Grasping the Void: Immersion tactics using gesture controlled interaction systems in virtual reality.

Independent Study Thesis

Presented in Partial Fulfillment of the Requirements for the Degree Bachelor of Arts In Computer Science in the Department of Mathematics and Computer Science at The College of Wooster

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2017

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THE COLLEGE OF
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CHAPTER 1

Introduction

One of the largest roadblocks to virtual reality (VR) is creating a successfully immersive experience for a user. The key elements that bring a virtual reality to life are a virtual world, immersion, sensory feedback and interactivity [30]. This paper focuses on sensory feedback and interactivity, specifically interaction systems within a virtual environment that use haptic feedback technology. This chapter provides a brief history of VR and its applications, immersion is explained followed by an introduction of human perception (touch, sight and sound). After an introduction to VR and the role touch, sight and sound play in creating virtual presence, two interaction systems are described that are used with haptic controllers in Unity to create immersion through object interaction. A VR application is created to demonstrate the effect a Newtonian object interaction system has in a virtual environment and its effectiveness in promoting an immersive experience for the user. The goal of this project is to collect the theory regarding human biological and cognitive interaction systems and transfer this knowledge into making a successfully immersive VR application using Unity 5 and the HTC Vive head-mounted display and haptic hardware.

1.1 Defining Virtual Reality

As a growing field, the definition of virtual reality is still in flux and has grown to mean different things in certain contexts. Users of VR naturally have their own interpretations, which differ based on their levels of familiarity with the field. Therefore, it is important to keep the reader grounded to one formal definition of VR in the context of this paper that can be used as a frame of reference. A formal definition is as follows:

> A medium composed of interactive computer simulations that sense the participant's

> position and actions, providing synthetic feedback to one or more senses, giving the feeling of being immersed or being present in the simulation [11].

In other words, virtual reality is a place that exists that we can interact with and experience. In order to create a virtual reality, a virtual world is presented that appeals to our senses in a similar way people perceive reality. VR's singular goal is to display an illusion so successful that the user believes they are somewhere else entirely.

1.2 History

Although VR seems like a fairly new science, the concept stretches all the way back to the 1930's. Alders Huxley and Stanley Weinbaum wrote books imagining movies that extend past just sight and sound to include taste, smell and even touch [24]. These sensory additions work to displace the viewer from their current reality and immerse them in another.

The first concepts of VR were brought to life around 20 years later by a man named Morton Heilig. Heilig created a machine called the *Sensorama*, which offered a virtual bicycle riding experience [24]. This machine enabled the user to observe a three-dimensional display while listening to sounds of a city and experiencing the wind, vibrations and even smells that one would perceive on a real bike ride.

Figure 1.1: Sutherland's Head Mounted Display [8].

In 1976, this innovative technology led Ivan Sutherland to create the first head mounted display that was connected to a virtual environment, seen in figure 1.1. Similar to modern virtual hardware, Sutherland's display consisted of glasses with two small screens that created the illusion of three-dimensional vision. The display allows the user to change what they observed by moving their head. This technology required a complex motion tracking system attached to the ceiling. Although groundbreaking, Sutherland's device did not let the user interact with the virtual environment.

Even though the technology did not exist, Sutherland had a vision of an ultimate stage of VR development, and how it could be achieved. A challenge was set that has motivated the progress of VR ever since:

> The screen is a window through which ones sees a virtual world. The challenge is to make that world look real, act real, sound real, and feel real [15].

The challenge was accepted by a man named Myron Kreuger, who coined the term artificial reality around 1970. Krueger created the first virtual system that allowed a user to interact with objects in a virtual environment. Through various sensors, the user's activities were monitored, allowing feedback within the program. Virtual object interaction was a major advancement towards completing Sutherland's challenge and inspired many new technologies to follow suit.

Since Kreuger, VR development has continued to grow and become more popular, seeing many new innovations. VR in the media played a huge part in the popularization of the term. Movies like Tron and the Matrix imagined virtual worlds so advanced that distinguishing them from reality became nearly impossible. Though VR technology advancements continued through the 70's and 80's, Sutherland's challenge had only been achieved through film and imagination. In the 1990's, the Cave Automatic Virtual Environment, or CAVE was created.

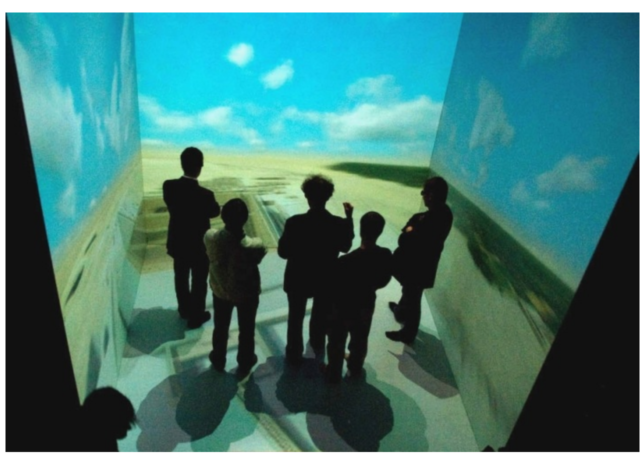

Figure 1.2: CAVE: 4 Screens With 4 Stereoscopic Projectors [22].

CAVE was a large room full of screens that displayed a virtual environment, taking a different approach to VR hardware [24]. One could also wear special glasses that made objects seem more three-dimensional in the eyes of the user. In addition, special sensors and surround sound were also used to promote immersion. Something else unique about this hardware was that and multiple users could fit in a Cave, enabling collaboration within the virtual environment. In just 60 years, the concept of VR was born and turned into a reality. Today, perfectly immersive virtual worlds have yet to be achieved, but the advancements and uses of VR have reached heights previously thought impossible.

1.3 Applications

Virtual Reality enables people's imaginations to run wild. Although the age of consumer VR is just beginning, the current range of applications is tremendous. One of the most prevalent areas of VR is within the gaming industry. Virtual reality gives gaming the potential for a user to become immersed in the virtual world. In lieu of a keyboard and mouse, haptic hardware gives users the opportunity to interact with virtual objects on a whole different level, changing immersive gaming as we know it. The potential for deep immersion, virtual presence and the production value VR has to offer as an industry is driving developers and manufacturers to take part in the emerging field [28].

Figure 1.3: VR Medical Applications [29].

However, new haptic and visual technology are not just being used for entertainment. Virtual reality is already successfully being used in many other applications, some of which are seen in Figure 1.3. The creation of immersive 3D virtual environments has enabled VR to be used in military training, medical training, and all types of design and engineering.These examples are just the beginning. The potential for VR in our modern day society is endless, ranging from interactive tourism to psychotherapy. With more and more foreseeable applications in todays society, the demand and technological innovations will just continue to increase, making VR development even more prevalent and expansive.

1.4 Virtual Presence

VR is a unique form of media quite unlike other medias such as books or movies and should be dealt with as such. To acquire virtual presence while reading a book, the reader must leave their current reality behind to enter the reality of the text [24]. VR requires the opposite. With VR, the user is placed into an environment and is meant to perceive and respond to it as though it were real. Virtual presence is the feeling of actually existing within a a virtual environment. In the words of Albert Einstein, reality is merely an illusion, albeit a very persistent one. Creating a successful virtual environment requires the creation of a successful illusion. An effective illusion is made possible through a strong virtual presence. Virtual presence is achieved mentally, physically, or by a combination of the two.

1.4.1 Physical Presence

Physical presence is an essential part of VR and takes place when the user's body physically enters the simulation or environment. It is truly what sets VR apart from other media. In response to the users actions, select stimuli are presented to the user that affect their perception of the environment. Specifically, virtual environments are described through sight, sound and touch. These sensory perceptions define user interaction in a virtual world and are described in greater detail in the following section.

The goal to obtaining optimal virtual presence is reducing as much real world stimuli as possible. When immersed in the environment, virtual stimuli work to replace the user's exposure to real stimuli, decreasing mental and physical presence in the real world. Physical and mental presence go hand in hand. If physical stimuli are tricked to make you think you are present in a different environment, your mental presence in that environment also increases.

Figure 1.4: Virtual Presence: Fear of heights - save the cat or die trying [21].

1.4.2 Mental Presence

It is possible for a user to be so immersed in a virtual world that it becomes their reality. Figure 1.4 is an example of a game made by Bandai Namco that challenges the user to save a cat from a wooden plank suspended thousands of feet in the air. This game creates mental presence by provoking very real fear among its users, so real that many are not able to save the cat successfully. Mental presence is the non-physical state of engagement felt after entering a virtual world. Achieving and maintaining mental presence is a very delicate and complicated process. There are many factors that affect mental presence. This also means many factors can destroy an immersive process. For example, a sense of virtual realism can be destroyed by small environmental defects because they distract the user from perceiving the scene as legitimate. The level of mental presence is affected by the virtual scenario, the quality of realism, the number of senses stimulated, and the delay between the users actions and its effect on the virtual world. Mental presence within a virtual reality is difficult to achieve because all of these factors must be taken into account. In order to successfully obtain virtual presence, a minimum level of physical and mental presence is key.

1.5 Conclusion

Virtual reality has a rich history and a bright future. The technological advances VR has made in the past 60 years and the current range of applications show the incredible potential of the growing field. For a virtual environment to be immersive, both the mind and body must believe they left their world behind and entered a new one. Physical and mental presence are crucial for a virtual space to be successful. The next chapter dives into the human sensory system and why it must be understood in order to model immersive environments that successfully capture the physical and mental presence of a user.

CHAPTER 2

Human Sensory Perception: Biological and Cognitive

VR is created through an exchange of information between the user and the virtual environment. For VR to be realistic, there must be a certain degree of responsiveness to a user's actions or inputs. Interaction within a virtual environment can be broken down into three categories: manipulation, navigation, and communication. Manipulation allows the user to interact and make modifications to the virtual world and the objects within it. This interaction increases mental presence within an environment by promoting creativity and expression. Navigation permits the user to maneuver through the world, giving an illusion of depth within an environment. Effective navigation techniques require the user to create a mental picture of the environment, inherently promoting mental presence. Communication enables interaction between users and intermediaries in a virtual environment. Having multiple users in an environment enables an exchange of information and experiences [24].

2.1 Human Visual System

Visual perception is considered to be the most dominant sense. Human cognition is oriented around vision, demonstrated by the fact that the visual system is given precedence over the other senses when conflicting inputs are present [15]. A large area of the brain is dedicated to interpreting how we process the information gained from visible light. Because human behavior is so visually oriented, visual perception is given the utmost priority during any virtual experience. Due to the significance of visual perception, the frequency at which intermittent stimulus appear to be steady and in constant motion, or the critical fusion frequency, is an integral aspect of the visual system. Light perception, color perception, depth perception, field-of-view, and critical fusion frequency are vital components of the visual system and are discussed briefly in the next subsections with an emphasis on depth perception.

2.1.1 Light Perception

It is important to understand exactly how light perception works. Figure 2.1 is useful for the following description. First, visible light from the environment enters the eye through the transparent cornea. The light intensity is controlled via the pupil, which can limit the amount of light entering the eye by dilating or contracting. Behind the pupil is the lens, whose job it is to focus light on the retina. The lens, which is attached and controlled by the ciliary muscle, is able to contract in order to change its thickness. Changing the thickness of the lens enables objects at different distances from the eye to be clearly seen [24].

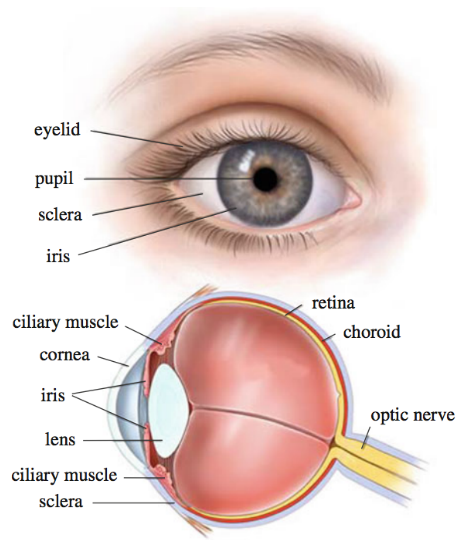

Figure 2.1: The human eye [24].

The retina contains photoreceptors that are specialized light-sensing nerve endings. Photoreceptors can be divided into cones and rods. Cones sense colors, react quickly to light intensity changes, and are less sensitive to light. Rods do not sense color, are more sensitive to light, and allow sight during conditions with low levels of light. The light picked up by these receptors is then converted into an electrochemical signal that travels across the optic nerve. The optic nerve connects to the visual cortex in the brain, which turns the incoming signals into the images we then see [24].

2.1.2 Color Perception

Using the cones in the retina, the human eye is able to sense varying levels of color. There are three types of cones in the eye that are able to pick up different wavelengths of light. The tiny wavelengths of visible light that humans can "see" range from 380 to 700 billionths of a meter, expressed as nanometers or nm. The first cone type senses red light (564-580nm), the second type senses green light (534-545nm), and the third type of cone picks up blue light (420-440nm) [24]. The shorter wavelengths are known as ultraviolet light and the longer wavelengths are called infrared light.

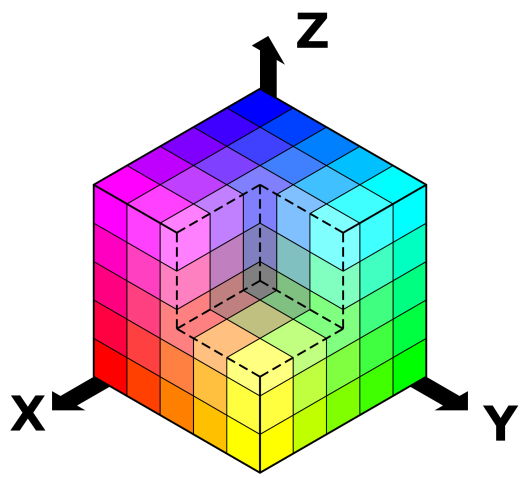

Figure 2.2: Representation of the RGB Model [5].

In virtual environments, modeling is usually done using these primary colors in order to match the three types of cones in the human eye. The most frequently used model is the RGB model, representing red, green and blue colors. This model, seen in Figure 2.2 allows any combination of colors to be created simply by combining a mixture of the three primary colors detectable by the human eye.

2.1.3 Depth Perception

One of the most important functions of the human visual system is its ability to determine the distance to particular objects. This concept, known as depth perception, is extremely important in virtual realty. Since virtual displays do not always incorporate depth into a scene, VR designers must understand depth cues in order to fool the human senses and and create a virtual illusion of depth. The human mechanisms for determining depth can be divided into monoscopic and stereoscopic depth cues.

Monoscopic depth cues are received by just one eye and exist in two-dimensional images. From [24], Monoscopic depth cues include those listed below and several are depicted in Figure 2.3.

1. *Occlusions:* Objects in the foreground obstruct those in the background.

Figure 2.3: Depth perception cues [7][6][12][9].

2. *Shading:* Shading indicates the relative size of different objects and offers an estimate of their shape.

3. *Size:* Size allows comparisons between objects of different sizes, allowing us to gauge their relative distance.

4. *Linear Perspective:* Parallel lines appear to converge at a point as they recede into the distance. This can be used to determine the relative size, shape or position of an object by imagining or drawing these lines.

5. *Surface Texture:* Since the human eye cannot pick up sutle detail at great distances, objects further away have a less sharply defined texture than those that are closer.

6. *Accommodation:* Accommodation is the dilation or contraction of the lens in order to keep an object in focus as its distance from the eye varies. This process allows the brain to estimate the distance to an object based on the lens thickness.

7. *Parallax:* When the viewer is in motion, objects further away appear to move less in the field of view than objects that are closer to the view.

8. *Movement of the view object:* When objects move further away from the viewer, they appear to

grow smaller. When objects move closer to the viewer, they appear to become larger. This information allows the brain to estimate how long an approaching object has before it collides with the viewer.

On the other hand, stereoscopic depth cues combine the information gathered from both eyes. Stereoscopic viewing is the primary way the visual system perceives depth. As objects become further than 30 meters away, many of the geometric benefits of stereopsis fade [15]. This makes stereoscopic depth cues extremely effective for observing objects that are at closer distances. From [24], the stereoscopic depth cues are the following:

1. *Convergence:* The process where the eye turns inward toward an object in order to focus on that object, pictured in Figure 2.4. This process allows the brain to judge the perceived depth of that object.

2. *Stereopsis:* A process that allows depth to be estimated based on the difference between what the left and right eye perceive.

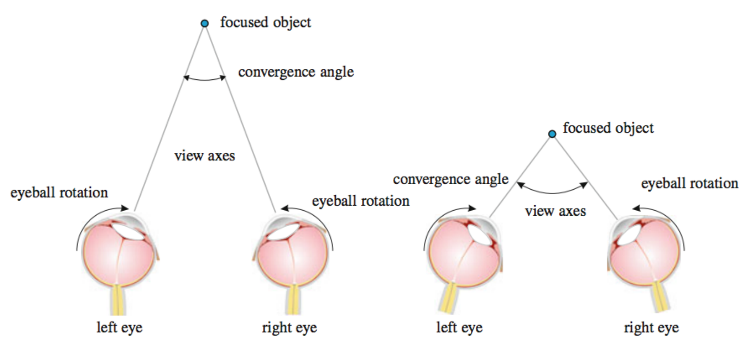

Figure 2.4: The Process of Convergence [24].

If there are conflicts between different depth cues, stereopsis takes precedence over all others [23]. A virtual environment can be designed using any of these cues to create a perceived feeling of depth. The more cues that are incorporated into a scene, the more realistic the illusion of depth becomes.

2.1.4 Field Of View And Critical Fusion Frequency

Field-of-view, and critical fusion frequency also have an important role on the visual experience of immersive virtual scenes. The complete field of view for human eyes is around 180 degrees

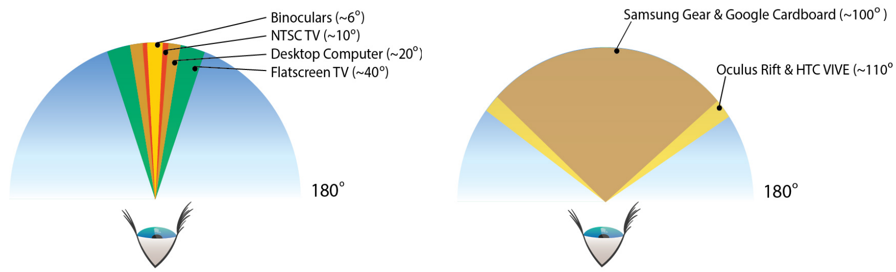

Figure 2.5: Field of view comparisons [20].

horizontally, and over 120 degrees vertically. Therefore, in order to create a successful optical illusion, the field of view should be 90 to 110 degrees [15].

Different head mounted displays offer varying fields of views. As seen in Figure 2.5, the HTC Vive offers 110 degrees, an optimal field of view for VR applications. The critical fusion frequency is the rate that humans can distinguish between successive visual stimuli. For example, when the frequency is too small, object movement is choppy and no longer fluid. In computer graphics, a rate below 30-60 Hz results in this effect.

A narrow field of view and low frame rates in VR cause distraction and remind the user of their presence in a virtual setting. Visual displays, like the VIVE, require stereoscopic vision and must deliver stimuli of acceptable resolution, high-quality motion representations and satisfactory levels of brightness [15]. Given the significance of the visual system, visual displays have become the most important piece of VR hardware. However, head mounted displays are not always enough. Virtual environments should not only engage a user's visual and auditory senses, but also offer user interaction mechanisms. Haptic hardware is able to create interactive connections between the user and their environment, an aspect absolutely critical in achieving an immersive application.

2.2 Human Haptic System

The word *haptic* comes from the Greek verb *hapto*, meaning *to touch*. Haptic refers to the exploration and process of identifying objects through touch [23]. An effective VR system utilizes haptic devices to enable a user to interact with objects in a virtual environment through gestures. Figure 2.6 shows the HTC Vive, an example of a commercially popular head tracking system that is also equipped with haptic controllers. A haptic device mimics tasks that would normally be performed in the real world, such as gathering information about an object and its properties. A haptic interface is a

Figure 2.6: HTC Vive with hardware - including haptic controllers [31].

device that measures a position or contact force and displays that contact force or position to the user. To put it even more simply, a haptic interface receives motor commands from the user and displays haptic images back to the user [23]. The human hand allows a user to push, grasp, squeeze or hit objects. When transfered into a virtual space, being able to touch, feel and manipulate objects results in a level of immersion that is not possible without a haptic system. Haptic hardware in VR allows the user to perceive information about the virtual world, and the rules that govern it. Many new games use haptic hardware that allows the user to interact and manipulate objects in the virtual world. A game called Job Simulator, illustrated in Figure 2.7, implements these strategies to allow the user to interact with objects as part of the storyline. The inability to have this level of interaction within an environment makes it impossible for a user to truly perceive a virtual world as real.

Figure 2.7: Job Simulator: An interactive game that uses haptic hardware and object manipulation as it's primary tool for creating an immersive experience [1].

Haptic perception is different from vision and sound because it provides the ability to sense and also act upon an environment. Through touch, different types of information can be gathered when manipulating objects in the environment. The human haptic system is divided into three subsystems made up of sensory capabilities, motor capabilities and cognitive capabilities. Sensory capabilities use kinesthetic and tactile senses to derive information about the environment through touch. In VR, sensory capabilities can be used to give the user cues and insight on the virtual world and its rules. Motor capabilities use the musculoskeletal system to gain information about and manipulate objects through interaction. Cognitive capabilities use the central nervous system to analyze information gathered from an environment and plan motor functions based on the objectives of the tasks. When designing haptic interfaces, understanding the haptic system is imperative.

2.2.1 Sensory System

Sensory information can be broken further into subclasses consisting of tactile and kinesthetic information. Tactile sensors transmit information to the brain about an object when initial contact is made. This information is gathered by low-threshhold mechanoreceptors in the skin such as a fingertip [23]. When the hand is stationary and comes into contact with an object, tactile sensors are the ones to transmit information concerning that object. The type of information gathered by tactile sensors can range from the fine texture, size, softness, slipperiness and temperature of an object. On the other hand, kinesthetic information conveys the position, movement and forces acting on a limb [23]. When an arm or other limb is active in free space, this kinesthetic information gives insight regarding the natural shape, compliance and stiffness of surrounding objects. During any active task, sensory information is simultaneously gathered from both types of sensors, giving the brain constant feedback.

2.2.1.1 Kinesthetic Perception

The Kinesthetic system is primarily used to acquire information about the forces generated by certain muscles, and the resulting movement of limbs. However, kinesthetics also refers to the perception of force, an aspect extremely relevant in the topic of haptic interaction systems within virtual reality. Mechanoreceptors provide information to the central nervous system about static muscle length, muscle contraction velocity, and forces generated by muscles [23]. Other sensory information regarding the change of limb position are acquired from receptors in the joints and skin. The receptors in the skin play an important role in tactile exploration and interpreting the position and movement of the arms. This subsection gives an overview of the kinesthetic receptors, specifically mechanoreceptors, which are responsible for the perception of movement, force, and the position of limbs.

Mechanoreceptors are found in muscle spindles and are classified as primary and secondary receptors. Seen in Figure 2.8, muscle spindles, found in muscles, are .5-10 mm in length and made up of bundles of muscle fibers [23]. Muscle fibers are attached at both ends to muscle or tendon fibers and are responsible for generating muscle force. These spindles identify changes of tension and length within muscle fibers. The primary role of muscle spindles is to act as an automatic safety device for the muscles. When the muscle is overly stretched, the spindles respond by stimulating a muscle contraction in order to prevent the muscle from extending or stretching too far. These automatic muscle contractions, or reflexes, are important for controlling movement and balance.

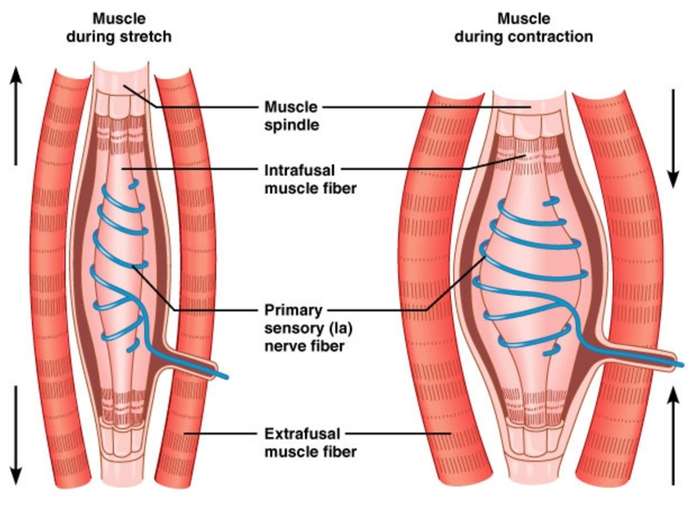

Figure 2.8: Kinesthetic Receptors [2].

Each mechanoreceptor, primary and secondary, react to a change in muscle length and act accordingly. The primary spindle receptors dynamically respond to changes in muscle length by dealing with the velocity and acceleration aspects of movement. The job of the primary receptors is to modify the sensitivity of muscle spindles based on the muscle's length, contraction history, and current velocity of muscle contractions [23]. Primary receptors actively influence the velocity, direction and movement of a limb. In contrast, the secondary receptor's job is to output a constant static measurement of muscle length and position of the limb. Normally, an area with a high density of mechanoreceptors means a highly functional tactile system. However, in a kinesthetic system, a higher density of receptors does not always mean better kinesthetic capabilities [23]. Instead, the size of the muscle, not the functionality, dictates the number of muscle spindles present.

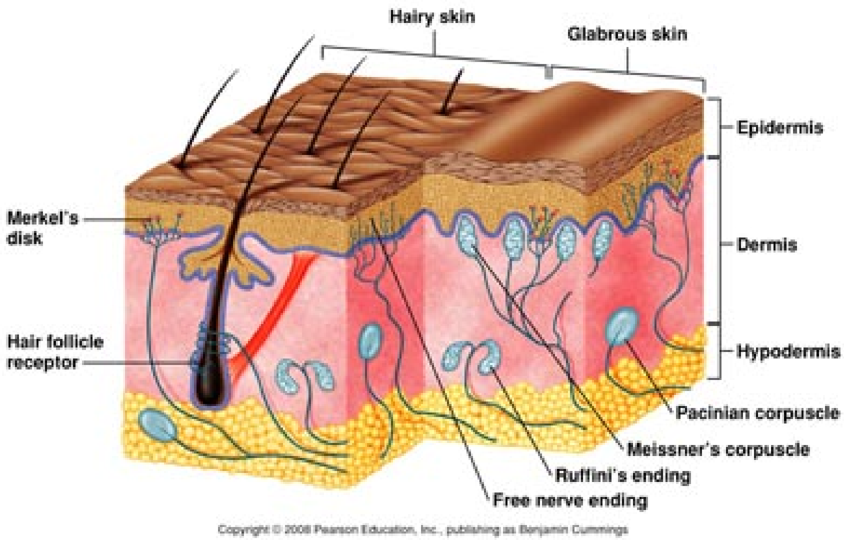

Figure 2.9: Ruffini Endings and Pacinian Corpuscles [3]

In addition to spindle receptors, there are other types of mechanoreceptors used within the human haptic system, displayed in Figure 2.9. Located where the tendon attaches to the bundle of muscle fibers, the Golgi tendon organ provides information about force exerted by muscles [23]. The Golgi tendon organ essentially serves as a safety mechanism by reducing muscle tension when the muscle is under an excessive load. Ruffini endings and the Pacinian corpuscles are other mechanoreceptors found in the joints. The Ruffini endings sense angle and angular velocity of the joint movements. The Pacinian corpuscles are used to estimate joint acceleration and have a natural sensitivity that responds to both vibration and pressure [23].

2.2.1.2 Tactile Perception

While the kinesthetic system works to acquire information regarding force and the movement of limbs, the tactile system defines and interprets sensations acquired through touch. The various and complex sensations generated during object interaction are made up of a few specific components. Roughness, lateral skin stretch, relative tangential movement and vibrations make up the sensations we receive when interacting with these objects [23]. The mechanoreceptors in the skin define the texture, shape, compliance and temperature that are all perceived through touch. Specifically, the Meissner's corpuscles, Pacinian corpuscles, Markel's disks and Ruffini corpuscles are the sensory organs in the skin that define a sensory experience. These sensory organs and their properties are displayed in Figure 2.10

These four types of mechanoreceptors differ in size, receptive fields, rate of adaptation, location

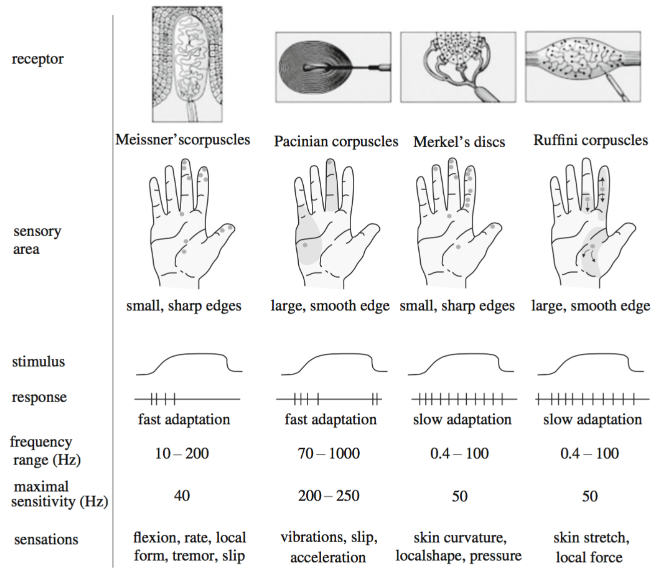

Figure 2.10: Properties of Mechanoreceptors [23].

in the skin and physiological properties. Spatial resolution depends on where the receptors are located in the skin. Certain receptors have large receptive fields, which means they have a low spatial resolution. Others have small receptive fields, meaning they have a good spacial resolution. Each receptor also has a different rate of adaptation. When a receptor has fast adaptation, it detects short pules of sensory information. An example of fast adaptation is the initial contact with an object or the detection of a vibration. A slow speed of adaptation means the receptor detects a constant stimulus, like a constant pressure. Figure 2.10 displays the rate of adaptation of receptors in the skin.

Like color perception, the quality of a sensory experience is determined by a combination of responses from different receptors. Receptors are able to achieve a wide detection range for detecting vibrations and frequencies ranging from 0.4 to 1000Hz [23]. Frequencies over 500Hz are no longer felt as vibrations, but as having textural qualities. Given the properties of a tactile system, specifically the perception area, duration and frequencies are important for modeling interaction systems in virtual environments.

2.2.2 Motor and Cognitive Systems

In addition to sensory capabilities, the motor system and the cognitive system make up the human haptic system. The motor system allows for active exploration of an environment and manipulation of objects within it. The cognitive system associates action with perception [23]. When designing a haptic experience in VR, understanding how these different haptic subsystems function and work

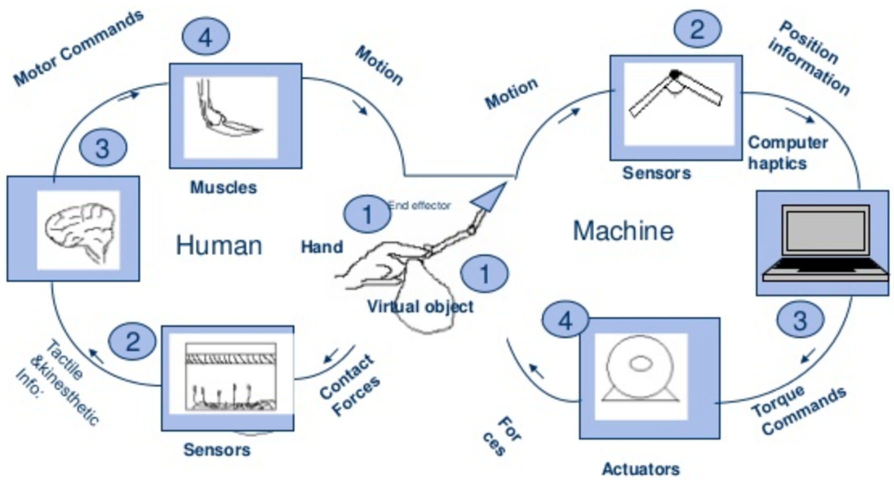

Figure 2.11: Human-Machine Haptic Interaction [14].

enables a designer to build an interactive and realistic virtual environment. Figure 2.11 displays how the haptic subsystems work together with a haptic hardware device to control the position of the hand and exert forces to simulate contact with a virtual object. The sensory, motor and cognitive systems all work together to construct a haptic experience. Both tactile and kinesthetic sensory information compose contact perception, while motor commands allow movement and navigation through an environment based on the cognitive objectives [23]. The more haptic subsystems used to define a virtual experience, the more a user feels engaged and immersed within that experience.

2.3 Aural System

While vision is primarily used for virtual perception and haptic controllers provide interaction systems, the use of sound is invaluable. Visual systems provide spatial information about an environment that exist in both space and time. In contrast, aural systems provide temporal information in a virtual space that exist in time and not space. The timing of sound presentation is therefore even more critical than the timing of image presentation in VR [23]. In addition, since sound is perceived the same no matter what direction a user is facing, sound is not limited by the orientation of the head. When realistically implemented, sound increases the feeling of mental immersion and provides informative cues about a virtual environment. Hearing and sound perception allow for verbal communication. Verbal communication increases situational awareness, cues visual attention and presents complex information that vision cannot always provide us. Audio perception requires the ability to synthesize sound and to locate and pinpoint auditory stimuli within a 3D space.

The most efficient hearing frequency in humans occurs between 1000 and 4000 Hz [15].Hearing is classified as a remote sense because it is used to detect the position of objects relative to a user.

Given that VR exists in three-dimensional space, three-dimensional sound must be implemented. A concept called *sound localization* represents a phenomenon that allows users to identify the distance and direction of a detected sound source [23]. Within a virtual environment, auditory stimuli can be generated using location-dependent filters to enhance a users virtual presence. In such environments, Stereo, or auditory, clues can be given for the users to evaluate. These stereo clues can exist for the users to make assumptions on elevational changes or to determine directivity [15]. Sounds can also be generated to approximate distance. Since sound decays the further away it is, the amplitude of a sound can be used as a distance cue for a user. Creating an illusion that sound originates from specific points in virtual environment creates a sense of realism for the user.

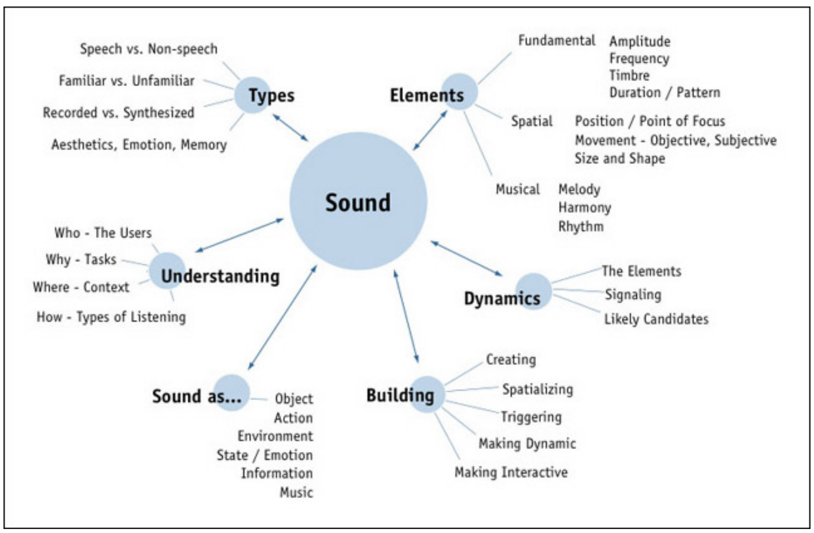

Figure 2.12: The Complex Nature of Auditory Processing [26]

The challenge for auditory implementation in virtual environments stems from the complexity of auditory perception, illustrated in Figure 2.12. Different types of sounds attract different types of attention. Ambient sounds give clues about the size and nature of an environment. The desired mood of an virtual environment is constructed through different ambient sounds. Individual objects can have sounds associated with them to give an understanding of each object and to demonstrate different possible actions that can accomplished with each object. Auditory processing is absolutely crucial but often overlooked in virtual settings due to the complexity of implementation.

2.4 Design Guidelines

2.5 Conclusion

Chapter 3

Interaction Systems

3.1 Introduction to Unity

Unity is a professional game engine that is used to create video games and virtual environments for a variety of platforms. Unity has two distinct advantages over other game development environments. The first is Unity's extremely user friendly visual workflow. Other game development tools are often overly complicated and require the user to set up their own integrated development environment, or IDE. Unity's visual editor is both sophisticated and extremely productive, allowing high quality games to be produced with relative ease and efficiency. The second advantage is Unity's wide array of cross-platform support. There are very few game engines that offer as many deployment targets, ranging from the PC, web and mobile to consoles. Unity also makes deploying to these platforms extremely simple. Compared to other game engines such as Unreal, CryEngine, or Game Maker, Unity stands in a fantastic middle ground in terms of the difficulty to learn and desired capabilities in engines. These comparisons and characteristics are brief examples of what makes Unity the engine of choice for many developers.

3.1.1 Unity's User Interface

Unity's user interface is split up into different tabs and sections as seen in Figure Blank

The Project tab is used to view and access all the files in your project and the Console tab is available to view the output from your code. The Scene tab allows you to view the objects placed into the 3D scene and the Game tab lets you view the 3D scene as though the game is being played. The Hierarchy tab shows a list of all the objects in the scene and how they are nested in relation to each other. The Inspector tab displays information about the object selected and lets you change different components. The Toolbar provides scene navigation, including Move, Orbit, and Zoom functions. Unity's interface allows the user to easily create a 3D scene, however scripting is what brings a project to life.

3.1.1.1 Scripting

Writing code in Unity is what controls your objects in the visual editor and makes the game interactive. The game objects in Unity are built as a collection of components. This collection of components often include scripts, which refer to code files. Another nice aspect of Unity is code is not compiled and run as a separate executable, but instead executed within the Unity engine itself. Being able to test your game in a separate window without the inconvenience of having to create builds is very substantial. Unity supports both Javascript and C-sharp programming languages, although C-sharp is often preferred because it is strongly typed. When it comes time for writing scripts, picking an ideal IDE or text editor is important. Unity comes bundled with MonoDevelope, which is the IDE of choice because it is open source and offers cross-platform support for C-sharp.

3.1.2 Creating VR Through Unity

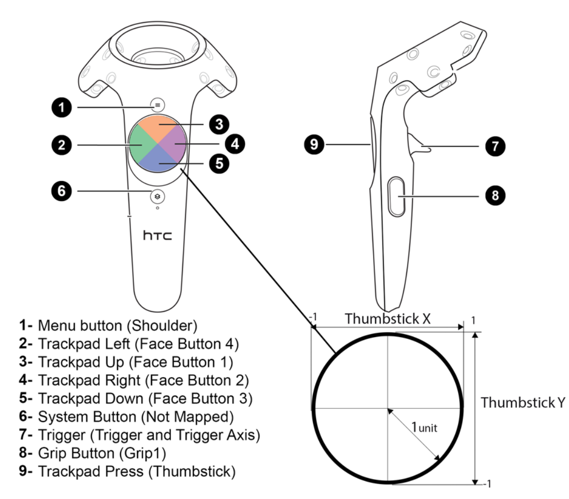

Figure 3.1: Vive Controller Inputs [4]

A distinct difference between virtual reality and an average game is the fact that when immersed in a virtual environment, quality is not just how good something looks, but how good something feels. Building an environment in Unity is one thing, but turning it into virtual reality involves a few extra steps. With a virtual reality application, different hardware is required, often with different types of input. With the HTC Vive, an effective user interface and realistic interaction systems must be implemented using the motion tracking capabilities and various input buttons on the Vive's controllers. Figure 3.1 displays all the inputs that can be utilized by the controllers.

A graphical user interface (GUI) is also essential for presenting information. A GUI refers to two-dimensional on screen graphics that overlay the main gameplay and present messages, gauges, or input controls such as menus buttons or sliders [18]. In typical non VR games, a user interface is rendered in screen space, which statically rests somewhere on the screen as an overlay, such as a screen edge. In virtual reality, there are no screen edges, and the GUI must be rendered in what is called the World Space. Figure 3.2 shows a common approach taken by Oculus to display a main game menu. Although somewhat intrusive to the central scene, this style and placement for a GUI is easy to access a great alternative static main menu screen.

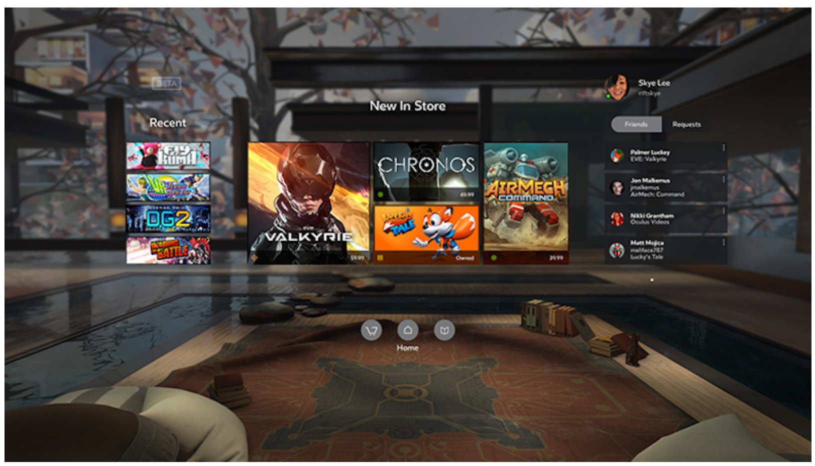

Figure 3.2: VR Game Menu - World Space [16]

3.1.3 VR Motion Sickness

Despite the wonders of VR immersion, it is also known to cause feelings similar to motion sickness such as disorientation and nausea. VR motion sickness is a fairly substantial concern and is studied by many researchers, physiologists and technologists to find the underlying causes. We do know that lag caused by screen updates and synchronization problems when moving your head are a major contributing issue. Given the potential impact rendering permanence, frames per second and latency have on a virtual reality application, optimizing implantation and content must be at the front of any developers mind [15]. Although these are the major issues corresponding to virtual reality motion sickness, there are a few others we should consider [18]:

1. Don't move too fast.
2. Look forwards when moving through a scene.
3. Avoid turning head too quickly.
4. Use a third-person camera in certain settings.
5. Provide visual cues to keep user grounded.
6. Provide an option to recenter the view.
7. Cut scenes break and transitions.
8. Optimize rendering performance wherever possible.

3.2 Steam VR Plug-in

3.3 Naive System

3.3.1 Allowances

3.3.2 Shortcomings

3.3.3 Improvements

3.4 Newtonian System

3.4.1 Theory

3.4.2 Allowances

3.4.3 Improvements

CHAPTER 4

Implementation Theory

4.1 Implementing New System

4.1.1 Haptic API's

4.1.2 NewtonVR Functions

4.1.3 Deciding Which Objects Should be Interactable

4.2 The Improvements

4.2.1 Low-Polly Worlds verse High Polly Worlds

4.2.2 Better Immersion

4.3 Applications

CHAPTER 5

Final Application Results

5.1 Asset Pack Model

5.2 Applied Theory and Software

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