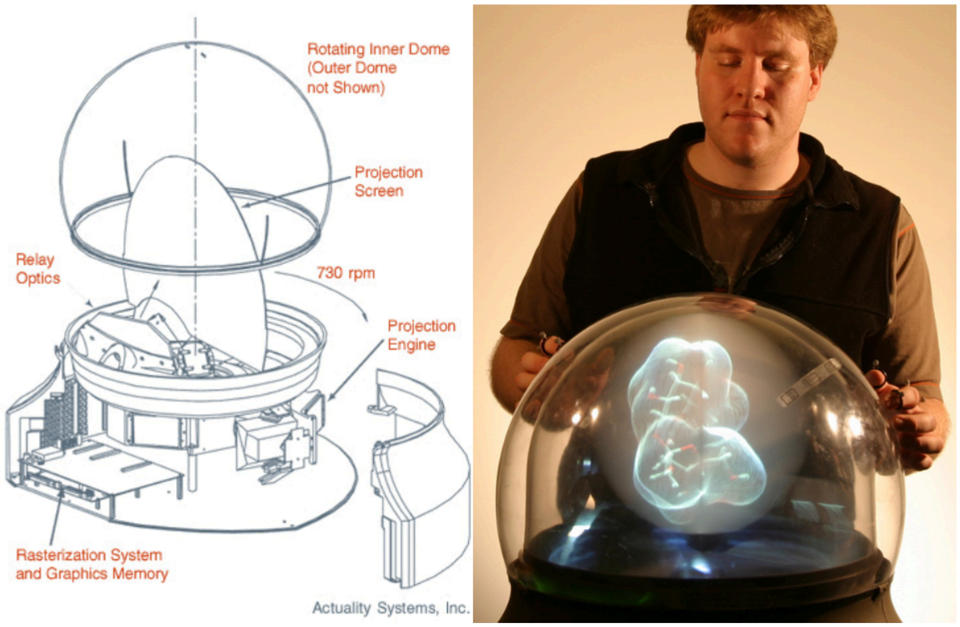

Figure **17**, Volumetric Display **[Grossman et al. 2004]**

Volumetric Displays are output devices that allow a user to display 2D image/scene into a 3D view (Figure 17). Until now, users were required to use an external input device like keyboard to interact with the display. In order to make it more user friendly, touch and gestural input were integrated with the volumetric display. In [Grossman et al. 2004] , the author has used surface menu and gestures to provide command input. A Vicon motion tracking system is used to track the position of finger. It consists of markers that are wrapped around the finger, which help to track the bending of finger and thus, identify the gestures (Figure 18).

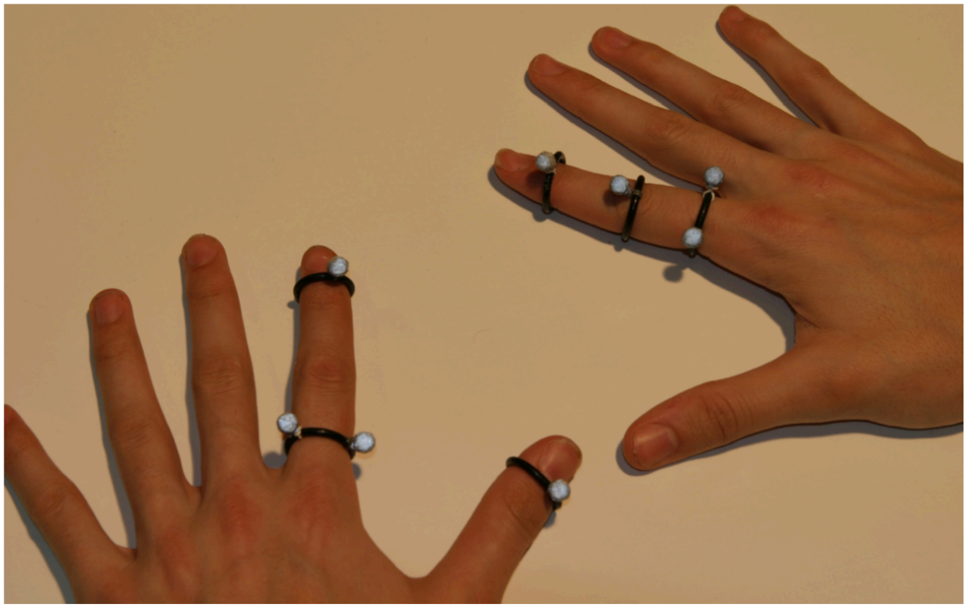

Figure **18**, Markers to track finger gestures **[Grossman et al. 2004]** .

The frequently used functions are provided on the surface of the display which look very similar to buttons. User can tap on these buttons to perform a particular functionality. But, it is not always convenient for users to use surface menu to interact with the display, especially when interacting with a virtual object. Thus, a set of hand gestures were developed which can be performed either on the surface or off the surface. Each gesture has a command associated with it. There are pinch gestures, display gestures, curl gestures, scrub gestures etc. which can be used to interact with volumetric display.

Haptic Glove

Haptic means related to the sense of touch. Thus, as the name suggests, Haptic glove is a device that simulates the touch sensations of virtual objects. They look like a normal glove, with space to insert your palm and fingers. Researchers have experimented with different type of gloves (Baseball gloves, woolen gloves) as the material/cloth of glove doesn't matter. However, it contains electronic wiring and devices that are responsible to simulate sensation and provides interaction with virtual environment.

The applications of Haptic Gloves can be divided into two broad categories:

Firstly, the gloves copy the behavior of actual physical contact with an object or a person. So, whenever the user interacts with an object/person in virtual environment, user can feel the simulation along the fingertips which is very similar to actual physical contact (Figure 19).

Secondly, the gloves allow the user to interact with the objects in real world, and reflect the same in virtual environment. Cornell University incorporated the temperature feedback as well into their haptic gloves. When a user hold a hot object in the real world, the object is colored red in the virtual environment to indicate that the object it hot. Similarly, if the object held is cold, the virtual environment paints the object blue. And, if the object is at neutral temperature, then color becomes yellow.

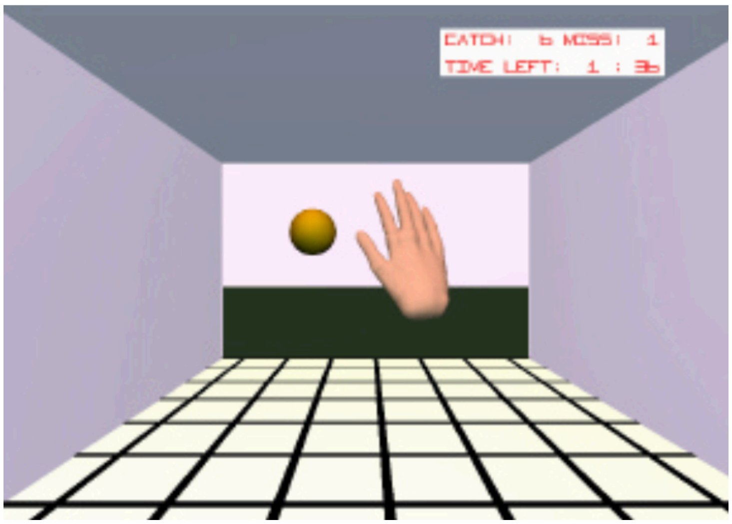

Figure 19, Throw and Catch Game, where user need to throw the ball above the black portion on the wall and catch when it bounces back. Shape of ball changes as user puts pressure while catching **[Popescu et al. 1999]**

Holographic User Interface

Dennis Gabor invented holography in 1947, but it was not until 1964 that the first hologram was introduced. Holography is defined as technique to create three-dimensional images by using coherent light to store the interference pattern (Figure 20).

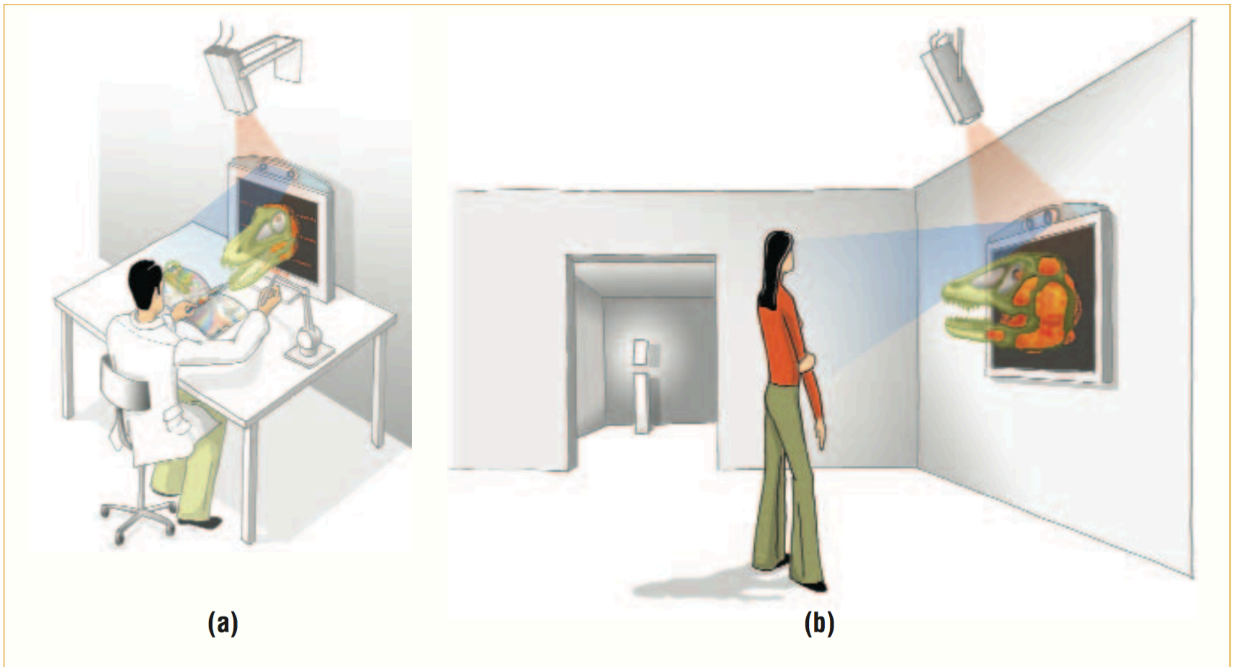

Figure 20, (a) Holographic 3D image along with pen type input device which allows interactions, (b) Holographic 3D display in the museum without any decrease in quality **[Bimber 2005]**

RealView has developed the most interactive 3D visualization system (Figure 21). This holographic system allows the physician to work with the true 3D anatomy of the patient, where the hologram represent the precise dimensions. The hologram appears in mid air without the use of any 2D screen. Unlike various other holographic images, they reconstruct the actual points of light in mid air. They have developed a new concept called Image Intimacy, which allows the user to engage with the image by reaching to the image, zooming it, translate it and manipulate it in any way they want. There is no doubt that Medical holography will play an important role in medical imaging industry over the next few years.

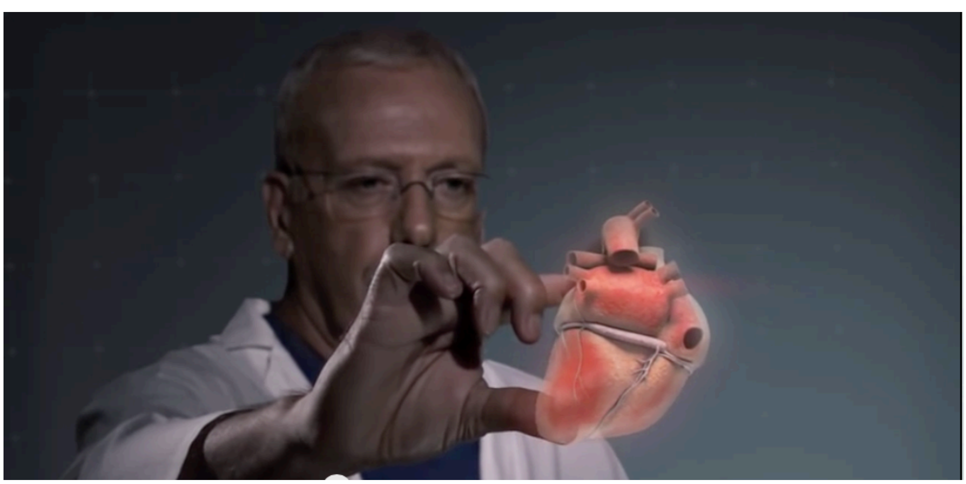

Figure **21**, RealView Medical Holography **[]**

3D Interaction Techniques

In this section we will discuss four types of three dimensional interaction techniques that revolve around concepts of manipulation, selection, and navigation. In both physical environments object manipulation and selection are some of the most basic tasks a user can perform [Hand 1997].

Selecting Objects

Target Acquisition

This type of selection in a 3D virtual world is akin to picking up something in the physical world.

Positioning

In a physical world object positioning means translating an object to a new x,y, and z coordinates in space. This is the same as in a three dimension virtual environment [Bolt]. In addition, users must able to contend with precision, which in a 3D environment could be difficult for a user depending on the how accurate the depth field is implemented the system.

Rotation

Virtual rotations [Hinckley et al. 1997] are analogous to its real world counter part, mainly concerned with spinning the object around a rotational axis from a fixed point. Precision is an issue, as the user needs to contend with the orientation and degree attributes.

Pointing

Pointing interactions [Bolt] allow users to interact with virtual objects by just pointing at them within a physical or virtual space (Figure 22). Coupling Pointing with some type of command signal (e.g., voice, button, etc.) gives the user the affordance of triggering events from a far.

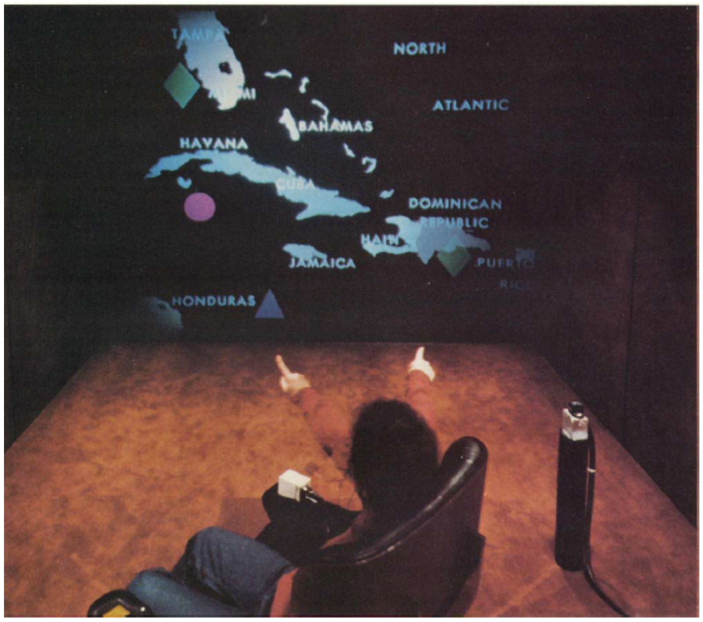

Figure 22, A user is pointing at a virtual map from a distance couple with a voice event trigger **[Bolt]**

Ray Casting

Ray casting allows users to cast a light virtual ray [Bowman and Hodges 1997] in a 3D virtual world and afford the ability to interact with whatever was attached to that ray (Figure 23).

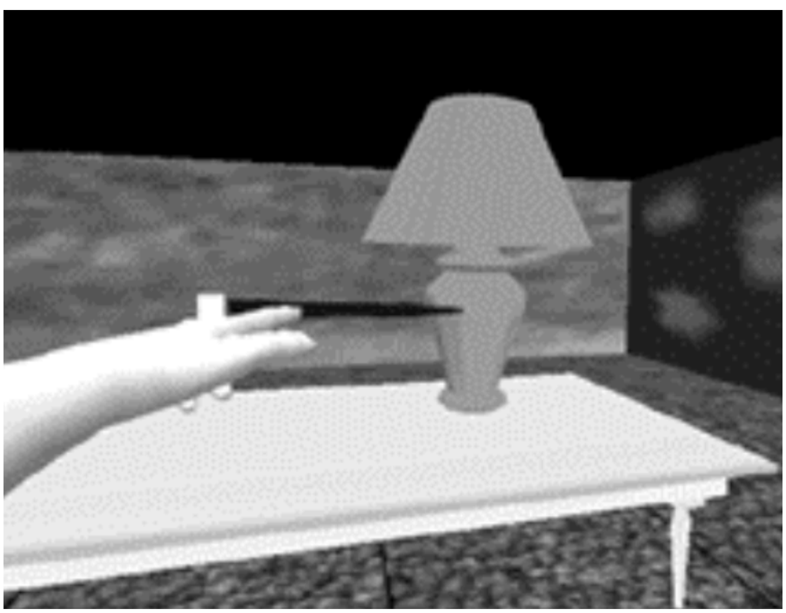

Figure 23, The user casting a ray and grabbing an object in the virtual world
[Bowman and Hodges 1997]

Flashlight and Aperture Technique

[Liang and Green 1993] improved the ray-casting technique by replacing the virtual ray with the flashlight representation. Objects are selected in the cast of the light in the direction it is pointed at. The advantage of this technique is that it is easy to select objects from a distance that need precision. The disadvantage is that if there are number of objects adjacent to the desired object, those will also be selected too. [Forsberg et al. 1996] solved this problem by introducing the aperture technique, which allowed users to control the selection volume of the flashlight (Figure 24).

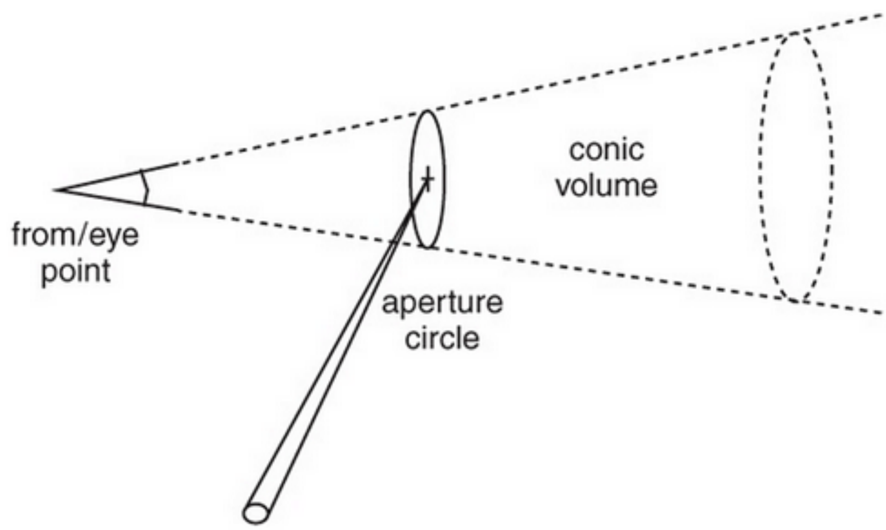

Figure 24, A diagram showing the aperture circle which can control the spread of the flashlight
[Forsberg et al. 1996]

Image plane Technique

The image-plane technique [Pierce et al. 1997] gives users the affordances for manipulation of a 3D object that has been projected onto a 2D image plane (Figure 25). This is akin to using a mouse to interact with a 3D representation on a 2D screen. This uses a variance of the ray-casting technique as a 'sticky finger'.

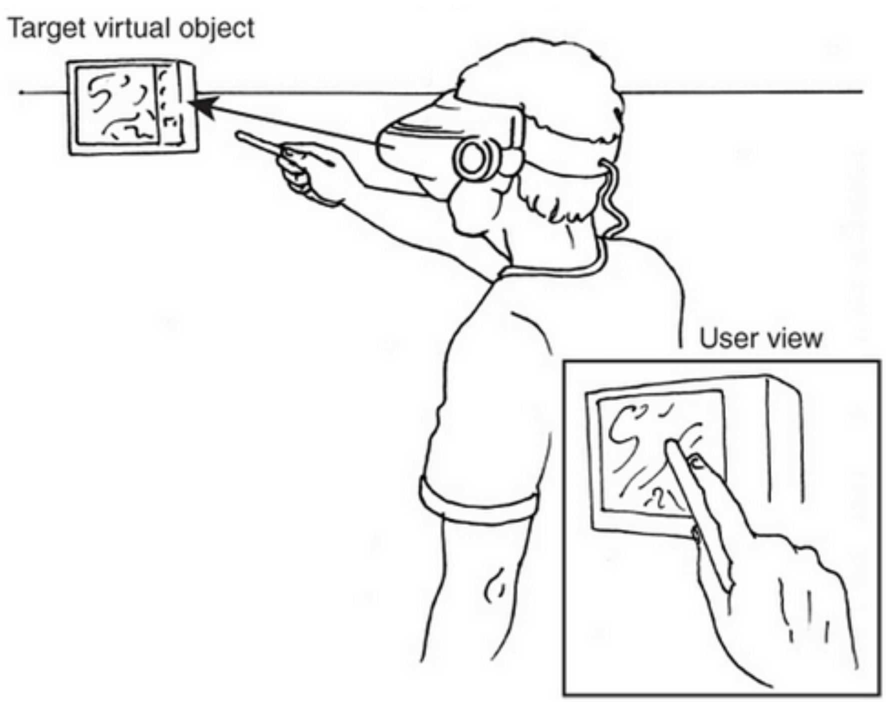

Figure 25, A diagram showing the image-plane technique when selecting virtual objects **[Forsberg et al. 1996]**

Manipulating Objects

Simple Virtual Hand

The idea behind the Simple Virtual Hand is that it uses a 3D hand representation that mimics a 2D cursor in a virtual space (Figure 26). Users have the affordance of Interacting with 3D virtual objects [Poupyrev et al. 1996]. The virtual hand orientation and position is mapped directly to the users hand in real physical space.

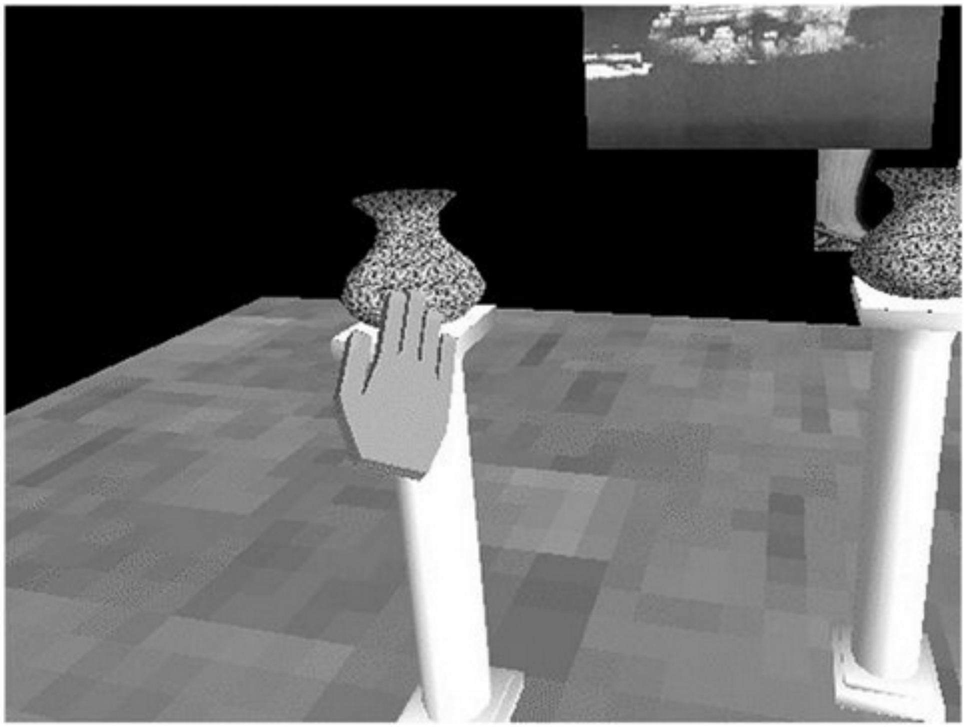

Figure 26, A users Simple Virtual Hand interacting with a 3D object **[Poupyrev et al. 1996]**

Go-Go Technique

Go-Go technique developed by [Poupyrev et al. 1996] improves on the simple virtual hand technique by allowing the user to modify the length of the virtual arm (Figure 27).

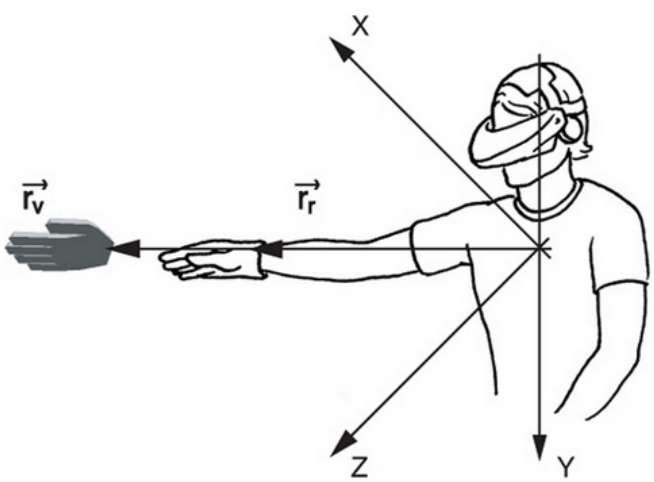

Figure 27, Users can modify the length of the virtual arm with the Go-Go technique **[Poupyrev et al. 1996]**

WIM: World in Miniature

The WIM technique developed by {Stoakley:1995ky} provides an alternative approach to extending user's arm to interact with objects, but instead scales the entire world to bring it within the user's reach. Once in reach the user can directly manipulate any 3D virtual within reach (Figure 28).

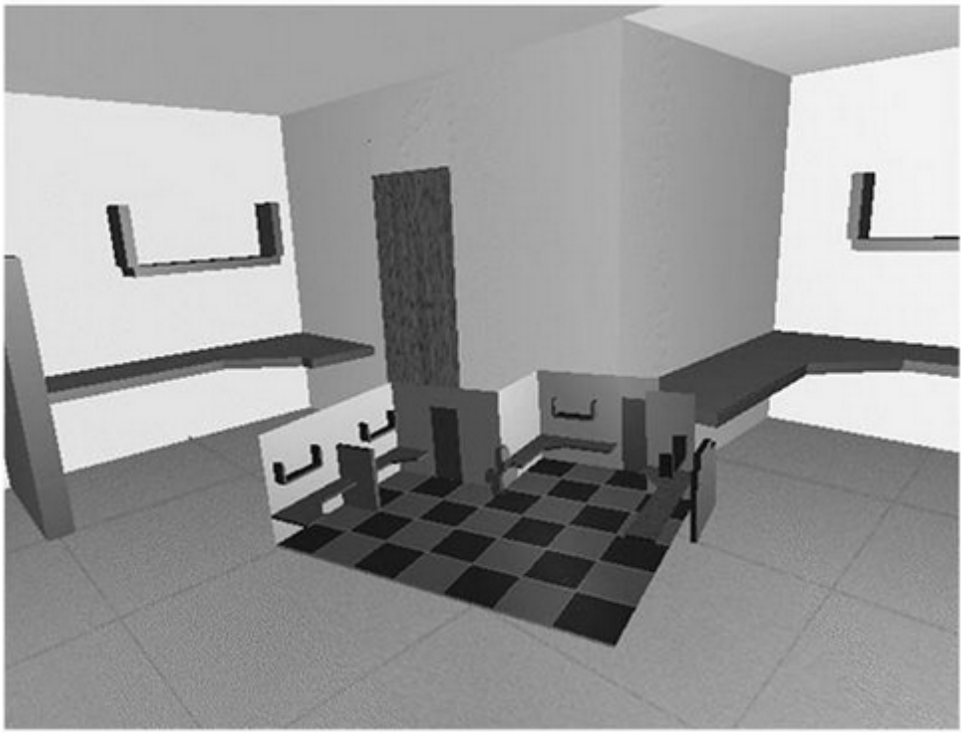

Figure 28, Scaling the world in order to manipulate objects in that world **[Stoakley et al. 1995]**

Navigation

Navigation is of the most fundamental actions humans perform in the physical world. In the virtual world techniques to afford users the same abilities have been investigated. The most important one is called way finding.

Way finding

Way finding is defined as the cognitive element of a navigation action in physical space using the users spatial knowledge in relation to objects, landmarks, road signs, etc. [Bowman et al. 2004]. This concept is the same in virtual space (Figure 29), but enhanced with navigation overlays.

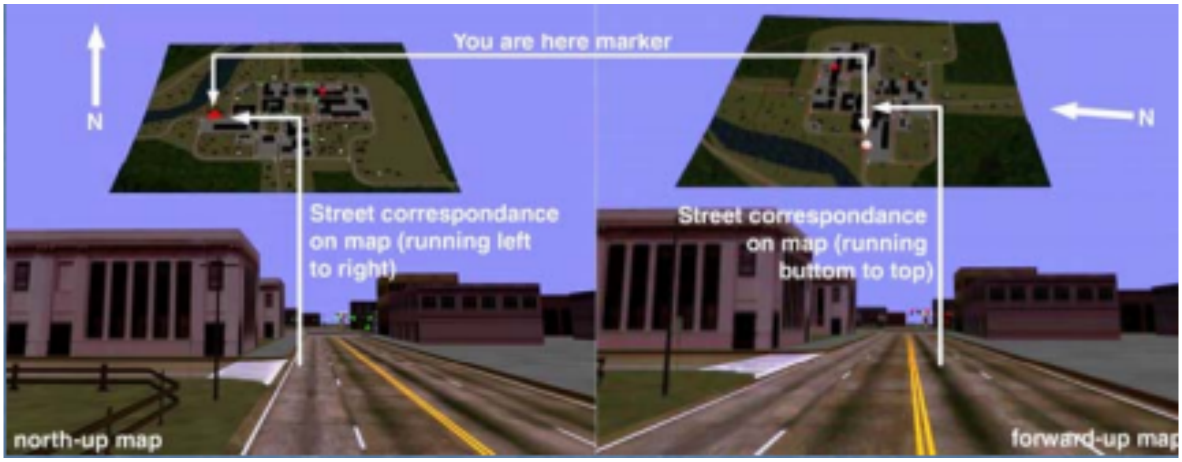

Figure 29, Way finding through virtual streets **[Bowman et al. 2004]**

Possible Futures

SpaceTop 3D Desktop Interface

SpaceTop [Lee et al. 2013] is a system that integrates the concepts of a desktop with augmented 3D spatial interactions into a single workspace. The system uses a transparent screen, which allows the user to interact behind the screen with virtual objects on the display (Figure 30).

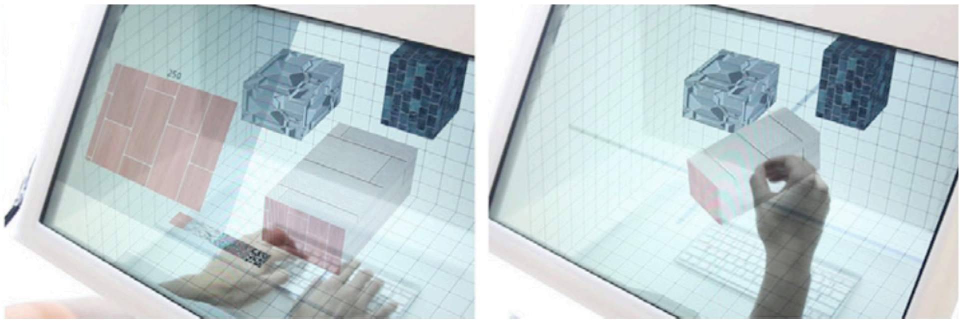

Figure 30**, Manipulating objects with finger gestures** [Lee et al. 2013]

It uses computer vision to recognize the users gestures and translates those to the augmented representations. In addition, it uses head tracking so that it can continuously adjust the parallax to the users shift in gaze (Figure 31).

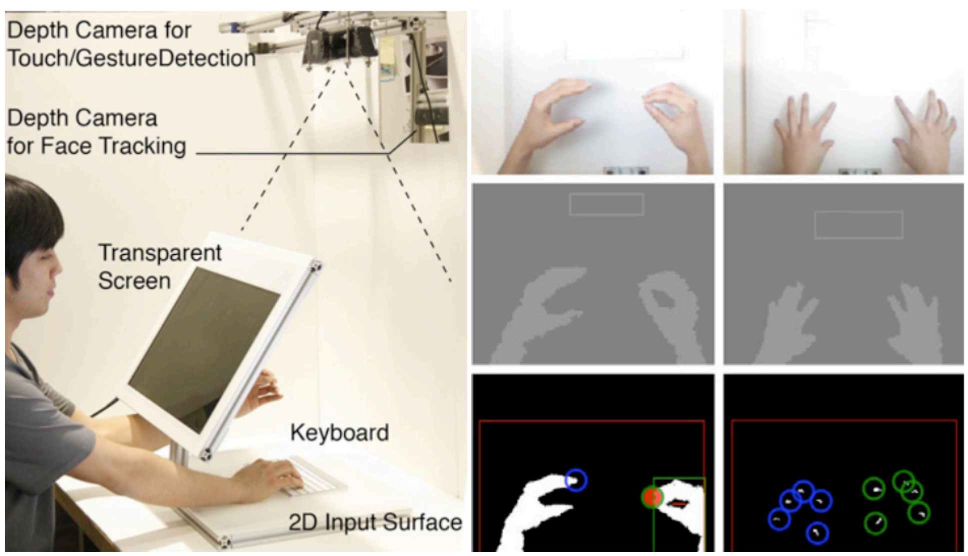

Figure 31, Hardware Setup for SpaceTop (Left) and tracking finger gestures while mapping them to representations (Right) [Lee et al. 2013]

inForm

inForm [Leithinger et al. 2014] is a creation of MIT's tangible media group that users to interact with digital information in a physical way with remote telepresence. It uses computer vision to detect bodily movements and then translates them to 'physical pixels' – a real life manifestation of a screen location. inForm updates the table (Figure 32) of physical pixels (Figure 34) in real-time creating an organic sense of the remote user being ‘there’ .

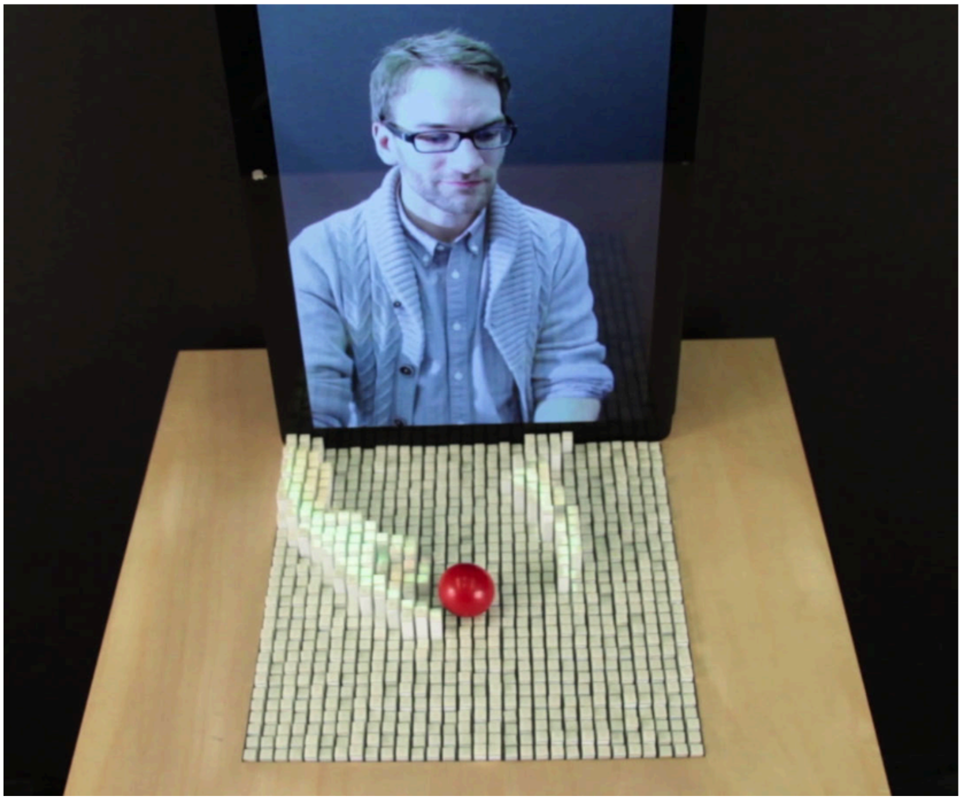

Figure 32, Moving a sphere around from a remote location [Leithinger et al. 2014]

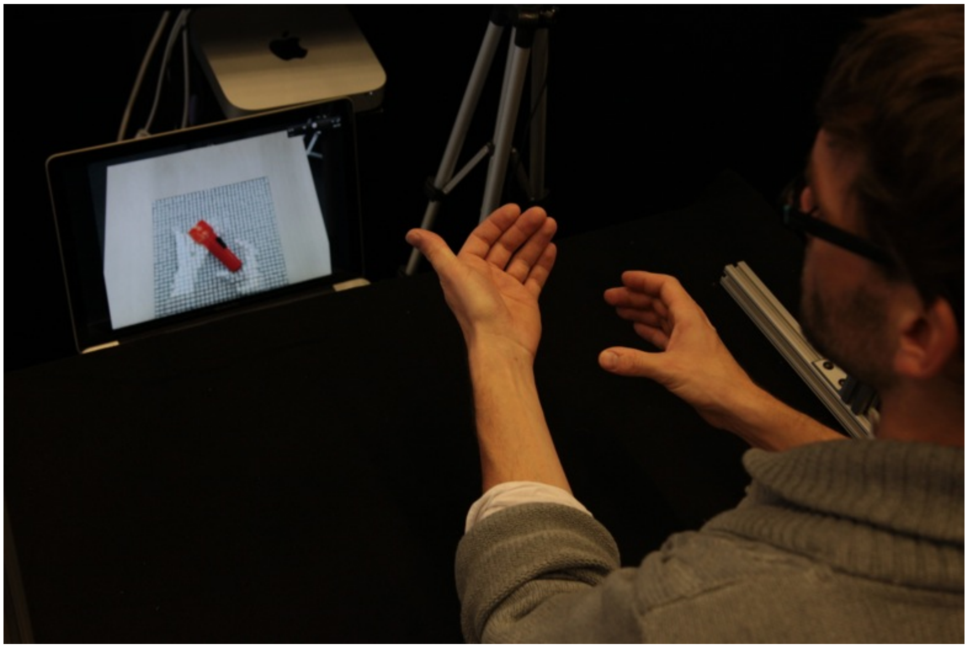

Figure 33, Manipulating a flashlight position from a remote location [Leithinger et al. 2014]

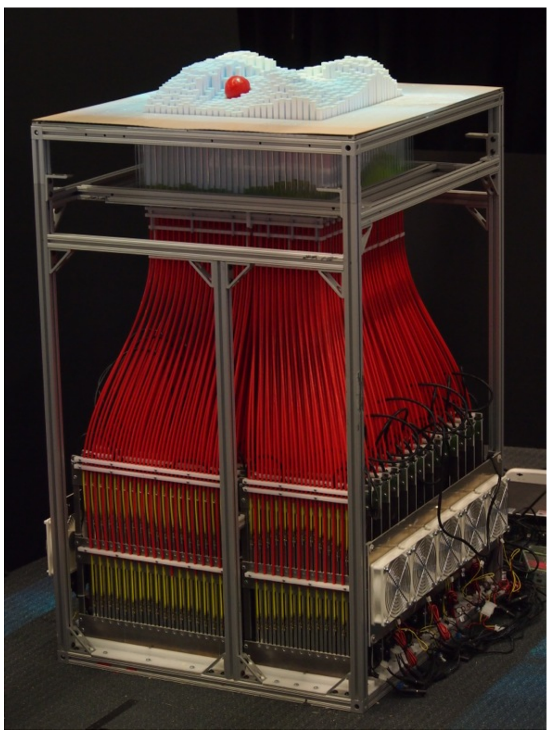

Figure 34, The belly of the table, 900 motorized physical pixels [Leithinger et al. 2014]

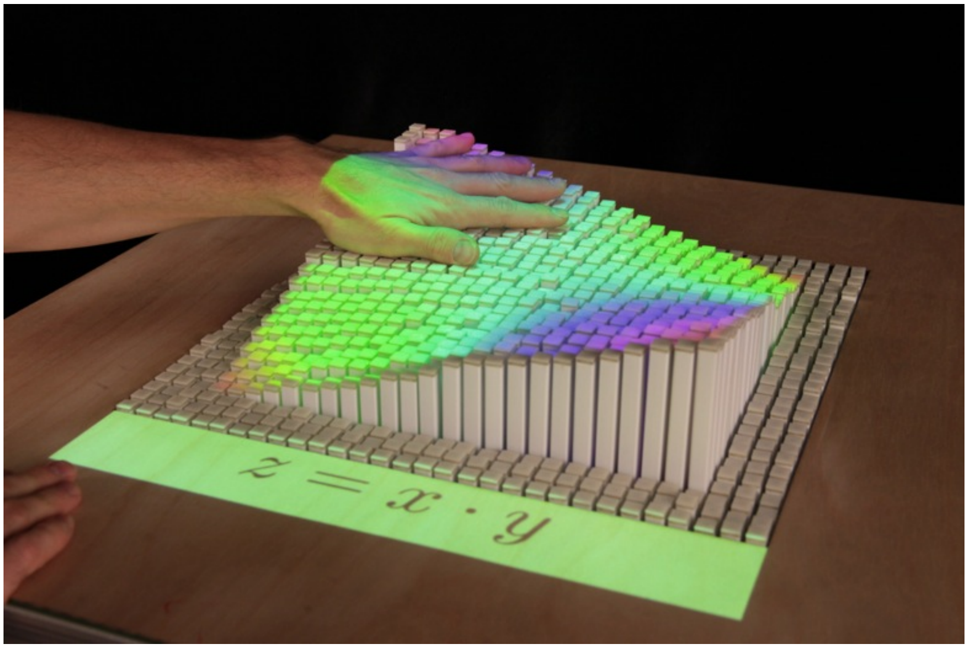

Figure 35, Projection on to the physical representations [Leithinger et al. 2014]

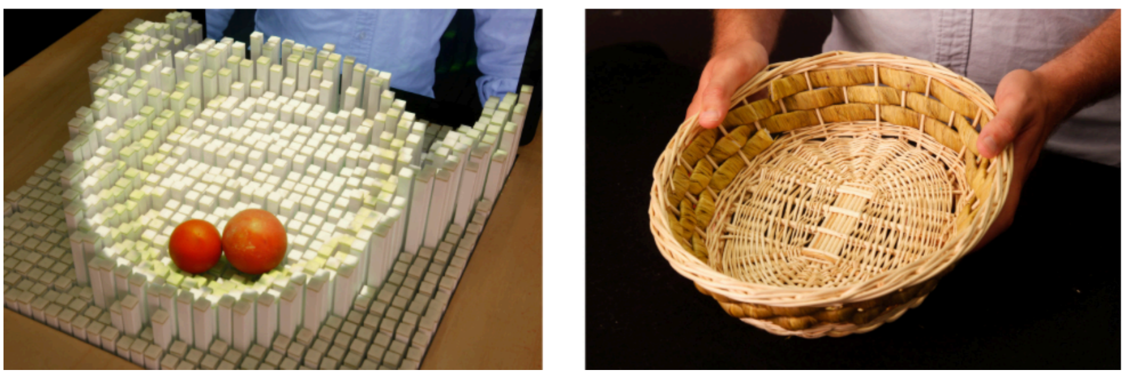

Figure 36, Manipulating the pixels with the help of an external physical object [Leithinger et al. 2014]

Summary

In this paper we presented early examples of 3D interfaces and interaction and we looked at the origin of 3D user interfaces from Sutherland's work of head mounted displays to the rise of computer vision. We identified some challenges that practitioners and researchers are facing in terms of fidelity, embodied action, and interaction design with the 3D interface design space. Systems that were once purely research materials are now in the hands of consumers. In addition, these types of interactive computing continues to expand at an exponential rate beyond the screen and into to the physical space to where one day we might see the notion of a ‘screen’ as being just as outdated as we see punch cards today.

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