Subject: User Experience Design With VR

Module 5: Introduction to Virtual Reality

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Virtual Reality System
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5.1

Defining Virtual Reality

Defines virtual as "being in essence or effect, but not in fact." This usage has been applied to earlier concepts in computing. What is meant by reality is more complicated the state or quality of being real. Something that exists independently of ideas concerning it. Something that constitutes a real or actual thing as distinguished from something that is merely apparent.

Four Key Elements of Virtual Reality Experience

The key elements in experiencing virtual reality--or any reality for that matter--are a virtual world, immersion, sensory feedback (responding to user input), and interactivity.

Key Element 1: Virtual World: A virtual world is the content of a given medium. It may exist solely in the mind of its originator or be broadcast in such a way that it can be shared with others. A virtual world can exist without being displayed in a virtual reality system (i.e., an integrated collection of hardware, software, and content assembled for producing virtual reality experiences) - much like play or film scripts exist independently of specific instances of their performance. Such scripts do in fact describe virtual worlds.
When that description is brought to life via actors, stage sets, and music, we are experiencing the play's virtual world. Similarly, a computer based virtual world is the description of objects within a simulation.
When we view that world via a system that brings those objects and interactions to us in a physically immersive, interactive presentation, we are experiencing it via virtual reality an

imaginary space often manifested through a medium. A description of a collection of objects in a space and the rules and relationships governing those objects.

Key Element 2: Immersion Considering the user must be immersed within some other, alternate reality, an admittedly simplistic definition of VR might be

Immersion into an alternate reality or point of view.

But what does this mean? Where do you go to get immersed into an alternate reality or point of view? What in fact is an alternate reality or point of view? According to our simple definition, a medium qualifies if its participants are able to perceive something other than they would have without an external influence. This definition acknowledges the possibility of perceiving something besides the world you are currently living in in two ways: you can either perceive an alternate world or the normal world from another point of view.

An alternate world might be a representation of an actual space that exists elsewhere, or it could be a purely imaginary environment. Alternate worlds are often created in the minds of novelists, composers, and other artists and creative individuals. Imagine for a moment that you are empowered with the magical ability to live in a world other than the one you currently inhabit. You are given new powers, objects have different properties, perhaps there is no gravity.

Other human and non-human beings inhabit this space. Space may or may not exist in the same way it does in our universe. Perhaps the shortest distance between two points is not a straight line. Is such a scenario possible? If you are able to imagine such a place then it is, indeed, possible.

Imagination is where virtual worlds begin and how numerous virtual worlds are experienced. The power of imagination can allow us to dwell where we choose, when we choose, and with whom we choose. We are limited only by what we can imagine and our ability to communicate it.

immersion sensation of being in an environment; can be a purely mental state or can be accomplished through physical means: physical immersion is a defining characteristic of virtual reality; mental immersion is probably the goal of most media creators.

mental immersion state of being deeply engaged; suspension of disbelief; involvement.

physical immersion bodily entering into a medium; synthetic stimulus of the body's senses via the use of technology; this does not imply all senses or that the entire body is immersed/engulfed.

Key Element 3: Sensory Feedback: Unlike more traditional media, VR allows participants to select their vantage point by positioning their body and to affect events in the virtual world. These features help to make the reality more compelling than a media experience without these

options. Without getting into that philosophical discussion of what reality is, we will consider that there can be more than the reality we experience firsthand with our unaided senses.
Imagined reality refers to the experiences we have in our thoughts and dreams or that we experience second hand in novels, films, radio, and so on. In imagined reality, we imagine ourselves within the world presented through the medium-also known as the diegesis. The diegesis of a world presented through a medium includes places and events that are not directly presented but are implied to exist or to have occurred.
Sensory feedback is an ingredient essential to virtual reality. The VR system provides direct sensory feedback to the participants based on their physical position.

Key Element 4: Interactivity: For virtual reality to seem authentic, it should respond to user actions, namely, be interactive. Thus, another necessary component in the full definition of virtual reality is interactivity. Interactivity comes more readily with the addition of the computer to the equation.
One example might be a scientific simulation of a thunderstorm, wherein the mathematical equations that describe the storm are solved based on the current weather conditions, and the resulting numbers are transferred into imagery.
Flight simulation, to take another example, is a computational simulation of various air foils (wings, propellers, turbines, rudders) interacting with surrounding air, as different flight controls are applied to these surfaces. Output of such a simulation need not be a visual representation of the out-the-window view from the cockpit, but might be simply a representation of the cockpit instrument displays.

Human Physiology and Perception

Human Physiology

- **Vision**: VR relies heavily on visual input, and human eyes are sensitive to factors like field of view (FOV), depth perception, and light intensity.
- **Stereoscopic vision:** VR headsets create a 3D effect by presenting slightly different images to each eye, mimicking how humans perceive depth in the real world.
- **Eye strain:** Long exposure to VR, especially with low frame rates or poor resolution, can cause discomfort or eye strain.

Perception in VR

- **Depth Perception:** VR exploits binocular cues (like stereopsis) and monocular cues (like size and shading) to create a sense of depth, allowing users to perceive objects in 3D.
- **Spatial Awareness:** Accurate perception of space, distance, and the relationship between objects is crucial for immersion. VR provides an enhanced sense of presence, making users feel as if they are "in" the virtual environment.

- **Motion Perception:** Virtual environments use head-tracking and hand-tracking to simulate natural movement. However, discrepancies between perceived and actual motion can cause motion sickness.
- **Interaction with Objects:** VR systems try to replicate the experience of interacting with physical objects. However, the lack of tactile feedback can sometimes create a disconnect between what users expect and what they feel, which affects immersion.
- **Latency:** Any lag between user action and system response can disrupt the sense of immersion. Latency issues in VR may also contribute to motion sickness and discomfort.

Virtual Reality System

1. Interface to the Virtual World-Input & output- Visual
2. Aural & Haptic Displays
3. Applications of Virtual Reality

1. Interface to the Virtual World-Input

a) User Monitoring (User Input to the Virtual World)
b) Position Tracking
c) Body Tracking
d) Other Physical Input Devices
e) World Monitoring (Dynamic Input to the Virtual World)
f) Persistent Virtual Worlds
g) Bringing the Real World Into the Virtual World

1. A. User Monitoring (User Input to the Virtual World)

Position Tracking A position sensor is a device that reports its location and/or orientation to the computer. Typically there is a fixed piece at a known position and additional unit(s) attatched to the object being tracked. Often position sensors are used to track the participant's head and one of the participant's hands.

Position Tracking
Tracking methods

1. Electromagnetic: Electromagnetic Tracking A commonly used VR tracking technology is electromagnetic tracking This method uses a transmitter to generate a low-level magnetic field from three orthogonal coils within the unit. In turn, these fields generate current in another set of coils in the smaller receiver unit worn by the user. The signal in each coil in the receiver is measured to determine its position relative to the transmitter.
2. Mechanical:Tracking may also be accomplished through mechanical means. For example, an articulated armlike boom may be usec! to measure the heacl position. Users can strap part of the device to their heads, or they can just put their face up to it and

grasp the handles. The boom follows their movements within a limited range, each elbow joint and connecting link of the boom is measured to help calculate the user's position

3. Optical: Optical tracking systems makeuse of visual information to track the user. There are a number of ways this can be done. The most common is to make use of a video camera that acts as an electronic eye to "watch" the tracked object or person.
4. Video metric: An alternate method of optical tracking is referred to as videometric tracking. Videometric tracking is somewhat the inverse of the cases just described in that the camera is attatched to the object being tracked and watches the surroundings, rather than being mounted in a fixed location watching the tracked object.
5. Ultrasonic: Ultrasonic tracking uses high-pitch sounds emitted at timed intervals to determine the distance between the transmitter (a speaker) and the receiver (a microphone). As with optical tracking, three transmitters combined with three receivers provide enough data for the system to triangulate the full 6-DOF position of an object.

Body Tracking

Body Posture and Gestures

In monitoring the user, the system determines the current position of the user or some part of the user's body. The static position of a body part or group of parts, such as an extended index finger or a clenched fist, is referred to as posture. The system can also maintain information on user movement over time. A specific user movement that occurs over time is referred to as a gesture.

The body parts and techniques of body tracking commonly used in VR applications include
The body parts and techniques of body tracking commonly used in VR applications Include

- Tracking the head
- Tracking the hand and fingers
- Tracking the eyes
- Tracking the torso
- Tracking the feet
- Tracking other body parts

2. **A. World Monitoring (Input to the Virtual World)**
   a. Persistent Virtual Worlds
   b. Bringing the Real World Into the Virtual World

a. **Persistent Virtual Worlds**:

The separate existence of persistent virtual worlds has several implications. In a nonpersistent world, each time a VR application is experienced, it will start from the same initial conditions. User manipulations in a persistent world can remain intact until another user (or agent) comes along and changes them. Persistent worlds can evolve over time and changes can continue to take place, even when no one witnesses them.

b. Bringing the Real World into the Virtual World:

Real-world data can be gathered by video cameras and other measuring devices. There are several applications where the inclusion of real-world data may be advantageous.

Broadly speaking, including real-world data in a VR application is most helpful in the following scenarios:

- Analysing and exploring acquired scientific data. For example, a realtime system for data acquisition allows a scientist to use various scientific visualization tools to explore a severe weather system as it unfolds. Or, a traffic engineer might need to observe traffic flow at a busy intersection using tools in VR.
- Preventing users from colliding with objects in real world. Integrating real-world data into the virtual world is important in order to avoid artifacts of the real world hindering the VR experience—
  for example, a wireless H BD application in which the user freely walks about in a room. A real-world obstruction would be represented in the virtual world coincident with the object to let the participant know they should not go there.
- Preparing for a real-world dangerous task. By becoming familiar with a dangerous location, the user can minimize the actual danger when navigating for the first time in the physical world-as might be useful for rescue and mining operations.
- Planning for modifying or using real-world space. Exploring an existing space via the medium of VR can also serve to give the user an opportunity to visualize how the space can be modified or used effectively.
- Educational experiences. For those without the immediate opportunity to visit the locale first hand, it would be possible to experience an existing historic or otherwise culturally interesting location for research or personal edification.

2. Interface to the Virtual World-Output

i. Visual Displays

Most VR systems include some type of physically immersive visual display.The head-mounted display (HMD) system is the most well known; however, it is not necessarily the best visual display for all types of applications. There are a variety of visual displays, each with unique characteristics and technologies for implementation.

We describe five categories of visual display stemming from our three display paradigms.

1. Stationary displays
2. Head-based displays
3. Hand-based displays

Visual Depth Cues

Four varieties of visual depth cues

1.Monoscopic image depth cues: Monoscopic image depth cues are those that can be seen in a single static view of a scene, as in photographs and paintings.
Shading gives information about the shape of an object. Shadows are a form of shading that indicate the positional relationship between two objects. We compare the size of objects with respect to other objects of the same type to determine the relative distance between objects.

2.Stereoscopic image depth cue (stereopsis): Stereopsis is derived from the parallax between the different images received by the retina in each eye (binocular disparity). The stereoscopic image depth cue depends on parallax, which is the apparent displacement of objects viewed from different locations.

3.Motion depth cues: Motion depth cues come from the parallax created by the changing relative position between the head and the object being observed (one or both may be in motion).

4. Physiological depth cues: Physiological depth cues are generated by the eye's muscle movements to bring an object into clear view. Accommodation is the focusing adjustment made by the eye to change the shape of its lens. The amount of muscular change provides distance information for objects within 2 or 3 m.

Properties of Visual Displays

- Visual Presentation Properties
- Color
- Spatial resolution
- Contrast
- Brightness
- Number of display channels
- Focal distance
- Opacity
- Masking

Logistic Properties

- User mobility
- Interface with tracking methods
- Environment requirements
- Associability with other sense displays
- Portability
- Throughput

- Encumbrance
- Safety
- Cost

Five major visual display types

1.Fishtank
2. Projection
3. Head-based (Occlusive)
4. See-through Head-based Displays(AR)
5. Handheld

1. Monitor-based-or Fishtank—VR

The name Fishtank comes from the similarity of looking through an aquarium glass to observe the 3D world inside.
This is the norm in fishtank VR, however, since this is virtual reality, the creator needn't adhere to this constraint-objects can be displayed on the other (near) side of the screen! When this is done, care must be taken to avoid the screen edge cutting off these objects and breaking the frame.

2. Projection-based VR

Projection-based visual displays are stationary devices. The screen may be much larger than the typical fishtank VR display, thereby filling more of the participants' fields of view and regard and allowing them to roam more freely. The size of the display influences the interlace to the virtual world.
Although large display walls can be created by setting several CRT monitors side by side, projection systems can create frameless adjoining displays, making the scene more seamless. Most projection VR systems are rear-projected to avoid the participants casting shadows on the screen.

3. Head-based VR

Visual displays are probably the equipment that most people associate with virtual reality. In this section, we will talk about occlusive headbased VR--displays that block out the real world in favor of the virtual. Unlike fishtank and projection visual display paradigms, the screens in head-based displays are not stationary; rather, as their name suggests, they move in conjunction with the user's head.

4. See-through Head-based Displays

See-through head-based displays are primarily designed for applications in which the user needs to see an augmented copy of the physical world-augmented reality (AR). There are two methods used to implement the "see-through" effect of these displays via optics or video. The optical method uses lenses, mirrors, and half-silvered mirrors to overlay an image from a computer onto a view of the real world. The video method uses electronic mixing to add a computer image onto a video image of the real world, which is generated by cameras mounted on the head-based display

5. Handheld VR

Another visual display paradigm that works well as an augmented reality display is the handheld or palm-VR display. As the name suggests, a handheld VR display consists of a screen small enough to be held by the user.
The handheld display paradigm is largely undeveloped. However, as computing devices become increasingly miniaturized and as people continue to take their computers on the road, palm VR displays will probably become more common, particularly for augmented reality application

ii. Aural Displays

Like visual displays, aural display systems typically fall into one of the two general display categories we've been discussing: stationary displays and headbased displays. Headphones are analogous to head-mounted visual displays.
Headphones may be constructed to isolate the participant from sounds in the natural world or to allow real-world sounds to overlap with virtual sounds. Speakers allow multiple participants to hear the sounds.
High-fidelity audio devices are much less expensive than video display devices, a fact that can be exploited when creating virtual reality systems. Often, the addition of high-quality sound can help in creating a compelling experience, even when the quality of the visual presentation is lacking.

Aural Localization Cues

- Localization is the psychoacoustic phenomenon in which a listener can determine the direction and distance from which a sound emanates, whether in the real world or a virtual world. The brain analyzes the set of cues that indicate where a sound is coming from, and the participant perceives the location of the sound.
- Localization of sound is analogous to the visual depth cues described in the previous section. The term spatialization describes the act of creating the illusion that a sound is emanating from a specific 3D location.
- Transfer functions are mathematical transformations that can be applied to a signal to alter the signal in some specific desired way.
- Transfer functions are used in devices such as the Convolvotron which give the virtual reality application developer a method of simulating these phenomena to create the illusion of directional sound.

- The basic principle of the Convolvotron is that a set of transfer functions is determined for sounds from a variety of locations.

Properties of Aural Displays

- Visual Presentation Properties
- Color
- Spatial resolution
- Contrast
- Brightness
- Number of display channels
- Focal distance
- Opacity
- Masking

Logistic Properties

- User mobility
- Interface with tracking methods
- Environment requirements
- Associability with other sense displays
- Portability
- Throughput
- Encumbrance
- Safety
- Cost

Head-based Aural Displays- Headphones Similar to the head-based visual display, head-based aural displays (headphones) move with the participant's head, are for one person only, and provide an isolated environment.
As with head-based visual displays, one can seal off the real world using closed-ear headphones, or allow real-world sounds to be heard along with synthetic sounds with open-ear (hear-through) headphones.

Stationary Aural Displays-Speakers Speakers are the stationary aural display system. Although speakers generally correspond more closely with projection visual displays, both work well as group presentation devices so it is possible to use speakers with head-based visual displays. One problem encountered with the combination of speakers and projection screens is that one display will often mask the other. If speakers are placed behind the projection screen, then the sound will be muffled; however, if the speakers are placed in front of the screen, then the visuals are blocked.

Haptic Displays

When it comes to believing something is "real," the haptic sense (our sense of touch and proprioception) is quite powerful. By coming into physical contact with an object, its existence is verified. Haptics are hard to fool, which means that creating a satisfactory display device is difficult.

We loosely refer to haptic perception as the sense of touch but, more specifically, haptic perception involves the combined sensations of kinaesthesia and taction.

Kinaesthesia is the perception of movement or strain from within the muscles, tendons, and joints of the body. The term proprioception, which means stimulation from within the body, is often used as a synonym of kinaesthesia, as is the term force feedback or force display. In fact, proprioception also refers to an individual's ability to sense their own body posture, even when no forces are acting upon it, but this ability is entirely internal and is not affected by external devices.

Taction is the sense of touch that comes from sensitive nerve sensors at the surface of the skin. Tactile display includes stimuli for temperature on the skin (thermoreception) as well as pressure (mechanoreception). Mechanoreceptor information is filtered by the nervous system, such that the brain receives information about both immediate and long-term changes in pressure. Mechanoreception enables the brain to sense such things as when an event is occurring or how the surface texture of an object feels as the skin rubs over it.

The primary methods of haptic interface used in and researched for applicability to virtual reality experiences can be divided into four categories.

1.Tactile displays provide information to the user in response to touching, grasping, feeling surface textures, or sensing the temperature of an object.

2. End-effector displays (including locomotive displays) provide a means to simulate grasping and probing objects. These displays provide resistance and pressure to achieve these effects.

3. Robotically operated shape displays use robots to present physical objects to the user's fingertips or to a fingertip surrogate. These displays provide information about shape, texture, and location to the user.

4. 3D Hardcopy is the automated creation of physical models based on computer models, which provides a haptic and visual representation of an object. Since the model is a static object, it functions only as an output system.

Properties of Haptic Displays

- Kinesthetic cues
- Tactile cues
- Grounding
- Number of display channels

- Degrees of freedom
- Form
- Fidelity
- Spatial resolution
- Temporal resolution
- Latency tolerance
- Size

Logistic Properties

- User Mobility
- Interface with Tracking Methods.
- Environment Requirements
- Associability with Other Sense Displays.
- Portability
- Throughput

Tactile Displays

Tactile Displays focus on presenting stimuli to the hands, particularly the fingers. This is because we usually use our hands and fingers when manipulating the world. Also most of our tactile nerve sensors are located in the fingertips. Compared with most visual and aural display systems, tactile displays are not very advanced. The market for these devices is small, so less research is done on them. The most common actuators are simple vibrators, which often substitute for other types of tactile sensation such as pressure

End-effector Displays

End-effector displays are force displays in which the user's extremities (hands and/or feet) grasp or otherwise contact a device that they can manipulate. In turn, this device can become active and respond to the user's actions with resistance and force.

Some end-effector displays are world-grounded. These displays include the ARM, which is ceiling mounted, and the PHANTOM, which either rests on the desktop or is built into a kiosk or stationary visual display. Self-grounded force display devices are worn by the user to restrict and to create movement with respect to some part of their body. One example of a self-grounded restrictive finger device.

Robotically Operated Shape Displays

Robotically operated shape displays (ROSD) refer to haptic display devices that use robots to place physical objects in front of the user's reach. This display typically includes only the user's finger or a finger surrogate.

A finger surrogate is a thimble like or sticklike object with which the user probes the virtual world.

3D Hardcopy

A type of "display" that can be considered a haptic display, though it is not particularly interactive, is known as stereolithography. Stereolithography is one form of automated creation of physical models based on computer models. This is done by solidifying a liquid plastic material a portion at a time, building up a complete object

Applications of Virtual Reality

1.Gaming and Entertainment:

- Immersive Gaming: VR revolutionizes gaming by offering immersive experiences where players can interact with virtual environments in 3D space, such as with Beat Saber or Half-Life: Alyx.
- Cinematic VR: VR is used to create 360-degree films and immersive storytelling, placing viewers inside a narrative.
- Virtual Concerts and Events: Users can attend live events, concerts, or sports matches virtually, such as in platforms like VRChat or AltspaceVR.

2. Education and Training:

- Medical Training: VR allows medical students and professionals to simulate surgeries and medical procedures without risk to real patients, enhancing learning experiences.
- Flight Simulation: Pilots can train in virtual environments, where they can simulate flight conditions, emergencies, and navigation, used by companies like Boeing and NASA.
- Military Training: Soldiers use VR for combat training, battlefield simulation, and strategic planning exercises.
- STEM Education: VR can be used in classrooms for interactive science experiments, historical reconstructions, or virtual field trips.

3. Healthcare:

- Pain Management: VR is used as a tool for distraction therapy in pain management, particularly for burn victims or in rehabilitation for chronic pain.
- Mental Health: VR therapy can help treat PTSD, anxiety, and phobias by gradually exposing patients to feared environments or situations in a controlled virtual setting.
- Physical Rehabilitation: Patients recovering from injuries can engage in virtual exercises designed to improve mobility and coordination.

4. Architecture and Real Estate:

- Virtual Property Tours: Potential buyers can take immersive virtual tours of properties, exploring homes or offices from anywhere in the world.
- Architectural Visualization: Architects and designers use VR to create interactive walkthroughs of buildings before they are constructed, allowing clients to visualize the space.

5. Retail and E-Commerce:

- Virtual Shopping: VR allows users to browse virtual stores, try on clothes, or even customize products before purchasing. Brands like IKEA use VR for virtual showrooms.
- Virtual Fitting Rooms: Users can try on clothes or accessories virtually to see how they would look before buying.

6. Social VR and Communication:

- Virtual Collaboration: VR can be used for virtual meetings, collaborative workspaces, and social networking. Platforms like Horizon Workrooms allow users to interact as avatars in virtual workspaces.
- Social Platforms: VR enables users to connect with others in virtual worlds, attending events, playing games, or just hanging out, as in Rec Room and VRChat.

7. Tourism and Travel:

- Virtual Tours: Users can take virtual vacations, exploring destinations, museums, or historical landmarks in 360-degree VR.
- Hotel Previews: VR enables travelers to explore hotel rooms and resorts before booking.

8. Manufacturing and Industry:

- Product Design and Prototyping: Engineers and designers can create virtual prototypes, which helps in visualizing and testing product designs before physical production.
- Training and Safety: Workers can be trained in dangerous environments like oil rigs or manufacturing plants using VR simulations, reducing risk and improving safety.

9. Sports:

- VR Sports Training: Athletes can use VR to simulate matches, improve reaction times, or visualize strategies. For instance, football players practice in VR environments to improve game-day performance.
- Spectator Experience: Sports fans can watch live events through VR, offering immersive views from the stands or even the field.

5.2

Representation of the Virtual World

VR experience is choosing how to map thoughts, ideas, and data into the visual, aural, and haptic forms that will be presented to the participant. How one chooses to represent the virtual world has a significant impact on the effectiveness of the overall experience. Simply put, representation is the choice of what to render.

First decide how the virtual world should appear and make decisions about what information needs to be conveyed and how best to do this. Once these deci sions have been made, the VR experience creator will have a good idea about what the system requirements will be.

Quantitative and Qualitative Representations

Choosing an appropriate representation depends largely on the goal of the task. One major choice is whether to focus on quantitative or qualitative representational forms. In some cases it might be important to be able to accurately perceive quantitative information from the data

representation and a display that allows users to retrieve numeric values from the presentation, either directly or indirectly.
For other purposes, it might be more important to gain an overall feel for the information, so a high-level qualitative presentation may be required. In the best of all worlds, the same representation might be suitable for both applications, but in reality, the designer normally needs to optimize the representation for one goal or the other. Therefore, it is often important to provide a choice of representations.
Qualitative displays provide a means for quickly getting a sense of the big picture. Often, a qualitative display is created by deriving summary information from the full pool of information to give a representative overall view.

Human Perception

As all representations are eventually filtered through human perception, the application designer must consider human characteristics ranging: from the physiological, to the psychological, to the emotional.
We do feel it is wise for anyone who is serious about creating compelling representations, visualizations, virtual worlds, and virtual reality applications to take advantage of the available material describing the research and opinions on human perception and cognition.

Verisimilitude

Verisimilitude is the quality of having the appearance of truth or depicting realism. Not all applications strive to appear realistic, and some may choose to deviate from verisimilitude in only very specific instances. Participants can still become mentally immersed if they are able to suspend disbelief regarding the less realistic components.

Semiotics

The human brain is optimized for recognizing patterns. Signs and symbols take advantage of this recognition. Some signs are very closely related to the content that they represent, while others are quite abstract in their construction. A sign is some□thing that stands for something else. A symbol is the expression of some content. When we are creating representations, we are actually making choices of signs and symbols that will be used to communicate the content of the message. The field of study dedicated to the use of signs and symbols is called semiotics.

Visual Representation in VR

- Visual perception is generally considered to be the primary means of gaining infor□mation about physical spaces and objects' appearances. A major function of vision in a virtual world is to determine our position relative to various entities. This is useful both to help us find our way through a space and to deal with objects, creatures, and people in the world. A variety of depth cues help us determine the distance and orientation of objects in a scene.

- In addition to seeing where entities are, we can see their form, color, and other attributes that help us learn more about them. Additional information about the nature of the objects can be inferred. The object might be a vehicle for transportation, a building for shelter, a character with whom to interact, or a button to press.
- The virtual world may contain objects visually represented at multiple points on the realism continuum or abstraction triangle.
- We also make inferences about objects by the way they move or change. Not all virtual worlds consist of dynamic objects, but the inclusion of changing objects can make the world both more interesting and better suited for interpreting the relationship between objects in the world. In the real world, the stop sign is often replaced by the more sophisticated (and dynamic) traffic light which also communicates how traffic is allowed to proceed at an intersection.
- Visual displays are also ideal for presenting quantitative information. Numeric displays can be integrated into the visual display through such devices as a temperature readout on a virtual thermometer or heading and speed values displayed on instruments in a virtual vehicle.

Aural Representation in VR

Despite the importance of the visual presentation of a virtual world, the aural presentation is also significant. Sound greatly enhances the participant's ability to become mentally immersed in the world. Sound is compelling. From ambient sounds that give cues to the size, nature, and mood of the setting to sounds associated with particular objects or characters nearby, aural representation is key to user understanding and enjoyment.

Sounds can be attention grabbing. Loud noises or sounds the participant is trained to respond to (such as their name) can be used to call attention to an object or location within the virtual world. Sounds also help determine an object's position relative to the listener.

Significantly, sound is also less expensive to produce, relative to the other display modalities used in VR, so the benefits of sound can be added to a VR experience without spending a lot of money.

- **Sonification:** In the symbolic region of the realism spectrum lies sonification. Sonification is the presentation of information in an abstract sound form. Examples include a sound that varies based on the changing temperature of an object and sounds used to represent levels of carbon dioxide or ozone in the lower atmosphere.

Every sound falls somewhere on the realism continuum. There are general ambient sounds, sounds that mark an event, sounds that continually provide information about the state of something, and sounds that augment or substitute for perceptions made by the other senses.

1. **Ambient Sounds:** Ambient sounds (or background sound) are generally used to set the mood of an experience, a technique well understood and used to great effect by playwrights and filmmakers, for instance. Ambient sounds can have the effect of

making the experience more compelling, increasing mental immersion. They can be used to guide a participant through an experience. For example, a hostile space might have a menacing sound. Of course, this may attract the curious participant, so to keep them away, an outright annoying sound may be used. Mood-setting ambient sounds are often musical and fall toward the abstract end of the realism continuum, but they can also be verisimilar.

2. **Markers:** Markers are sounds that mark the occurrence of some event. The types of events that can be marked include world events, user interface events, sonification events, or sensory substitution events. A world event sonic marker might be the sound of a door closing, an explosion, or the "pluck" of a flower.
3. **Index:** Sounds Index sounds directly map a continuous value (e.g., temperature) to some sonic parameter (e.g., pitch). Unlike marker sounds that denote discrete, fleeting events, index sounds are continuous, and the sound varies to reflect the changing value of whatever it represents, be it temperature, carbon dioxide levels, or other characteristics.

Haptic Representation in VR

We get a lot of information about physical reality from our sense of touch. This is not currently the case in most virtual reality worlds. The lack of haptic sensation is not detrimental for many types of information gathering, however, when touch is an important aspect of an experience, we rely on it heavily. With haptic displays, the trend is to represent the world as realistically as possible. Abstract haptic representations are seldom used, except for interactions with scaled worlds, sensory substitution, and reduction in danger.

The types of information represented by haptic systems include surface properties, such as texture, temperature, shape, viscosity, friction, deformation, inertia, and weight.

Restrictions imposed by most haptic displays preclude the of many types of haptic representations.

For example, a display that presents forces through a stylus typically does not include a means of temperature display.

While haptic display usually comes from direct physical contact, changes in temperature and air movement can be felt in the air surrounding the skin

Subject: User Experience Design With VR