V-SPHERE RUBIK'S BOOKCASE INTERFACE FOR EXPLORING CONTENT IN VIRTUAL REALITY MARKETPLACE

A Thesis

by

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ABSTRACT

In this work, we developed a new interface concept for content exploring in immersing Virtual Reality environments. In our shopping interface, we represent products as true 3D shapes with global illumination effects. This representation can provide more realistic and consistent Virtual Reality experience. Our shopping interface is really a giant spherical Rubik's cube that consists of closed loops of book-shelves or cabinets. Users, who are located inside of this spherical Rubik interface will feel like they are in front of a spherical bookcase that consists of an infinite number of rows and columns. They can view the products by simply sliding rows horizontally and by sliding columns vertically. Further more, we discovered additional scenarios where users can grab the products by distance and examine their suitability by placing them into real environment. This new 3D interface concept can help to develop more realistic 3D interactive shopping framework in the future.

DEDICATION

To my committee chair Dr. Ergun Akleman, committee members Dr. Ann McNamara & Dr. Richard Furuta, the employees of the Visualization Department, and my family.

CONTRIBUTORS AND FUNDING SOURCES

I would like to thank my chair of my committee, Dr. Ergun Akleman. I could not finish my thesis without his help and guidance. I thank my committee member Dr. Ann McNamara for her insightful feedback and constructive criticism. I would like to thank Dr. Richard Furuta for teaching me a lot of knowledge of computer-human interaction. Staci Dunn has been very helpful for keeping me informed with time lines for graduating. The Department of Visualization is really an outstanding program with outstanding faculty and staff. I would like to thank everyone and I am very proud of being one of the students here. Finally, I want to thank my mother and father for their understanding and encouragement.

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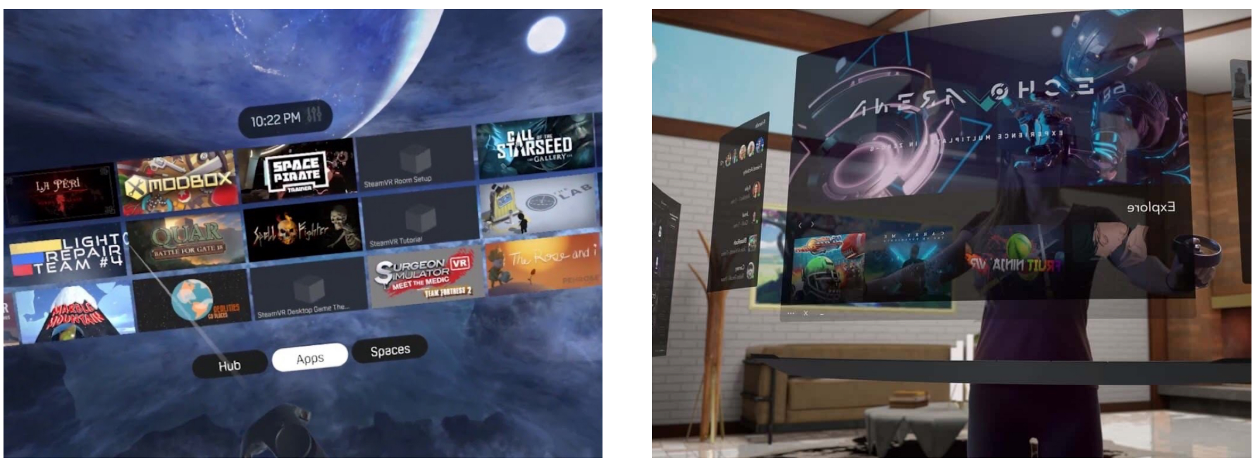
1. INTRODUCTION AND MOTIVATION

Virtual reality is a computer-generated world which enables users to immerse in that environment and produce a sense of presence or "being there". Immersion is a key feature in virtual reality [6]. Virtual reality is simulating the 3D world which makes the world look real, sound real, and respond realistically to the viewer's actions. A virtual reality environment should be immersive, believable, explorable and interactive. The user interface is playing a more and more important role in the current virtual reality marketplace. However, they are mostly built in 2D by using flat or curved panels which passing information to users, and most importantly, those interfaces have rich interaction patterns (See Figure 1.1).



(a) Htc Vive User Interface [44]

(b) Oculus Debuts Dash and Home Software Interface [34]

Figure 1.1: Examples of User Interface in Current Virtual Reality Marketplace

The constrains of 2D interface in virtual reality are obvious. It is not possible to obtain 3D look which is expected in 3D world and in virtual reality. Also, the 2D virtual reality interface does not include realistic global illumination effects such as reflection, refraction and soft shadow. They do not look truthful as the real world and definitely interrupt the streamlined experience in

3D world. Therefore, there is a need for proposing a new concept and framework to solve those problems. In this work, we developed a new interface concept for content exploring in Virtual Reality environment. In our shopping interface, products were represented as true 3D shapes which obtains global illumination effects. To demonstrate the usefulness of our concept, we created a V-Sphere Rubik's bookcase interface and mechanisms stimulating the real-world interactions. Two additional scenarios are created for product viewing and placing, as election and manipulation are major interactions in 3D virtual world and physical world as well. It is a creative breakthrough to embrace virtual reality technique and geometry.

How to generate a realistic scene in Virtual Reality? Global illumination [33] is the vital factor. Global illumination, also known as indirect illumination, is usually used in 3D computer graphics. While images rendered with direct illumination only look fake, images rendered with global illumination could achieve photo-realistic. With global illumination, lights can bounce among objects, so that an object can take lights reflected by other objects' surfaces which generates a realistic shadow, reflection, and refraction. When scenes are rendered with global illumination, they not only generate more realistic effects but also have dynamic shadows and reflections of objects. However, we learned from the Unity document that there are many GI limitations when designing for virtual reality environments [21]. GI baked in Unity could only support static objects. In this process, the indirect illumination is pre-calculated and stored for efficient computation of realistic soft shadows. The moving objects can not bounce light onto other objects.

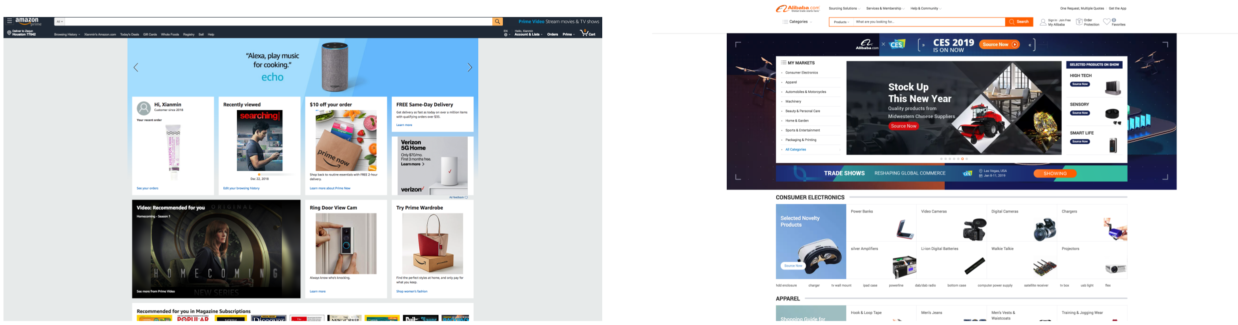
Before the internet age, window shopping [57] (See Figure 1.2) is the most popular approach for people browsing products . It refers to an activity where a customer browsers and investigates a product without a instant intent to purchase. Customers normally step into the shop when they were attracted by objects which greatly incites their activities.

Accompanied by the emergence of the internet, a new trend of shopping approaches has been accepted by the popularity with its user-friendly and attractive user interface. People are using e-shopping at home by just clicking one button on the website, or swiping a page for viewing and purchasing on the smart phone. Meanwhile, advertising which is embedded in the page also

Figure 1.2: Window Shopping

drives business growth [2]. Electronic commerce is the cutting edge for today's business, the user interface usually consists of plenty of hyperlinks, buttons, and icons. Although many stores are quite successful in attracting customers using window samples, there are yet many stores facing difficulties in increasing traffic. The interface design is so critical for the E-commerce store to present product information. A well-designed store could deliver information more accurate, and a user-friendly work flow could ensure a successful experience for customers to visit and make a purchase (See Figure 1.3).

The user interfaces for normal software applications are becoming more and more diverse. Mice, keyboard, icons, and menus, all these standard elements emerged in the early eras of interfaces are still fashionable nowadays. The Interface Design for desktop, web, and mobile applications are a relatively mature field comparing to the Virtual Reality world. There are plenty of user interface design guidelines for designing these applications, such as Google material design, iOS UI guidelines, IBM design etc. We understand that different stages of design should satisfy different users' requirements. As in the shopping activities, the UI design need to consider user requirements such as which kind of the products to present, how to categorize the products, what



(a) Amazon Homepage, 2019 [50] (b) Alibaba Homepage, 2019 [49]

Figure 1.3: E-commerce Store Homepage

the layout looks like, what color pattern should be adopted, where the advertising should be placed, what interaction patterns should be used for user browsing and searching, etc. The main user activities in an e-commerce site is stimulating the customers' experience in the real-world purchase. However, it would be a challenge for users to find the items they need since one e-commerce site usually sells thousands of items. Above all, the design quality and reducing customers' transaction risk are essential elements for impacting customers' choice in e-commerce store [31].

While most studies were focused on shopping in the web, or on the phone, there is no widely-used design guidelines or design instances addressing shopping experience in virtual reality. With the new technology, new problems have been revealed and nontraditional devices or interface components are proliferating rapidly. The spatial devices like 3D pointing devices, whole-hand devices, head-mounted displays, spatial audio systems, and haptic devices are also emerging. People often find it inherently difficult to understand 3D spaces and to perform tasks in free space [22]. Virtual reality is really an uncharted territory. However, regardless it's traditional shopping, e-shopping or virtual-reality shopping, the purpose remains the same. The design is to make items attractive and satisfying user's needs in shopping activities.

The virtual reality environment is composed of a range of 3D graphics and avatars. When customer was placed in a realistic 3D environment, they need to feel immersing and are able to explore and interact with surrounded objects just like in the real world. Thus, researching a new paradigm interface and creating a realistic user interface in virtual reality environment becomes necessary. In virtual-reality shopping, virtual sensory affluence could affect customers' experiences in browsing product information more richly and engaging in more actively during the shopping activity [30]. The authentic and attractive items as prerequisites are crucial to increase customers' engagement in browsing items.

1.1 Motivation

A true 3D experience goes much beyond simple stereo parallax, perspective, and shading. For realistic 3D interaction, there is a need for inclusion of global illumination effects such as shadow, reflection, refraction, caustics, subsurface scattering, and even realistic haptic feedback. Unfortunately, since some of these effects are harder to obtain in real time at interactive speed, people try to develop essentially 2D interfaces in virtual reality environment. With the recent developments in technology, we can expect some of these global effects can be obtained in real-time in interactive environments. Therefore, there is now a need for new 3D interface paradigms that can be used in such virtual reality environments that can provide true 3D experience.

Looking at the user interface in the current virtual reality marketplace, they are mainly composed of curved panels or flat panels. The advantage of using these 2D panels is to reuse the rich interaction patterns which were already been explored and testified in 2D UI systems. But there are limitations and disadvantages. Firstly, it could not possibly obtain a 3D look which is expected in virtual reality. Secondly, the 2D interface does not include realistic global illumination effects such as reflection, refraction, and soft shadow. Those limitations prevent to provide a streamlined experience in a 3D world.

1.2 Principles of User Interface Design

The interface interaction principles and guidelines are relatively mature in the computer and mobile based applications. Shneiderman [58] offers practical techniques and guidelines for interface design based on his 20 years of experience. He proposed eight golden rules of interface design. Making a consistency operation action is critical for users to get familiar with the digital landscape without a need to learn new representations for the same user actions. The users are grouped into several levels based on their familiarity with the digital product system which are beginners middle-level users, and experts. Providing shortcuts to experienced users is an effective way to operate the interface. Users should know where they are all the time and could find a way to go back. For example, the navigation, such as breadcrumbs, always places on the pages, so the user knows where they are. The user should still know what the next step for their operation is. To design dialogue to yield closure. The shopping website could create a thanks dialogue to notify the user they have finished purchasing. The customers might operate an error action, but the system should intuitively remind the user to make the user avoid the error and help them to solve this problem as soon as possible. A great user interface should win the user's trust and let them know how to reverse their operation. Human attention is limited, and they are only capable of maintaining five items at one time. The simpler interface the better. How to make a simple and intuitive information hierarchy is an essential part of the user interface design [41].

1.3 3D User Interface

Designing 3D interfaces have not yet reached the same state of maturity as 2D UI systems. There are yet no cohesive 3D interface paradigms. Although many 3D interaction techniques and devices have been reported, there is no common vision to form a cohesive picture that guild the interface designer a clear direction in designing and building spatial interfaces [5]. Compared to the 2D interface, the 3D interface has its advantages to obtain realistic 3D look which could ensure a realist and streamlined experience as every other objects in the same environment are in three dimensions as well. 3D user interface design is a critical component of any virtual environment application [45] (See Figure 1.4).

Designing for the 3D environment is very similar to designing for everyday things. Take Norman door [36] [37] as an example (See Figure 1.5), when people first saw the door handle, they want to push it to open. While it does not work, people have to pull it to open. Norman door is a ill-designed object which fails or confuses the user whether to push or pull it to open it. Norman also proposed two important features of the good design. The first feature is discoverability. The designer should keep in mind that if the users are possible to figure out what actions to take and

Figure 1.4: Example of 3D User Interface in Virtual Reality

where and how to perform them? The second one is understandability. What does it all mean? how is the product supposed to be used? What do all the different controls and settings mean? The design of the door should indicate how it works without any need for signs. Bad design often appears in people's daily lives, so we need designers to help us to create usability guidelines and generate more products which are ease of use.

It is a similar situation when designing for user interfaces in virtual reality environments. There are challenges to overcome. It is extremely difficult to design the dynamic 3D models, and has it rendered realistically is computationally expensive. The interactivity is not easy to obtain which increases the difficulty of creating dynamic modals. Unlike designing for 2D applications where designers have plenty of design guidelines and principles to follow, designing for virtual reality is totally a different thing. It's really an uncharted territory.

Figure 1.5: Norman Door

1.4 Rubik's Model

Rubik's Cube [56] is a 3D combination puzzle invented in 1974 by Hungarian sculptor and professor of architecture Ernő Rubik [13] [15] . Rubik's cube as a Multidimensional Model is very accessible to both children and adults [14]. It includes six faces, and each face contains a large number of small faces. Each face could rotate in x, y, z-direction separately. The interesting fact of the Rubik's cube is that it could formulate all kinds of patterns which have visually different looks (See Figure 1.6). It is a popular geometric puzzle that each face could be twisted in three directions in the space [18]. So imagine that, if the user stands inside the Rubik's cube, and each faces reverse, it's just like the user has been placed in a cube room. The user could interact with each item in the room by twisting them in all three dimensions. Also,there are many variations of Rubik's Cube. For example, spherical Rubik's cube, V-Sphere, Professor's cube [55] and Pocket cube [54] (See Figure 1.7). Our approach is to start with a dynamic bookcase, for instance that we examined spherical bookcase and toroidal bookcase to consider what kind of the dynamism should be, and how to model limitless bookcase with these models?

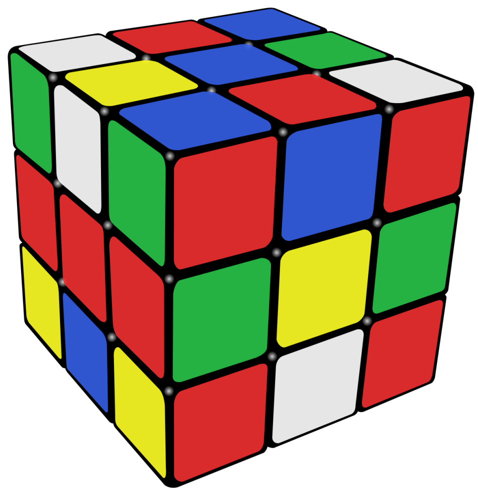


Figure 1.6: Rubik's Cube Model

1.5 Visual Fidelity

Virtual Reality [32] as a new medium has drawn considerable attention in the last few years. People want to step into a new world and interact and experience with 3D objects. In 1965, Ivan Sutherland [43] proposed an idea of the virtual reality which makes the world look real, sound real, and respond realistically to the viewer's actions. It is an artificial world which is constructed by interactive graphics, sound, smell, tastes and force feedback [42]. A Head Mounted Display (HMD) was created by Ivan Sutherland which supports a view according to the user's head position and orientation. With the developing of visualization techniques, a new application called architectural walkthrough systems emerged [8]. Another impressive application called the Visual Wind Tunnel was developed at the NASA Ames Research Center [9] [10]. Scientists could manipulate the streams of virtual smoke in the airflow around a digital model by using a data glove. Those applications need the support of input and output devices. Meanwhile, the virtual environment needs to simulate the real world, and people should have the pieces of knowledge on how to "fool the user's senses" [23]. There are five human senses, sight, hearing, smell, touch

(a) Rubik Sphere (b) V-sphere (c) Professor's cube (d) Pocket cube

Figure 1.7: Variations of Rubik's Cube

and taste, while the visual system contributes a lot up to 70, and the second most important sense is hearing. Smell, touch, and taste as five of the human senses do not play a significant role in general, because of difficulty in simulation.

As we know, visual information is the most significant aspect of creating the illusion in a virtual world, and it could make the people have a feeling of "being there." The output devices need to stimulate human eye to generate a realistic visual illusion. The human eye has both vertical and horizontal field of view (FOV). The horizontal view has up to 120 degrees binocular overlap based on the limitation of cheeks and nose. The vertical field of view has up to 150 degrees based on the restriction of cheeks and eyebrows [20] (See Figure 1.8).

Based on human eye structure and research on human perception, human vision could be divided into central vision and peripheral vision [46]. Central vision is the most important part of a person's vision. It is used to read, drive, and see pictures or faces. Good central vision allows people to perceive colours, shapes, and details clearly and sharply. Peripheral vision is a vision as it occurs outside the centre gaze. Peripheral vision allows people to see objects all around them without turning their head or moving their eyes. It helps people to sense information [59] (See Figure 1.9).

Most HMD were designed based on the theories of human vision. Same as the user interface systems in virtual reality, the objects in users' central vision are usually highlighted so that users can see the details clearly, and there are also objects or UI components placed in users' peripheral

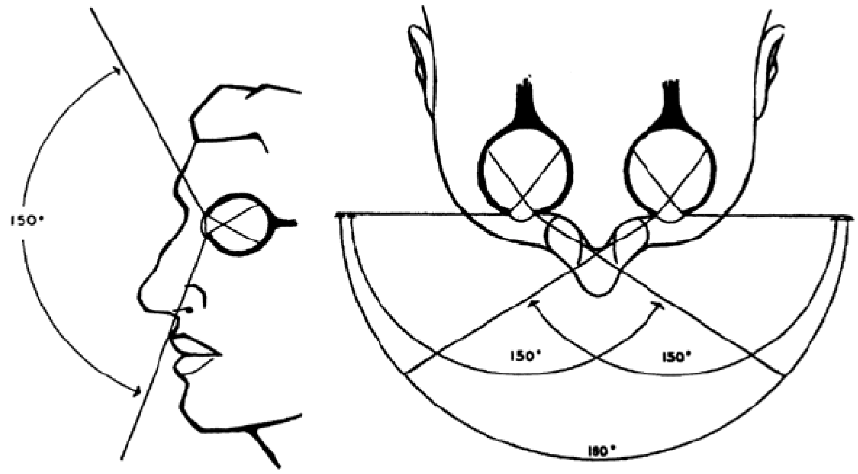


Figure 1.8: Human Field of View: Vertical and Horizontal

vision zone so that users are aware of the surroundings. Sutherland proposed that virtual reality should be indistinguishable from "real" reality (RR). Most of the current applications are recognized poor quality and lacking a sense of reality. To enhance the sense of present, the user interface design should not only focus on components in users' central vision, but also leverage users' peripheral vision to inform users where they are, and draw their attention to certain spots not in the central vision zone if necessary.

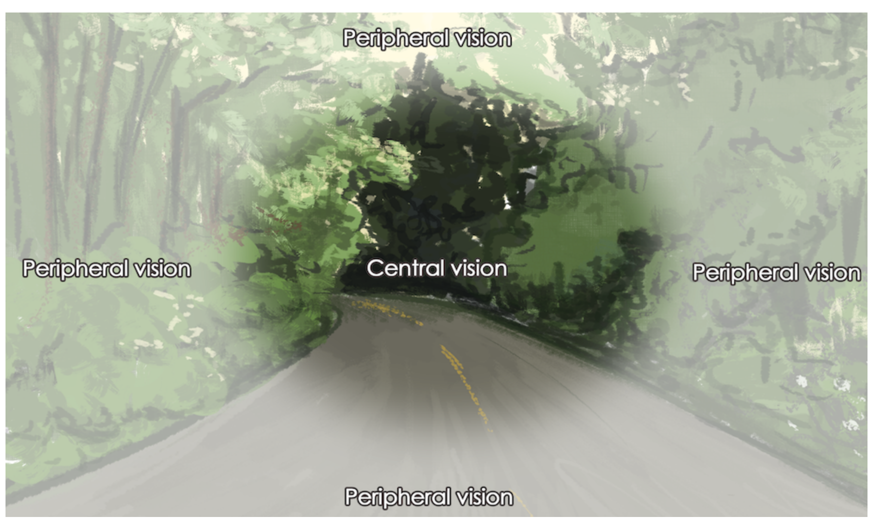


Figure 1.9: Entire Visual Field in One Eye

2. BACKGROUND AND LITERATURE REVIEW

Computer graphics [47] has been used in many domains, from the art industry, education, to psychology, medicine, and architecture. With the development of the microprocessors, better and faster computers emerge everyday in the market. Those machines are equipped with faster graphics boards. It is hard to imagine that engineer, architecture or interior designer who can work without a graphics workstation. Artists and engineers could work on better and high-quality pieces with the advanced graphics and it brings the design to a 3D world.

Virtual reality is defined in the online Oxford dictionary as a computer-generated environment which simulates a real interaction and a 3D image by using a special electronic equipment [16]. VR promised to be the next big thing. Doug et al. [7] presented that the goal of the VR environment is to create a real environment which let the user experience a computer-generated world, and produce a sense of presence or being there, in addition, they mention that real experience is not a single outcome of immersion. From the experiment, it also demonstrated that all aspects of immersion could provide advantages. In some types of phobia therapy, realistic auditory and haptic stimuli play a more critical role than realistic visuals. Mazuryk et al. mentioned that sight as the primary human senses provide the most of the information passed to our brain and capture most of our attention. Therefore the stimulation of the visual system plays a central role in both the virtual and physical world.

Yu et al. [60] proposed that visual realism enhances realistic response in an immersing virtual environment, people might carry out actions unconsciously. People have different emotions in front of different objects. They might laugh when facing a funny event, or be scared by a horror scene. Visually realist scenes are generally created by accurate models and realistic illumination effects. Global illumination in the 3D environment could bring realistic experience for people. However, there are many rendering problems. Real-time rendering is computational complexity, and the frame rate is daunting. As we know, ray tracing [48] and radiosity [19] are considered the global illumination solutions for VR rendering, but it still has many limitations. Ray tracing could solve real-time shadows and reflections, but the performance is still limited by the update rate and complexity of the scene elements.

Virtual-reality shopping as an emerging shopping medium receives much more attention in the modern e-commerce period. As well-known, in the traditional e-commerce shopping sites and mobile applications, people usually interact with the user interface by clicking the hyperlinks, icons, 2D graphics, menus, etc. Those elements in an e-commerce shopping application could shape users' behavior and feeling of engagement. In contrast, in the VR shopping mall, users interact with items or user interface components on the basis of 3D graphics and avatar. Lee and his teammates conducted a study to test whether the user interface of the VR shopping mall can provide higher interface involvement than the ordinary shopping mall. The results show that convenience, enjoyment, and quality assurance as variables provided more improvements than an ordinary shopping mall. Those variables improved customers' satisfaction in the VR environment. Virtual presence, virtual sensory affluence are strongly related to the user interface. The user interface of the VR shopping mall is characterized by 3D environments and 3D item visualization, generating an sense of immersion for the consumers. VR is a medium capable of yielding immersion [3]. Consumers could grab objects or zoom in target products just like they are in the physical world. It gives consumers a sense of presence. Also, people could immerse in the realistic 3D environment and play around with the realistic products. Mo matter the user is in traditional shopping or VR shopping activities, the shopping mall should display items as accurate as possible for customers view and select.

There are not plenty of studies on 3D user interfaces regarding shopping activities, especially in the virtual environments. However, plenty of user interfaces have already existed in video games [28] (See Figure 2.1). Creating a useful and intuitive interface is essential for improving the overall usability. Danil and Janet proposed how important of the flow [12] in creating a compelling user interface design in computer games [25]. When in a flow state, one becomes absorbed in an activity. Jennet et al. mentioned that millions of people accepted computer games and the modern games usually have varieties of virtual environments for the user to explore [24]. They also pointed out that a good video game always draws people in, good video games always make people 'lost' themselves. They describe themselves 'in the game,' such experience refers to the term 'immersion.' Jennett et al. implement three experiments to demonstrate that the immersion could be measured both in a subjectively and objectively way, while Luís Miguel Alves Fernandes et al. presented a research that two participants who have experienced the same VR environment were recruited to use two different devices to test the user experience of a multi-modal educational video game prototype [1]. The prototype exposed learning potential, facilitating entertaining, authentic, situated, and self-oriented experiences. Also, the authors believed that the prototype is providing the user a sense of immersion, high fidelity, interaction, and flexibility which incites the user to take a part of it. The paper also presented evidence that the 3D interface could successfully be applied in an educational video game.

Figure 2.1: An Interface Example of Games of Glory

Bowman et al. presented an overview of 3D interaction and user interface in their paper. 3D user interface is a critical component of any virtual environment application. They mentioned that the successful 3D interface should be designed based on human factors in computing system. Designers should also reuse interactions techniques, then it has to employ creative approaches to invent interfaces. Finally, a successful interface should use existing models and strategies of 3D interface design. They also mentioned that we should borrow design ideas from 2D user interface into 3D user interface, seamless integration of 2D and 3D interaction techniques. In addition, selection and manipulation is a major interaction in 3D virtual world and physical world. Interaction techniques for 3D manipulation in virtual reality environment should provide three basic tasks: object selection, object positioning, and object rotation. They also mentioned that selection and manipulation could improve quality of user interface in virtual environment.

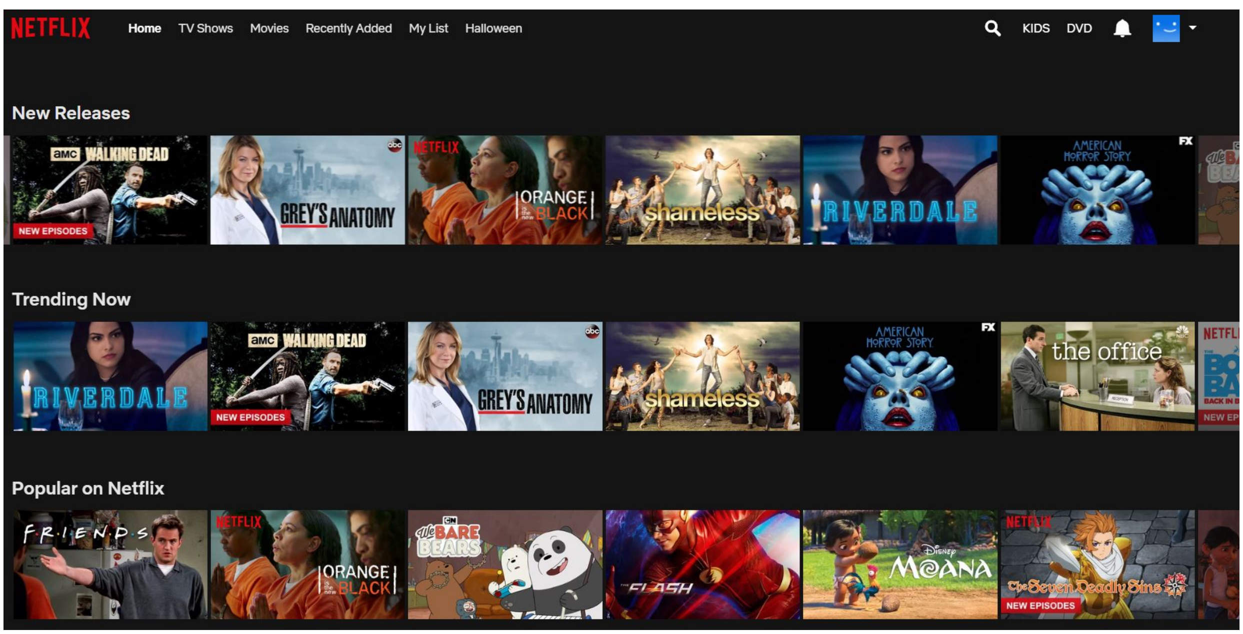


Figure 2.2: An Example of the Netflix TV Interface

Additionally, the 3D interface is gradually being used in the virtual reality environment. In 2017, Hyo Jeong Kang [26] began his experiment work in the field of virtual reality. In this paper, he proposed three types of interface in the virtual environment: 2D interface style, 3D skeuomorphic interface style, and interface that combines features of both 2D and 3D interaction techniques . He proposed their initial hypothesis and expected outcomes. He mentioned that the user perceives the product easily by utilizing the 2D interface. The 3D skeuomorphic interface could incite an enjoyable exciting experience, while the integration of 2D and 3D interface could let the user get the highest satisfaction. However, the outcomes were not demonstrated.

Compared with the 3D user interface and interaction, 2D user interface design and interaction is pretty mature in normal web and mobile application design. Many researchers have proposed and demonstrated their theories. Shneiderman [40] offered practical techniques and guidelines for interface design. Effie et al. mention that the user experience includes all aspects of interaction in products and systems[29] [35]. Netflix (See Figure 2.2) is a media-services provider . It provides online movie and TV shows right on smart TV. The interface has experienced several periods of iterations. It founded in 1997 by Reed Hastings and Marc Randolph in CA. The redesigned interface is aiming to help users get watching faster and find the content easier [27]. Stephen Garcia, a Director of Product Innovation at Netflix [17] mentioned that the new TV interface makes the Netflix experience intuitive and straightforward. It is easier to watch and view new content and make an easy way to save the title for later viewing. The testing also showed that the simplicity of the interface helps customers find the content they are interested to watch. The horizontal rows could be scroll when users click the arrow button to switch the movies, and they can also scroll each row separately. The tile turns larger when hovering on it, and the page would turn into the detailed page by just clicking on it. It used a large amount of horizontal scrolling arrangement to allow users to greatly immerse in the movie exploring activity.

Rubik's cube, as a 3D combination puzzle, is composed by a bunch of hexahedral boxes, and each hexahedral box could slide separately in x, y,z directions. Rubik's cube could work as containers like cabinets or bookshelves, and products could be placed in it. The containers and items in the environment work as a 3D interface so that consumers could view the products by merely swiping the shelves horizontal or vertically. The consumers could view and manipulate all different kinds of items in the 3D world. There are many variations of Rubik's cube, and V-Sphere is one of them. It is a specific spherical shape based on Rubik's cube. This geometry can meet the needs of people for the 3D user interface and we still need to dig dipper in this field. However, there are few papers which are related to Rubik's cube and virtual reality. There is one paper which is talking about playing Rubik's cube in mixed reality. Sato et al. described a prototype system for virtual objects manipulation in a mixed reality environment. From this paper, it informed the movement of Rubik's cube in virtual environments [39].

3. METHODOLOGY

Based on theories of human eye structure and human visions, we know people have the central vision and peripheral vision. People can perceive and see information around them. Based on this, we are assuming people could perceive more information in front of the curved panel than the flat one. Our initial 3D interface comes from a modal of bookcase. We came across a bookcase in the office which is composed of several rows and columns, and there are a bunch of books on it. The books cast the shadow on the bookshelves. Then we consider what the 3D interface looks like if it would be a dynamic bookcase (See Figure 3.1a). What kind of dynamism should be and how to model limitless bookcase? After a few days of research, we find there are several possible solutions, for an instance, spherical bookcase and toroidal bookcase (See Figure 3.1b). Those two models aligned with our initial ideas which could be slid horizontally and vertically in the 3D space.

Given the limitations of 2D interface and the structure of the human eye, we proposed the Spherical Rubik's 3D Interface (See Figure 3.2). In this interface, the products will be placed on each shelf of a cabinet that is composed of a Rubik's cube. These shelves will visually form a 3D curved interface. The user will be located in the center of the Rubik's cabinet, where the user could view and manipulate the 3D interface horizontally and vertically. Each column and row in the space should be able to scroll. We will try to develop several interactive mechanisms for content exploring. Considering the selection and manipulation are important actions in the VR world, we will discover more scenarios for viewing the products in detail and placing items in a new environment.

To address the limitations of current rendering techniques in virtual reality which will affect global illumination effects such as reflection, refraction, and soft shadow. In addition, those limitations will prevent to general a visually realistic and appealing scene. Realistic is a significant factor for VR shopping, it plays an important role in ensuring an immersing shopping experience. Thus, in this work, we decided to design the new 3D interface paradigm in Maya which refers to

(a) An Example of Bookshelves

(b) An Example of Curved Bookshelves

Figure 3.1: Examples of Bookshelves

how to create a spherical Rubik's bookcase interface.

How to create a spherical Rubik's modal? We investigated many different approaches in Maya. Our need for this modal is it must have the ability to slide vertically and horizontally. All of the components of the spherical Rubik should have a common pivot, and each item should be placed in the spherical Rubik's model. Then we have to explore the different interaction patterns upon the structure. The most important proprieties of the spherical Rubik's model is it could formulate all kinds of patterns when the user twists the faces in the 3D space. In the next step, we have to come up with an effective way to create a realistic environment. We are planning to use Maya to help us to generate a realistic 3D environment and considering all the design of lighting, texture, and rendering methods. Beyond that, we also need to explore more applications to understand common

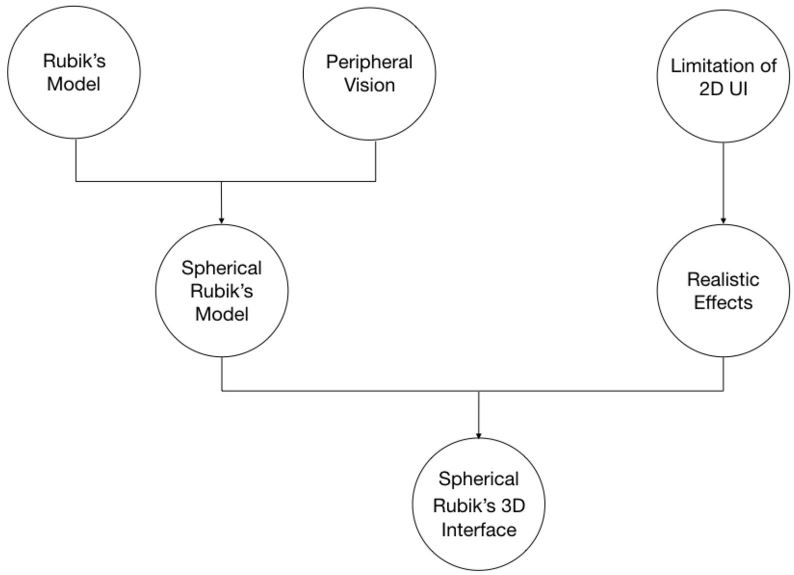


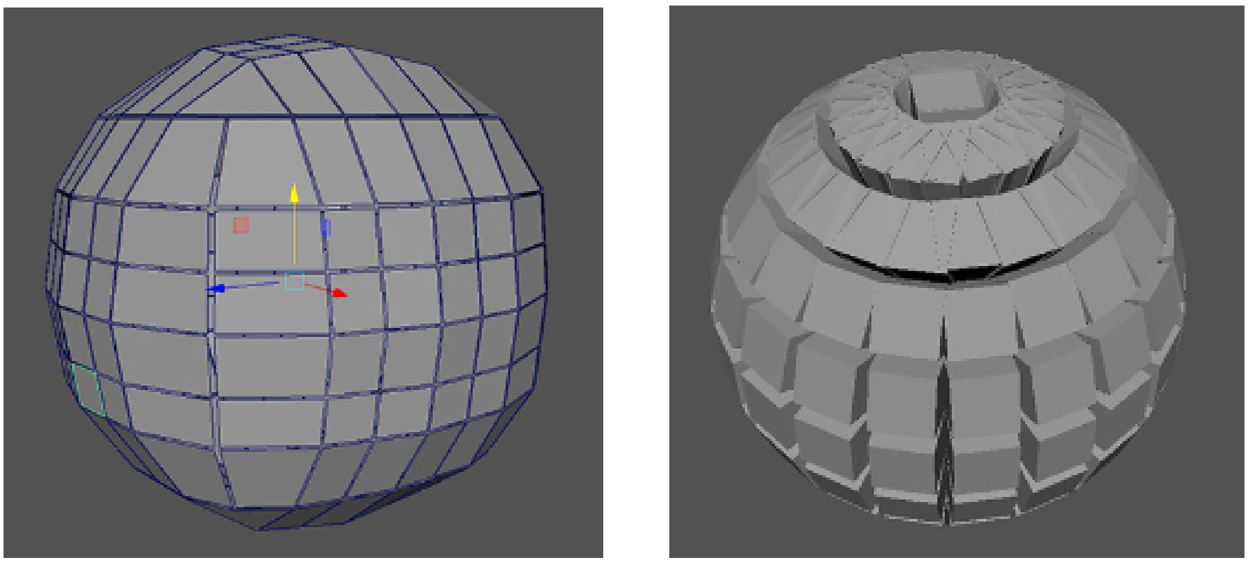
Figure 3.2: Conception Flowchart

content exploring patterns. For an example, we played Netflix TV to experience the connection and interaction between the users and the environment. The patterns of using a remote to interact with the TV interface is very similar to interacting in the VR environment with a controller.

Based on the requirements for creating the spherical Rubik's modal, our process requires three stages to obtain a realistic 3D interface: (1) Creation of Spherical Rubik's Cube Model; (2) Exploration of Interaction Patterns; (3) Creation of Realistic Environment; In this phase, a true 3D interface paradigm concept is proposed and created.

3.1 Creation of Spherical Rubik's Cube Model

In the Creation of realistic environment stage, it includes three steps, the first step is lighting design, the second step is texture design, the last step is designing the rendering methods. Each of these stages is simple and intuitive. The first and most critical stage is the creation of spherical Rubik's model. As we know, the human eyes have both vertical and horizontal field of view, the horizontal view is up to 120 degrees based on the limitation of noses of cheeks, while the vertical is up to 150 degrees based on the restriction of cheeks and eyebrows. Also, people could feel the surrounding stuff based on peripheral vision. Thus, we proposed a curved modal so that users can perceive more information in the VR environment. Based on this preliminary concept, we explored a wide variety of solutions. The first try is a sphere model. We are trying to cut a sphere



(a) The first attempt. (b) The second attempt.

Figure 3.3: The First Two attempts of Modeling a Spherical Rubik's Cube.

into several parts and drag vertices to formulate a rough spherical Rubik's cube. However, this approach could not ensure an accurate model and it is too time-consuming. It generates a lot of unnecessary vertices, edges, and faces, and each single element is not equal (Figure 3.3a). An accurate model is vital for generating a realistic and appealing experience. So we started over with another approach, a hexahedral box (See Figure 3.3b). For the development of a virtual 3D interface, we decided to cover a spherical surface with the same type of hexahedral boxes that can move freely. We calculated the radius of the sphere and then used sine law [53] to calculate the length and the width of the hexahedral box (See Figure 3.4). However, when we rotated the cube and look at it from the upper side of the sphere, we noticed there are a lot of hexahedral boxes overlapping with each other. With this approach, we could only create an approximate subset of a sphere. We discarded this method and try to find a more effective solution to make an accurate model.

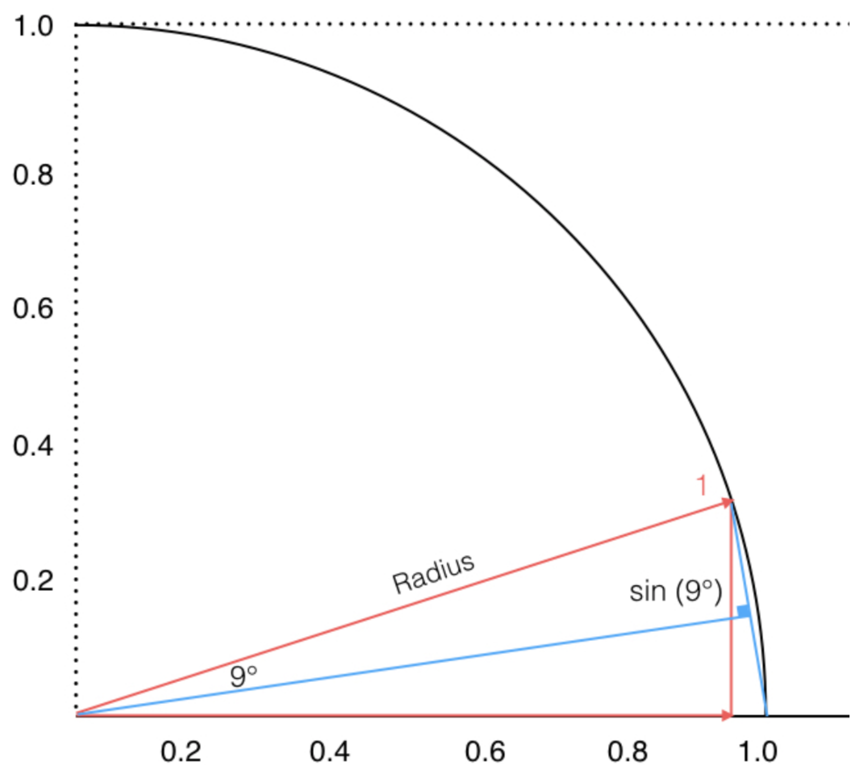


Figure 3.4: Mathematics Formula

Then we moved on to the third approach. We started with a cylinder geometry and separated it into 20 parts. Then we deleted nineteen parts and only kept one sector in Maya. After that, we used the extrude function in Maya to make the sector into a hexahedral box [51] (See Figure 3.5). In the next step, we turned the hexahedral box model into a container by using extrude function and finally we rotated the container element 19 times with 18 degrees, and a single axis was created. From there on, we rotated the single axis twice in y and z directions with 90 degrees separately, then we got a three axes model. In the last step, to close the modal up, we covered the three axes model with the sphere which helped us to generate the overall model. After all, this solution helped us to generate a relatively accurate model compared to the other two approaches. So we decided to go with this solution.

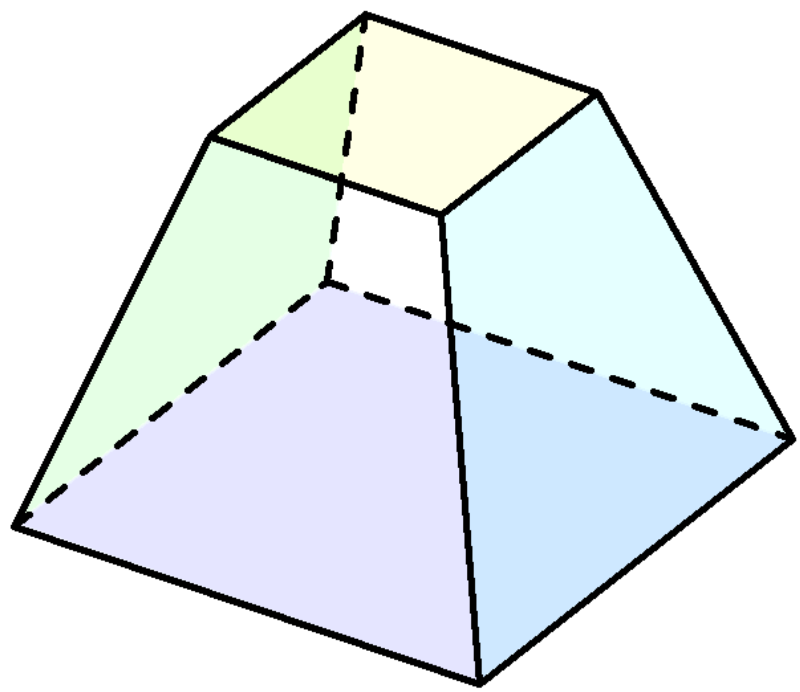


Figure 3.5: An Element of Hexahedral Box

3.2 Exploration of Interaction patterns

Imagine people staying in the center of the spherical Rubik's cube, and they can interact with the objects by using ray-casting in the virtual reality environment. The spherical cube is composed of a range of columns and rows of the hexahedral boxes. However, those boxes could be slid in horizontal and vertical directions. We are planning to put several items on our bookshelves so that hey could cast the shadow on the shelves and reflect light from other surfaces to stimulate the real world environment.

With the 3D bookcase interface, what are the possible interaction patterns for content discovering? In this stage, we are trying to think of all possibilities of the interaction patterns. To discover interaction patterns, we started look at 2D interface systems. From the literature review, we know that it is a good solution if we could borrow design ideas from a 2D user interface into a 3D user interface, seamless integration of 2D and 3D interaction techniques. Inspired by the Netflix TV interface in which people can target a certain TV show by just pressing the "up, down, left, right" buttons on the remote controller, we proposed similar interaction patterns that users can also press the certain buttons to make the targeting interface move correspondingly. So we started with 2D prototypes trying to illustrate concepts of different interaction patterns.

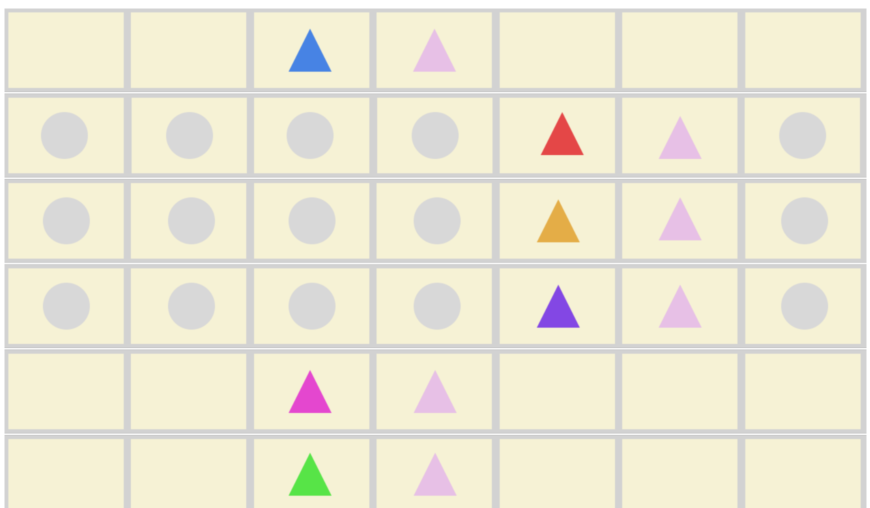


Figure 3.6: Global Horizontal or Vertical Slide

We proposed three different interaction patterns. The first pattern is global movement, which means that the whole spherical Rubik's cube could be rotated. Customers could get a general idea about what type of store it is, what the overall items are there. They could get a sense of rough product information quickly. People could move the whole structure just like rotating the entire Rubik's model, they can do it either horizontally or vertically. This pattern gives them an overview of all the items (See Figure 3.6).

The second pattern is multi-row and multi-column slide. People can zoom into a couple of rows and columns and slide those rows and columns only. With this pattern, people could get information of specific items. It helps users target multiple items(See Figure 3.7).

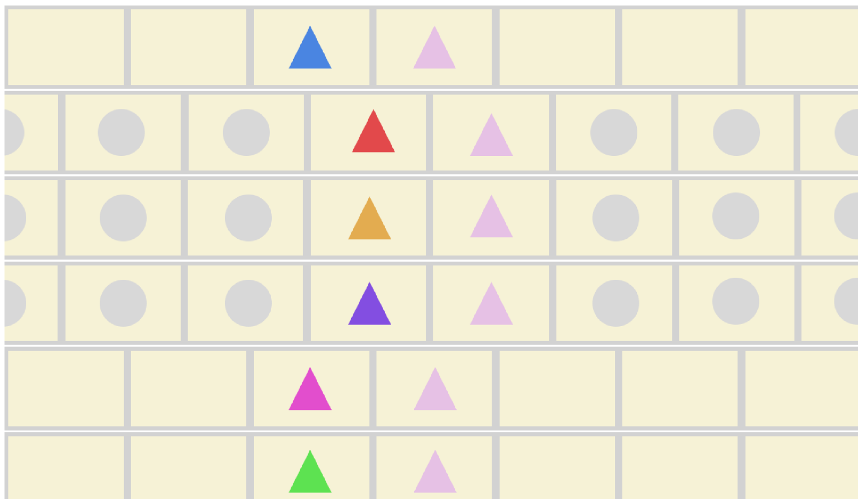


Figure 3.7: Multiple Row or Column Slide

The third pattern is a single row and single column slide. In this pattern, the user can really look into a specific row or column and slide that row and column only. In this pattern, the products could be swiping separately in horizontal and vertical directions (See Figure 3.8). For example, if all the chairs place in x directions and tables place in y directions. People could only swipe x-axis to view all types of desks, then display all kinds of tables in the y-axis.

Once people learned enough about all of the products, the next step is to examine details of products they are interested. So we are planning to implement a function called "distance grab," with which people could grab an item closely and view them carefully. We do not exactly know if the product fit the environment or not if people are planning to buy this product. So we provide people with an environment to place the product and see how it looks like in a real situation.

3.3 Creation of Realistic Environment

In this stage, we mainly focused on how to create a realistic 3D environment. Lighting, surfacing and rendering methods are playing an important role in generating a truthful 3D world. So

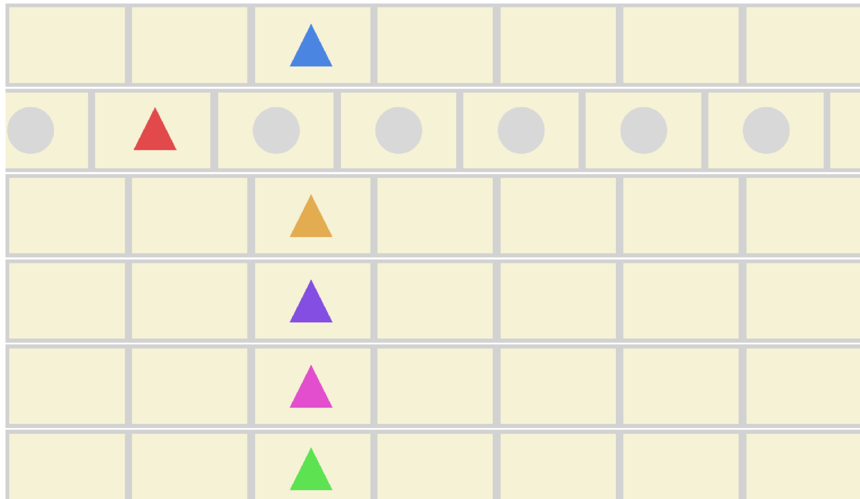


Figure 3.8: Single Row or Column Slide

we separate this stage into three parts. The first part is lighting design, the second phase is texture design, and the third part is rendering method design.

In the creation of lighting phase, we used three different types of lighting methods to illuminate the environment. The first one is PxrRectLight, and it works like a one-sided area light to stimulate softboxes used in photography. It was also used for adding bounce lighting off the walls. We used a light with the specular amount of 0.2. Since our 3D environment takes reflection, we do not want to generate too much light on the surface of the cabinets. It could avoid adding highlights. The second one is PxrDomeLight in which we add a high Dynamic Range Image. It could help generate the scene with a more realistic effect. This light simulates environment lighting which works via Image Based Lighting to illuminate sets and characters with an environment map. The third light is PxrEnvDayLight. It helps generate the scene with a more simple and realistic effect. In this scene, Renderman for Maya supports Global illumination effects, and this technique could yield high quality realistic results.

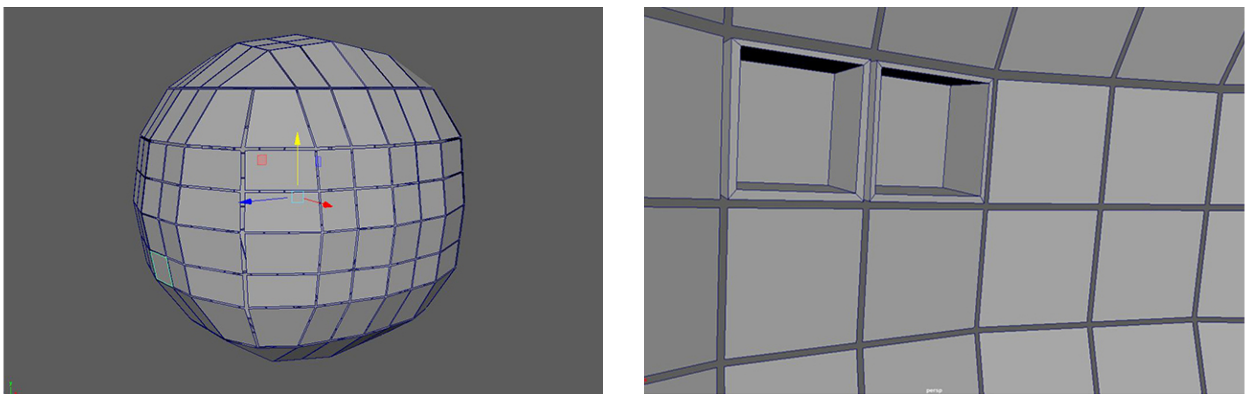
In this designing texture phase, we designed the texture based on various attributes of products. We basically adopt PxrSurface as our shading. This shading could handle most of the materials, like wood, skin, plastic, glass, car paint, and many more types.

For the design rendering methods, we adopted the Renderman22 for Maya. We used preview render method to adjust shader and lighting parameters and made them display a visually realistic effect, while we used "batch rendering" to generate animations. Renderman22 is a brand new tool, and it’s yet not as stable as Renderman21. So we spent a lot of time to do research on how to denoise the rendering results.

4. IMPLEMENTATION

The implementation process has four stages: (1) Creation of V-Sphere Rubik's Model; (2) Creation of Realistic Environment; (3) Creation of Interaction Patterns; (4) Discovering More Scenarios.

4.1 Creation of V-Sphere Rubik's Model

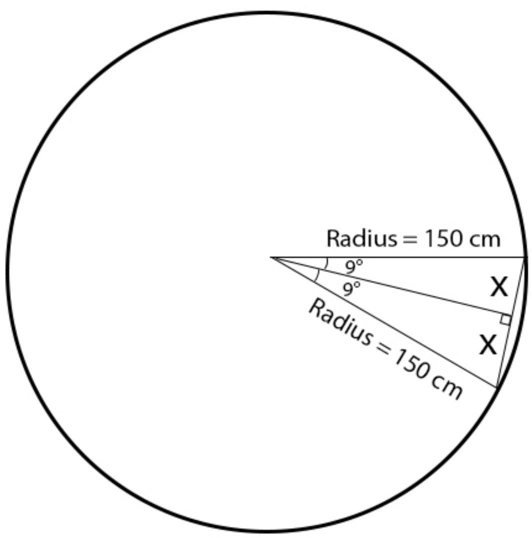


(a) The Outside Look. (b) The Inside Look.

Figure 4.1: The First Attempt of Creating a Spherical Rubik's Model.

For creating an accurate and intuitive model, we have tried many different approaches. Firstly, we started to build this structure by using a polygon sphere in Maya and drag the vertices in x, y, z directions to make the vertices keep align. Meanwhile, we also need to keep an eye on each window (top, left, front, perspective) in case of the vertices intersect with each other. Then, we extruded each face with proper value of thickness and offset, enabling them to formulate a container to place different kinds of items such as chairs and tables in this example (See 4.1). However, with this method, it only creates a rough Rubik's model since the size of each cabinet is different. Furthermore, it would extremely increase the workload and trouble in the future when making it dynamic. For example, it prevents the container to move vertically if one of the container has a different size with others. As we know, most of the vertices are dragged by hand, it could not be possible to generate an exact model, the model's aesthetic and realistic of the structure are definitely affected.

In the next step, we investigated another method by using a polygon cylinder, and making the radius of the cylinder equal to 150cm and the height equal to 40cm, and the subdivision axis to 20. Then, we used sine law to calculate the angles, the width, and the length of each hexahedral element [52]. Here is the equation I employed (See 4.2).



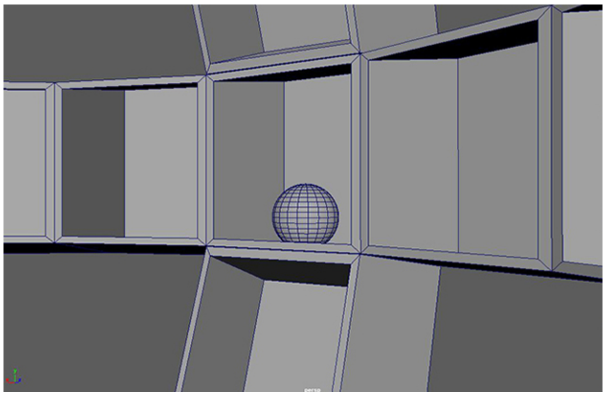
$$\text{Sin } 9° = \frac{x}{150\text{cm}} = 0.156$$

$$x = 150 \text{ cm} * 0.156 = 23.4 \text{ cm}$$

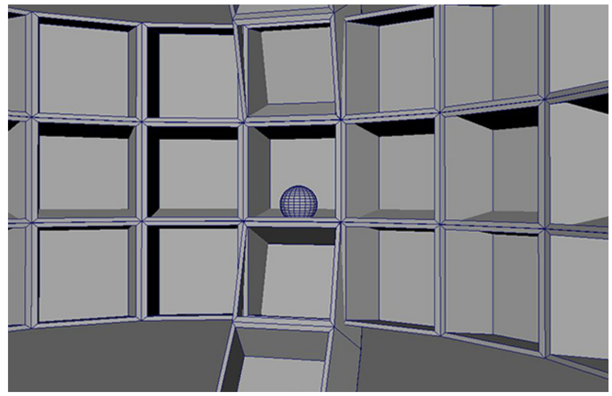
$$y = 2x = 23.4 * 2 = 46.8 \text{ cm}$$

Figure 4.2: The Width and Length of a Single Cabinet

Then, we started to create a polygon cylinder in Maya and delete the rest of the 19 pieces of the polygon. Then we get a hexahedral element by using the extrude function in Maya. Finally, by rotating this cube in the y-axis with every 18 degrees, we get the model (See 4.3). To make the structure look more realistic, we duplicate a group of the model and move it a little bit up forward, but it still has a lot of constrains. Only the middle group of the cabinet could be rotated because the center of the axis is different from the other groups. To fix this problem, we moved to the third method.



(a) A Single Track.

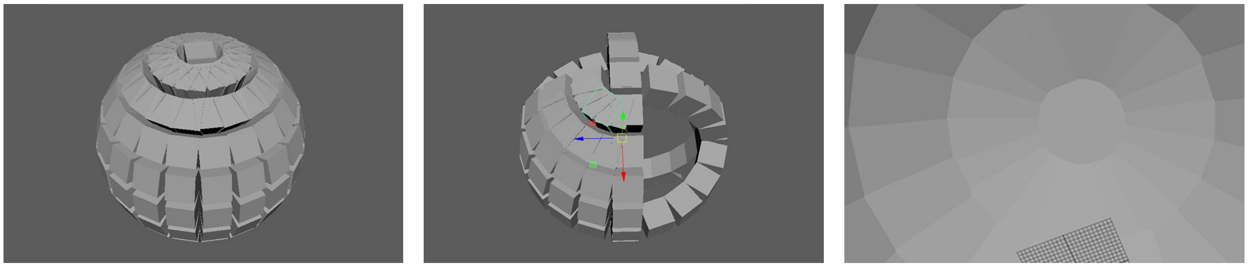


(b) Three Parallel Tracks.

Figure 4.3: The Second Attempt of Creating a Spherical Rubik's Model.

As we know, spherical Rubik's cube is composed of a serious of the truncated quadrilateral pyramid. And the truncated quadrilateral pyramid looks very close to the cube geometry. Meanwhile, the spherical Rubik's cube is composed of a bunch of cubes, which the length equals to the width. Theoretically, this geometry is similar to what we imagined. Then, we tried to test it out (See 4.4). From this model, it is not difficult to see that many geometries are overlapping with each other, the structure does not look correct and it only formulates an approximate a subset of the sphere. Even though this model does not make to a success, we were still excited as it paced the path toward the right direction.

For the development of the virtual 3D interface, we decided to cover a spherical surface with the same type of hexahedral boxes that can move without constrains. The main challenge for this approach, as it is well-known from discrete geometry, is that it is only possible to approximate a subset of the sphere with such the same type hexahedral boxes. To cover the largest subset of a sphere, we considered a wide variety of solutions and we eventually decided that the best approach



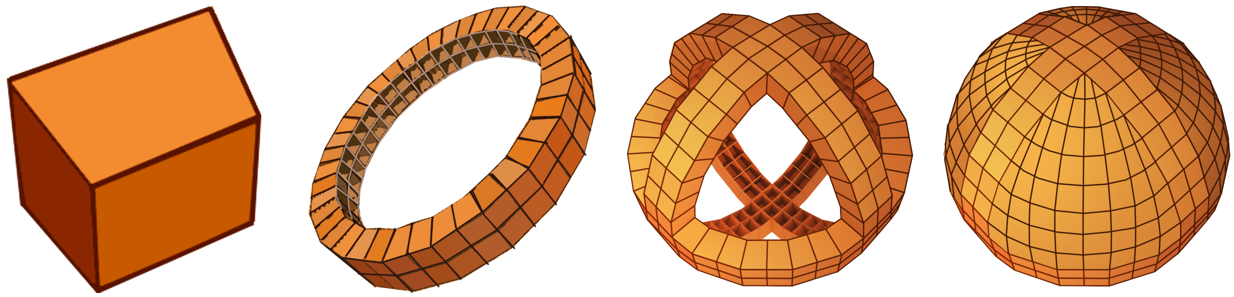
(a) The Outlook of the Third Attempt. (b) The Decomposition Structure. (c) The Inner Side of the Third Attempt.

Figure 4.4: The Third Attempt of Creating a Spherical Rubik's Model.

is to extend to the V-sphere, which is a specific spherical shape based on Rubik's cube. V-sphere [38] (See Figure 4.5) is a 3D sliding puzzle that consists of movable thin square parts and three orthogonal circular rings on the surface of the sphere. Each circular ring of a V-sphere consists of two parallel tracks. An important property of V-sphere is that all the thin square parts have the same shape and they can be slid freely from one circular ring to another.

Figure 4.5: V-Sphere Rubik's Structure

To construct our 3D shopping interface we extended the thin square parts into three dimensions



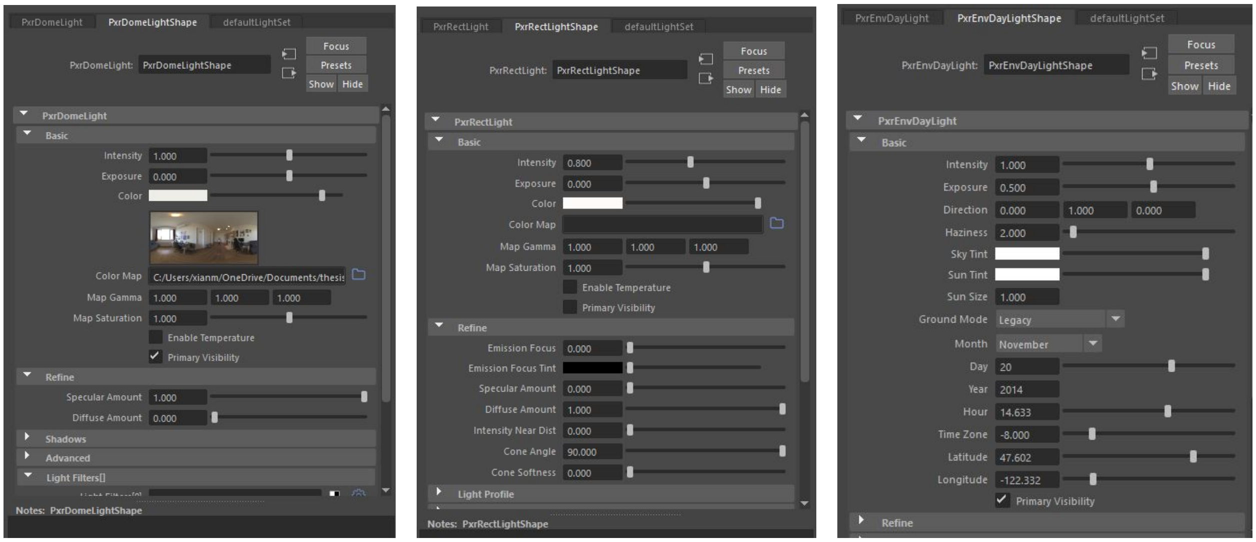
(a) A Single Hexahedral Element. (b) A Single Axis (c) Three Axes Together (d) Overall Model.

Figure 4.6: The Last Attempt of Creating a Spherical Rubik's Model.

by constructing hexahedral elements as cut-pyramids using lines emanating from the center of the sphere. One of these cut-pyramid shapes is shown in Figure 4.6a. These cut-pyramid shaped hexahedral elements can form three rings that are orthogonal to each other as shown in Figure 4.6c. Each of these rings consists of two parallel tracks, similar to V-sphere (see Figure 4.6b). Finally, we covered the model with a sphere which helps us to generate an overall model (see Figure 4.6d). We, then, replaced each hexahedral element of this spherical Rubik's cube with a shelf looking inward. The user is placed inside spherical Rubik's cube by turning V-sphere Rubik's cube concept into a dynamic 3D spherical bookcase with movable shelves.

4.2 Creation of Realistic Environment

In creation of a realistic environment, we divided it into three steps. The first step is lighting design. Firstly, we placed a PxrDomeLight in a scene which could make the scene generate a more realistic effect, such as shadow, reflection, and refraction. Then I put a PxrRectLight to simulate softbox which usually uses in photography. The scene at the corner still looks dark, so we added two more area lights to illuminate the surrounding environment. Then we used a third PxrEnvDayLight which simulates the sun, and it helps to generate a more realistic shadow (See 4.7). In the creation of lighting stage, we adjust the angle of the lighting to generate a more realistic effect in Maya. Thanks to the free HDRI map which we get from Renderman official website. It helps us get a more visually realistic global illumination.



(a) PxrDomeLight (b) PxrRectLight (c) PxrEnvDayLight

Figure 4.7: Lighting Design

Then the second and third steps are texture design and design rendering methods. We used PxrSurface as our main shading because it could handle most of the types of material in our scene. We placed all the tables and chairs in the correct positions then assigned texture on the items based on their attributes (4.8). For example, the sofa has a bit of bump and reflection, and a little roughness. For the design of rendering methods, we mainly used Renderman22 since it supports "live rendering", and could provide fluid feedback for iteration. Also, we checked the "denoise" box on in the "AOV" setting in the Renderman22 setting panel, then adjusted the "Max sample" to "512". Besides that, we also adjusted the "Pixel Variance" up to "0.001" which helps to reder a realistic 3D environment(4.9).

4.3 Creation of Interaction Patterns

To create the 3D interface, we first put several different kinds of tables and chairs on the curved shelves, then move each items' pivot to the center of the structure. We adjusted the axis by using the front, top, and left windows in Maya. After that, by using the "freeze the transformation" tool in Maya, all the items should have the same pivot so that they could rotate in either x, y, z directions. It ensures an relatively accurate structure. Then, we have to think of a way to transform the sector

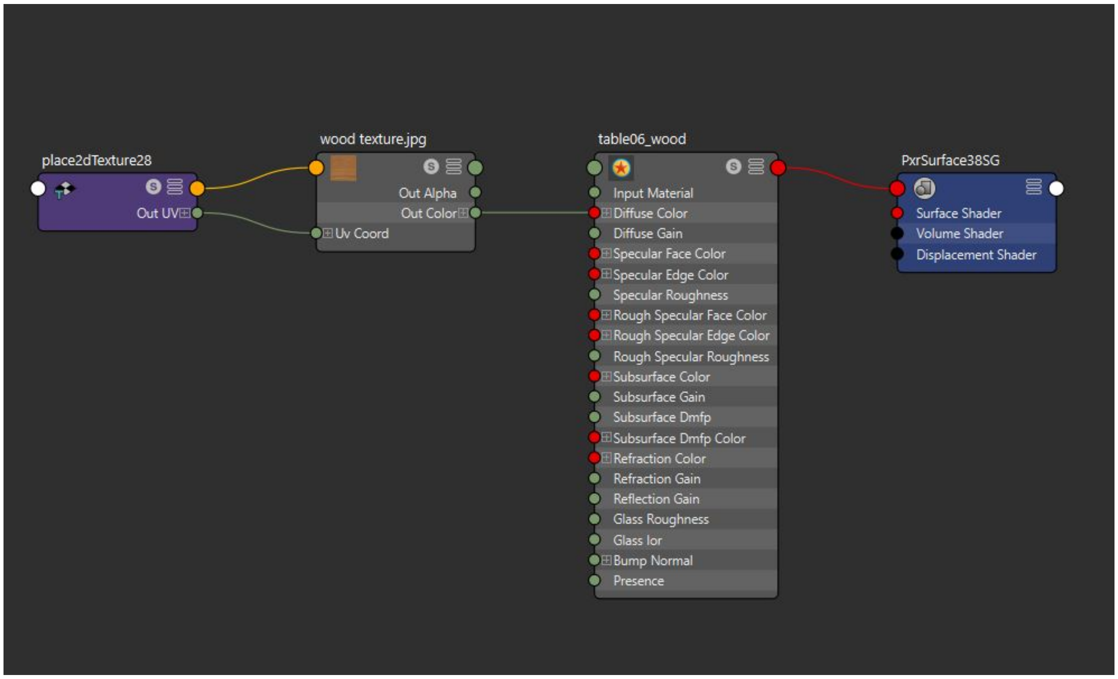
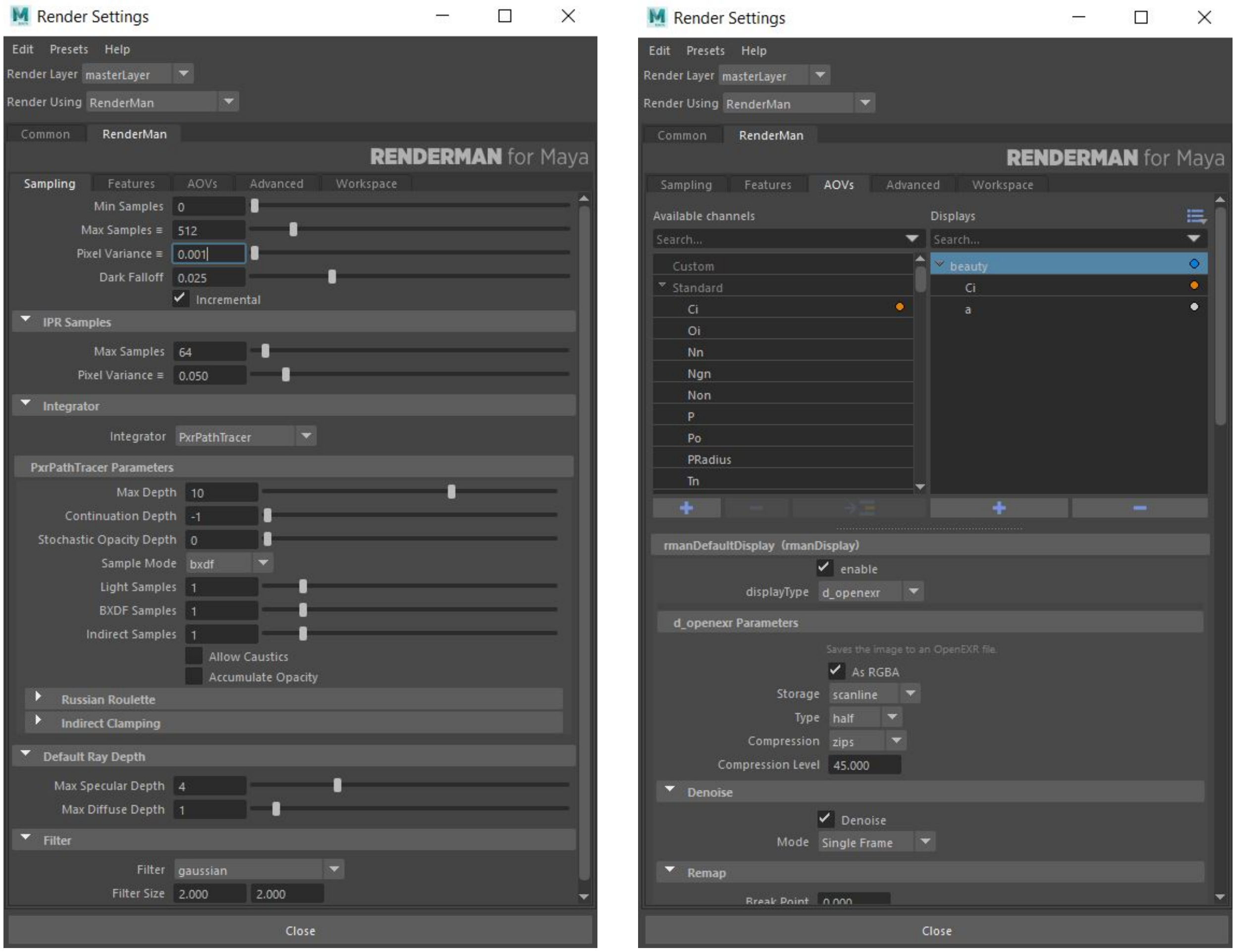


Figure 4.8: An Example of Texture Design

into a truncated quadrilateral pyramid model. In this case, we used "adding a loop edge" tool to add a loop edge around the truncated quadrilateral pyramid and delete extra lines and vertices, then, cut the pyramid model into four equal parts, then make the model to formulate a container by using extrude tool in Maya.

Before the interaction patterns are settled down, we tested a bunch of different solutions. We investigated different patterns within a realistic environment. In the concept, any of the bookshelf row could be slid horizontally, any column could be slid vertically, and the whole structure could also be moved horizontally or vertically. The interaction patterns experienced a range of iterations. Here is how the patterns look like in the preliminary test (See 4.10). From the image, we can see clearly that the 3D environment has real-time lighting and the shape of the shadow also changed over time.

Then we improved the environment with realistic effects. We came up with three interaction patterns based on the explorations in 2D prototypes. The first pattern is horizontal scrolling. The single row of the 3D bookcase moves left when the user presses the thumbsticks button left on



(a) Variance Setting.

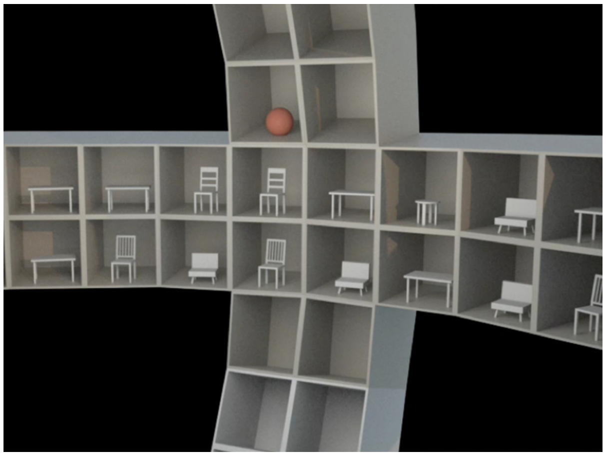
(b) Denoise Setting.

Figure 4.9: Design Rendering Method

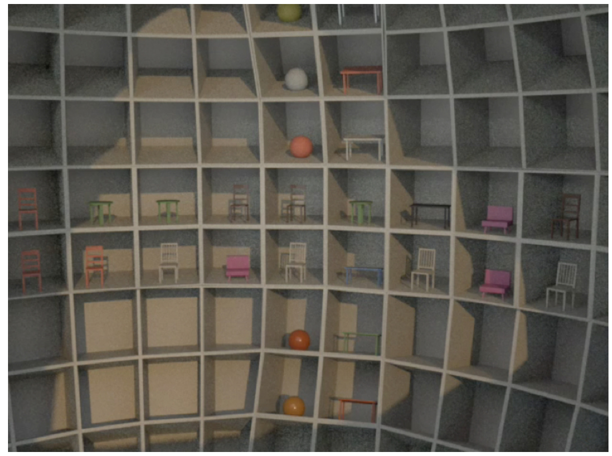
the Oculus Rift controller. It also comes with real-time effects, such as shadow, reflection, and refraction (See 4.11).

The second pattern is vertical scrolling. When the user presses the thumbstick button down, the corresponding 3D interface also moves down. It also comes with realistic global illumination effects (See 4.12).

The third pattern is the global movement. The whole 3D interface rotates horizontally or vertically if the user presses uses the trigger button to control it. All items and the whole structure rotates together with the interface (See 4.13).



(a) The First Attempt of Interaction Pattern.



(b) The Second Attempt of Interaction Pattern.

Figure 4.10: Preliminary Interaction Patterns Experiment.

Figure 4.11: Horizontal Scrolling with Improved Effects.

4.4 Discovering More Scenarios

We discovered more scenarios based on the 3D bookcase interface. As learned from related work, selection and manipulation are the major actions in a VR shopping system. We took a step

Figure 4.12: Vertical Scrolling with Improved Effects.

Figure 4.13: The Whole Structure Movement with Improved Effects

Figure 4.14: Manipulate Products in VR

Figure 4.15: Place Furniture in a New Environment

further and discovered the scenario that user should be able to grab the items on hand and view the objects from all different angles. To implement interactions for these scenario, we created a V-Sphere environment in Unity and placed all items. In this scenario, the user could point at a certain item, and grab the item on hand immediately by pressing the trigger button. The user then could take a look at the item closely for more detailed information (See 4.14).

In a typical flow of shopping activities, users might want to know whether the product fit the environment or not after learned about product details. It is an essential scenario because the user might make a purchasing decision in this phase. So we implemented the scenario of placing the product in a new environment. The user could point at a specific item and they will be brought to a new environment. In the new environment, they are able to evaluate the suitability of the product. In this scenario, the new scenario is composed of a 360 image which presents a new environment and we also implement a scene transition in this phrase (See 4.15). It's also easy for users to test the product in different environments by simply changing the 360 image backgrounds.

5. CONCLUSION AND FUTURE WORK

5.1 Conclusion

In this work, we presented a method to create a true 3D interface paradigm for shopping in an immersing Virtual Reality environment. We implemented a V-Sphere Rubik's cube bookcase interface which was applied with realistic global illumination effects such as reflection, refraction, and soft shadow. Besides, we discovered different interaction patterns for three typical scenarios of content exploring in VR environment: First, to create a V-Sphere Rubik's bookcase interface for browsing items; second, to select and manipulate items in a close distance; and third, to place items in a new environment.

Firstly, we created a V-Sphere Rubik's cube to present a 3D Interface in the VR environment and investigated several kinds of interaction mechanisms. The V-Sphere Rubik's cube could enable users to view and manipulate products in all x, y, and z directions. The 3D interfaces could obtain global illumination effects which makes it more realistic and ensures a more streamlined user experience in VR environment than 2D interfaces. Based on the V-Sphere Rubik's modal, we investigated three different interaction patterns for content exploring: single-row and multiple-rows horizontal scrolling, single-column and multiple-columns vertical scrolling, and global movement. With the first pattern, users are able to manipulate the objects in the x-direction, while in the second pattern, the users can slide the 3D interface vertically. In the third pattern, the users can control the whole movement of V-Sphere Rubik's structure. The three interaction patterns can serve users' basic needs to browse the information effectively.

Besides that, we investigated the next step when people need to learn more information about certain products after the browsing phase. In the same scene, users are able to grab the item to themselves by pointing at them and look at the item in details closely. It helps the users to better understand the structure and materials of products by viewing the product from all different angles. In this phase, we implemented the interactions by referring to Oculus's framework with functions of distance-grabbing.

In the third scenario, we take a step further to allow users to place the item in a real environment to evaluate whether it's a fit or not. Users can easily place the product into a specific environment which is implemented with web VR technology using a composed 360 degrees image.

To sum up, we proposed a new solution of creating real 3D User Interfaces based off V-Sphere Rubik's Modal and demonstrated the different interaction patterns that can be applied to different user scenarios to ensure a streamlined user experience of exploring and manipulating items in virtual reality shopping activities. The 3D interface paradigm proposed in this thesis guided a direction of utilizing realistic 3D interface in the VR environment and provided a practical method of creating a dynamic 3D interface in VR. Moreover, there is a huge potential that the V-Sphere bookcase model can be applied to a lot more different scenarios other than VR shopping, and even in new 3D User Interface systems.

5.2 Future Work

Although we have proposed a new method of creating 3D User Interface in VR environment and discovered how it could be applied to several usage scenarios in VR shopping, we still need much more time to dig dipper.

In the first phase of this paper, we proposed a spherical Rubik's cube 3D interface concept and only implemented three different interaction patterns. However, we believe that there remain more 3D interaction patterns to be discovered based on V-Sphere Rubik's model.

Due to the time constraints, we only implemented a small portion of the VR shopping workflow in this paper. There are a lot more scenarios we need to address in future work. For example, how the user should purchase the product if they choose three different items at once, how should they add them into the basket, and what the 3D purchasing user interface should be. A lot of different interactions can be used, such as the purchasing interface could be pulled out by the left-hand controller; The item could be added to a shopping cart automatically if the user presses the thumbstick button down when pointing at a specific product; While there is a check-out interface popped up on the left-hand controller, the interface should consist of a range of icons, like basket icon, check out icon and remove icon, etc. The user should also be able to view all products which were added in the shopping cart by simply pressing the basket button through ray casting, and the items could also be easily removed by clicking the remove icon.

As we know, VR shopping as a new medium still needs integration between various disciplines. And it also requires more people to investigate the market and conduct necessary user research. In our case, our aim goal is to propose a 3D interface concept and implement features about basic viewing and exploring content in the VR environment. We did not conduct a user study to evaluate the effectiveness and efficiency of the new concept. We believe it should be done in the future when we have a better-developed prototype where users can conduct real VR shopping tasks. For example, we still need to evaluate if true 3D shapes with global illumination could provide more immersing user experience and we need to evaluate the effectiveness of the 3D interface interaction patterns of exploring items.

We believe that user experience in VR needs more attention from designers and engineers to improve overall usability. In the future, we hope we could dig deeper into the user experience in the VR framework. For example, when people selected a chair, the rest of the chairs with the same color in the containers would be highlighted so that it might be easier for users to view the same category and the same color items quickly. It could facilitate user activities in browsing similar items. Another area to dig deeper is the use of a reasonable navigation hierarchy for VR shopping. The system might be composed by a range of 3D elements, like the menu, navigation, icon, video, and audio which could provide a multimedia VR environment. Users should be able to navigate easily through different categories of the item, filtering items by different colors, materials, etc.

Besides, we still need to explore more 3D geometry other than V-Sphere Rubik's model in the creation of 3D User Interfaces. There might be other good solutions which work better as a 3D user interface in VR shopping. For instance, the cylinder geometry and donut geometry have a huge potential for interactions in certain scenarios. In order to discover more possibilities, we should invite some architecture experts to help us to define and analyze the problem. Another thing we should consider is that the users might feel sick when they are locating in a huge V-Sphere Rubik's model especially when facing so many items. We need expertise from different disciplines to address the challenge.

Although the example in this thesis demonstrated a 3D interface with realistic global illumination, the realistic global illumination effects are still a challenge in the VR environment. Currently, we use game engines like Unity and Unreal to develop the VR application. However, generating a realistic effect on dynamic objects is not easy. We believe that in the future with new methods of simulating the reflection and refraction effects the real-time rendering with global illumination effects in virtual reality could be more effective. We have the confidence that it must come true with the development of rendering and shading techniques.

Last but not least, multi-user is hot topic for virtual reality interactions [11], as the users could collaborate with each other in the same video games. We should consider the multi-user factor into the virtual reality shopping system [4]. When the use enters the VR shopping system, users could operate their interface independently or they could choose to collaborate with other users by sharing the scene to another user remotely. They should be able to talk with each other, see aviators of each other in the same scene. We need to think deeper for the multi-user interface and we still need more time to research on the impact of the multi-user interactions on user experience in virtual reality.

Acknowledgments: We have used free models from turbosquid website.

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