Facilitating Real-Time Sketch-Based Storyboards for Stereoscopic and Virtual Reality Environments

by

Rorik Henrikson

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Abstract

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Rorik Henrikson

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Department of Computer Science

University of Toronto

Recently, we have seen a resurgence in stereoscopic movies, and an explosion of interest with stories for virtual reality (VR). Though these art forms share many similarities with traditional film, there are numerous differences. Some differences result in aspects that are more challenging to discuss, and are therefore often ignored, frequently resulting in bad decisions.

This latest resurgence with stereoscopic cinema has resulted in a better understanding of the artistic challenges and opportunities provided by this form of storytelling. There has been a realization that creating stereoscopic movies does not mean simply adding depth, but rather involves a complex set of considerations to lead the audience through a pleasant viewing experience; one that engages them as consumers of the visual story, rather than using stereopsis as a gimmick that disconnects the viewer from the show. To facilitate these differences, the
stereoscopic community encourages directors and producers to think of projects in stereo as early as possible, to make good design decisions. However, there are few early stage design tools to help support this design process.

Likewise, with the consumerization of VR through devices such as Oculus Rift, Samsung GearVR, and Google Cardboard, directors have the ability to connect with audiences in new ways, and have started creating stories for virtual reality. However, directors are unsure how to direct a VR movie, or plan for these experiences. Due to factors such as the stereoscopic nature, 360° surrounding view, and uncertainty of how to perform transitions, directors have difficulty planning for this environment using traditional means.

This work explores different approaches, and feedback to allow artists to sketch on tablets, leveraging existing drawing skills, yet allowing for quick creation of stereoscopic and virtual reality storyboards in real-time. The presented approaches allow artists to create stereoscopic and VR storyboards with minimal pre-planning, and almost no increase to the exerted effort by the artist. These techniques when applied to VR, allow artists to work in more immersive environments, and collaborate more easily. These techniques can help directors and producers plan films more effectively and easily with these new, unexplored stereoscopic and virtual sketched worlds.
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Several sections of this document have previously appeared in ACM publications. Permission from ACM has been granted for these works to appear in this thesis. Where appropriate, each chapter is marked with references to the relevant publication, each of which is listed below:

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Chapter 1

Introduction

Over the last century, the art of movie making has changed drastically. It has evolved from a simple process of filming silent characters on a traditional stage to immersive experiences that take audiences anywhere and everywhere; from your neighbor’s kitchen, to deep under the Pacific Ocean, to distant galaxies and fictitious worlds. Modern movies, however, take a significant amount of planning, imagination and communication between many different people and departments. Many unique approaches have evolved over the decades, but some tools have become mainstays in the filmmaker’s arsenal. One such technique is what is known as a storyboard.

With many movies, a director starts by reading a script and creates an image in their mind for each scene of the movie. These visions and ideas then need to be communicated to the heads of the many departments working on a film (e.g. the director of photography, the lighting head and the visual effects supervisor). Though the ideas that the director has in mind could be describe verbally, this method is not very specific, and leaves many aspects open to interpretation. This is not a good predicament when creating a movie, as a film team needs to work towards a common goal. If every team has their own idea of the appearance of the movie when the team arrives on set, each team would do their own thing. The lighting team may try lighting a scene in one manner, while the set designers lay out the set in a different fashion – simply based on the fact that different people interpreted the scene in different ways. It is exactly to avoid this type of issue that many directors turn to a technique developed by Disney [Whitehead, 2004, p47] to create storyboards, a tool that relies on the old adage, “A picture is worth a thousand words”.
Storyboards are a comic book-like representation of a film, a sequence of still images that capture the key moments of a scene in the film. By creating storyboards, the director can focus on the major moments of a scene and figure out layout and blocking; different camera angles, different looks; and get an idea of the overall quality and cohesion of the film before hiring actors, building sets or shooting film. To create these storyboards, the director may draw them himself, or he may hire a storyboard artist based on the quality, look and style of her drawings. The initial drawings (referred to as thumbnails) are usually crude and simply capture the essence of the idea of the given moment. These are quick to make, easy to visualize, and are discardable. These thumbnail storyboards will later be cleaned up, where they are made to look neater, have better shading and better perspective. These storyboards are then distributed to all the key members of the film team, so that ideas can be discussed and to ensure that everyone is working towards the exact same set of goals.

Storyboard artists are trained and are familiar with drawing using pen and paper. Alternately, they may use pencils or Sharpe markers and note cards, sticky notes or napkins, or they may draw on computer tablets (such as a Wacom Cintiq). All of these approaches have the artists working with some type of stylus on a solid surface. There are other systems that require an artist to wave a wand in the air in 3D space in essence “sculpting” an image (such as the SANDDE system [SANDDEJ]). A wand waving technique, however, usually requires a large space (equipped with specialized hardware) within which the artist moves. This technique consequently requires longer for creating images, provides no physical feedback from the drawing implements, and becomes tiring when used for long periods of time. Further, many techniques that rely on wand waving are solutions implemented for Augmented Reality (AR) or Virtual Reality (VR) systems. Many of these systems are difficult to use for long periods of time, as they cause visual fatigue, further compounding the issue of speed and practicality when being used for creating storyboards for large productions.

The storyboard artist’s goal, is to capture the director’s ideas (and her own) on a canvas as quickly as possible without distraction. A storyboard artist is often paid by the number of panels she produces in a given period of time, so speed is of the utmost importance. Therefore, to create a solution tailored to storyboard artists, a system needs to be non-intrusive so as not to distract the artist from her primary task, quick for authoring, provide instant feedback so that the artist is
able to assess what she has produced while drawing (rather than relying on some post-processing technique), and still provide an overall view of all the panels for a storyboard.

1.1 Understanding the problem

Though the technique and process of creating storyboards has been well established over the last century, movies themselves have changed. Thanks to new innovations and technologies, director are trying new ways to capture and tell their stories. Some of these innovations include stereoscopic film and stories told through a digital, virtual environment (or virtual reality). Though the core of what comprises these stories remains constant, with each new technology the process of planning must adapt to support the unique aspects and challenges of the specific method, as well as facilitate the needed discussions that arise as a result.

1.1.1 Stereoscopic Film

In 1922, an audience wearing red/green anaglyph glasses discovered “The Power of Love”, the earliest stereoscopic movie played in a theater [Zone, 2007]. This illusion of 3D, achieved by projecting two superimposed images, separated into each eye by anaglyph, polarized or shutter glasses, is undergoing resurgence through the recent popularization of stereoscopic displays and improved supporting technology. With each successive revival, the art form is further refined and our technology improves to meet the demands of this medium. It has been mostly in this last iteration (in the 2000’s) that it has been recognized that a stereo movie is much more than just a gimmick to trick visual perception and shock the audience. There is a realization that, when used properly, stereo can be used much like the soundtrack of a film to help immerse the audience in the story being told, and has the potential to further elicit emotional response. The film community has acknowledged that a stereo movie is more than just solving the technical challenges of aligning two cameras and the resulting two complementary images to create an illusion of objects extruding from or recessing into the movie screen. In this latest iteration of stereoscopic film making, with the support of technological advances, the film community has also recognized that a stereo movie is much more than simply planning the depth of a scene; that there are many more elements and opportunities that can be used artistically with stereoscopic film that need to be properly planned from the beginning. Yet, in spite of these advances [Lipton, 1982] and research to reduce visual discomfort [Du, 2013], filmmakers are still prone to make
choices that may cause unpleasant viewing experiences, and there are few tools to support the early creative process of designing and planning stereoscopic 3D (S3D) film. Tricks and techniques that traditionally work in 2D do not necessarily transfer to 3D because the latter requires a smoother and gentler editing style [Liu, 2011]. Many new factors exclusive to the S3D medium need to be considered, such as plane separation, parallax position, and depth budgets [Atkinson, 2011] (see section 4.1.3 for a full list); and while filmmakers have developed a language to discuss these concepts, textual descriptions remain “a little broad” to capture the essence of a 3D scene [Pennington, 2012, p9].

A stereoscopic film is different from its traditional 2D counterpart and has different considerations that need to be kept in mind while planning. The effect of a stereoscopic film – where the image appears to extrude or recede into the movie screen – is achieved by providing a slightly different image to the left and right eye, where the components of one image are shifted horizontally compared to the matching element of the other eye. The brain resolves this discrepancy by assuming that the image must exists at a depth that corresponds to the magnitude of the eyes convergence, when the object in the left and right eye align and are in focus. Traditional depth cues are still being used by the brain, but this depth cue, called stereopsis, creates an effect that makes an object seem tangible and to actually occupy the space in front of or behind the movie screen (see section 2.4 “Stereopsis and Other Depth Cues” for more information on these topics). Yet, creating a stereoscopic movie involves more considerations than just the horizontal offset, and thus adding depth to the scene. Bernard Mendiburu [Mendiburu, 2009, p79] notes that:

> When you are looking at a 2D picture, you look at a flat object defined by the edges of the screen. When you are looking at a 3D picture, you look at objects floating in a space [...] a 3D world through a window.

Due to this nature, a director must start considering factors such as object placement, plane separation, parallax position – the placement of the objects in front of the screen (in audience space), behind the screen (in screen space), or on the screen plane (convergence plane) – as well as concepts such as the use of the depth budget and the creation of depth scripts. Leaving decisions such as these until later in the film production cycle can result in a significant expenditure of time and money to fix avoidable problems, if it is even possible to fix the incurred
issues. Often the errors are not easily correctable, and the result is a stereoscopic movie that is presented in theatres that gives people headaches, causes nausea, and generates an all-around miserable viewing experience (i.e. a “bad 3D movie”). Motivated to foresee these difficulties exclusive to stereoscopy, but also to exploit the unique possibilities of this medium, the 3D cinematography community encourages filmmakers, directors and producers, to start “thinking in stereo” as early as possible, arguing that “the sooner you think about 3D, the better your movie will be” [Mendiburu, 2009, p91]. This allows filmmakers to try to avoid as many of these problems as is feasible, or at least to be aware of problems that may arise based on the decisions being made while planning the film. Yet, there are very few early stage tools to support the ideation and discussion of a stereoscopic film. Traditional computer graphics solutions for early visual development and design, in current practices, are either strictly 2D or require 3D modeling skills, producing content that is consumed passively by the creative team [Patel, 2009]. Unfortunately, one of the earliest planning tools for film – storyboards – is a tool that, currently, only exist in 2D.

A storyboard is a powerful tool that supports the organic process where the director and artists explore the film space, try ideas and change visual and narrative aspects in real-time before committing to a plan. Not only do storyboards allow the director to concretize and refine their vision, they also serve as the main communication medium between the creative team members [Hart, 2013; Katz, 1991] ensuring everyone works towards the same goals—not some approximation of them.

This problem of storyboards only being 2D, is one of which some directors are aware, and consequently they have tried to modify existing techniques to accommodate for this shortcoming. These techniques may be done with traditional tools such as pen on paper, sticky notes, or note cards on which artists draw, or using digital solutions using programs such as Storyboard Pro [Toon Boom Storyboard Pro], Adobe Photoshop [Adobe Photoshop] and Autodesk SketchBook [SketchBook]. In any case, artists have used techniques such as changing the line thickness of a storyboard panel (Figure 1) or the darkness of the line to indicate depth. Other artists have tried using colour to represent the different depths, shading some depths with blue, others with yellow, and some with red (Figure 2). The problem with these techniques is that the images are still flat – only 2D – and only vaguely suggest what the artist intends (i.e. “how close are objects to one another”, “what is the depth budget of the scene” and “what is
considered in audience space and what is in screen space” are just some of the questions not easily conveyed with these techniques). It still relies on the interpretation of the viewer to determine the depth of a given image and to make assumptions based on these guesses. However, the point of a storyboard is to ensure that everyone is working with the same image and goals in mind, and not some approximation. Other tools that can be used, such as Toon Boom’s Animate Pro [Toon Boom Animate Pro], allows artists to import 2D and 3D content to work on a 3D stage, setting camera angles and movement; however, creating models, and setting up camera trajectories is all time consuming and not ideal for fast ideation and early discussion – one of the main purposes of storyboards.

Another approach that directors often suggest is to use programs like Google SketchUp [SketchUp], Autodesk Motion Builder [Autodesk Motion Builder], or FrameForge [FrameForge] to solve this issue of planning in 3D space, as all of these tools work in 3D and are primarily used to create 3D models. Using 3D models to plan a scene is a technique referred to as Previsualization (Previs). Previs is a wonderful tool when trying to figure out whether a camera rig fits within a defined space, or to ensure that actors do not trip on camera rails – laid down for camera movement, or to calculate the amount of green-screen needed for a shoot, or when planning the timing for complicated shots. Previs, however, is too time intensive, and provides too much information for the purpose of ideation and conceptualization. It is the equivalent of an architect building foam board models every time they have an idea, rather than first sitting down and creating concept sketches and blue prints. Due to the time needed to ensure accurate measurements, setup cameras, and to define surfaces that are often not visible to the

Figure 1. Storyboard panel using line thickness to indicate depth

Figure 2. Storyboard panel, using colours to indicate different depths
camera, this technique is better used as a “next step” once the storyboards have been created.

These problems and concepts raise the question, “what technique and solution can one create to allow artists to quickly sketch storyboards stereoscopically?” Such a solution has promise to significantly ameliorate these planning issues for stereoscopic movies, and help the creative team to better plan their film.

Devising a solution and implementation that would allow for the creation of stereoscopic storyboards necessitated an analysis of how artists currently work within the design space. As with any tool, one could insist on artists learning new sets of rules and develop new skills to create content for this identified drawing form; however, professional artists already have a strong skillset for working on paper, and are used to using pencils and pens for drawing. Focusing on this fact, it seemed logical to try to incorporate these existing drawing techniques into any tool being developed, to empower artists when drawing in stereo. Furthermore, if an interaction is too complicated or requires the artist to master new techniques and interactions, these individuals are more likely to simply continue using pen and paper rather than adapt to the added benefit that a software tool could provide. Therefore, to properly devise a solution that would be workable and appropriate for storyboard artists, it is important to first understand how an artist works, their needs, and their habits.

This work proposes a solution to solve these problems, while planning for a stereoscopic environment, by treating the 3D volume as a 2.5D space and extending on a concept that storyboard artists already use while drawing – the concept of foreground, mid-ground and background. By dividing the 3D viewing volume into a stack of transparent sketch sheets (or stereoscopic 3D depth planes), an artist can simply select the sheet on which she wishes to draw, and start sketching. The results can be drawn and displayed in stereo. This allows the artist to draw items in 3D space in real-time, assessing her work while the image is being created. This simplistic approach, however, is not without some shortcomings, as this planar restriction results in scenes that suffer from an artifact known as “cardboarding” and only allows the viewer to observe the scene from one specified viewing location. However, since the goal of a storyboard is to capture an artist’s vision, to enable discussion, and try different scenarios and ideas, these restrictions are considered acceptable for this problem.
Chapter 4 and Chapter 5 discuss in detail the analysis of this problem and the implementation of the stereoscopic 3D depth planes through a tool called Storeoboard (*story-o-board*). This tool supports the storyboard workflow, but focuses on issues that are specific to stereoscopic film – factors such as depth placement, floating windows and depth scripts. Generally, the tool implements techniques to solve stereoscopic problems while creating storyboards. This text further provide feedback on the tool, which was collected from numerous focus groups. Apart from the feedback received on several occasions from a professional storyboard artist during the development of the tool, a session was conducted with students studying to be professional storyboard artists at Sheridan College. These students used the tool and provided feedback though questionnaires and a group discussion. Further feedback was elicited from three directors, two technical directors and one stereographer who work with, or have worked on stereoscopic movies. Finally, the prototype created as part of this work was used on the 3D Lumière award winning film “40 Below and Falling” – the first romantic comedy shot in stereo – as the only storyboard tool for the film. The director provided feedback on the tool through phone interviews.

### 1.1.2 Virtual Reality

Another technological trend which has seen a resurgence in recent years, is Virtual Reality (VR) – the technique of providing a fully digitally created environment through the means of a head mounted display (HMD) which completely immerses a user’s visual environment, and often the audio environment as well (provided proper audio apparatus is present). With the introduction of consumer hardware such as the Oculus Rift [Oculus Rift], Samsung GearVR [Samsung GearVR] and Google Cardboard [Google Cardboard], VR is very quickly becoming an area of interest, not just to computer enthusiasts, but to the public at large as well. This trend has not been ignored by the film industry and there are many directors who have started or are interested in creating films for virtual reality. Yet, this film environment is significantly new enough that directors are not really sure how to work in this medium. This includes an uncertainty for how to plan for virtual reality projects.

At the turn of the 20th century when “traditional” movies were first being explored, directors had to figure out the rules of film, such as what they could do, what they needed to be aware of, how to block shots, how to create suspense and evoke emotions, how to insinuate situations, and how
to cut between shots. These rules took decades to develop, however, they are now common enough that we as viewers do not even notice them; we take them for granted. Films in VR are currently undergoing a similar discovery process. Directors are still not aware of how to film a scene in VR, as film rules for VR have not yet been established. This makes planning for VR very difficult and consequently there is very little standardization in the approach for creating a film in VR.

Despite this lack of rules, certain rules can be inferred from elsewhere. VR movies are similar to stereoscopic movies in many ways and live-theatre in others; though there are numerous factors and problems unique to the VR environment. This has not stopped directors from creating films for this medium, but it has presented unique challenges, some of which have been partially solved, others which are hurdles production companies hobble around until they find something that works “well enough” for their purposes.

Directors are already actively experimenting with various configurations for telling their narratives: a virtual movie theatre; immersive environments where the viewer can look anywhere, but the narrative is focused in one primary place; and environments were multiple narrative moments happen simultaneously in different places. These are all examples of some of the techniques being explored.

How does one quickly create content for VR? As with stereo, a director may use stereopsis as a key depth cue for visual presentations, both modalities need to allow the artist to create content at different depths, and both systems need to allow the artist and director the ability to think about the depth placement of objects. However, VR also has several challenges of its own. Unlike stereoscopic movies, VR needs to worry about factors such as lines of sight, 360˚ of information, and the lack of boundaries (borders) to define the space and blocking for where a viewer should look (see section 6.1.1.2 for a full list).

In other ways, VR shares similarities with live theatre; similar in ways such as moving an audience to a new location is difficult; therefore, scenes generally occur in the same space and transitioning between locations requires a more creative and gentle approach (compared to the transitions we see in regular movies).
In general, virtual stories have different considerations that are unique to the virtual medium. Consequently, the workflow is inevitably different. The workflow for each VR studio is also unique, however, as no one really knows how to approach the problems experienced in VR.

This work proceeds to propose a system for enabling storyboards for a VR environment. This is done while trying to leverage an artist’s finely honed drawing abilities while working on a flat surface, coupled with displaying the output of their drawings in a 360° virtual reality environment in real-time, allowing a director, or the artist themselves to see the results in a virtual setting. This is done without the need for large rooms within which to move about, does not result in undo strain on one’s arm or visual system, and provides pressure as feedback against which the user can draw. Through this mechanism, the system tries to achieve a “best of both worlds” solution, taking the best from the traditional sketching metaphor, yet enabling a user to experience the image in a way that is exclusive to VR.

Chapter 6 explores the differences of working with VR and the concepts that are unique to working in this visual space. It explores the different considerations that a system needs to support and potential workflows while working with virtual reality. Chapter 7 proceeds to describe an implementation created to support the concepts developed in chapter 6, and the feedback received from professionals in the industry.

The system has two elements, the tablet component, and the virtual reality component presented through a head mounted display. With the tablet, one has three main areas within which to work. First, there is a stereoscopic, panoramic drawing surface, which allows an artist to sketch 2D models at different depths based on unwrapped concentric cylinders that encompass a point. Second, one can view a panoramic storyboard view, which shows unwrapped panoramic thumbnails of each scene. These thumbnails are further enhanced with bounding boxes showing the intended focus of the scene, and shading to draw attention to the intended focus and away from what would ideally be behind the viewer. Finally, there is an overhead view of the environment where users can quickly see the placement of objects within the scene. These three views work together to help the artist build up the scene in a panoramic setting.

The HMD view has two main areas. First, there is the VR equivalent of the sketching surface, and a VR storyboard represented through a series of diorama models. Interaction with these two
views is done through a combination of keyboard commands and tablet actions (depending on the mode). The two devices are connected via a network allowing changes on the tablet to be reflected in real-time in the VR environment.

The proposed system provides for multiple workflows depending on whether the artist and director wish to work synchronously or asynchronously. Working independently, the artist or director can choose to work solely on the tablet, or on the tablet in the VR environment. Working simultaneously in collaboration, the artist can work on the tablet while the director choses to view the content in VR, or discuss items with both members focused on the tablet.

The feedback received from industry professionals after demonstrating the system to them, and letting them explore the tool for a period of time was very positive, showing the potential for this approach for creating storyboards for VR.

Through these simple mechanisms, the power of the system provides for opportunity and flexibility while leveraging the skills of the artist, and providing the director with the needed information to discuss the film project under development.

1.2 Thesis Statement

This dissertation provides evidence in support of the following thesis:

*It is feasible and often desirable to provide storyboard artists with fast, real-time feedback mechanisms while sketching, to enable the artists to quickly create stereoscopic and 360-degree storyboard drawings. This visual feedback of stereoscopic and virtual reality storyboards enable film teams to reflect earlier, and more easily about concepts unique to stereo and VR enabled film; concepts not easily discussed with traditional boards.*

This dissertation, analyzes how storyboard artists approach drawing storyboards, their workflows and limitations, and concepts that are unique to stereoscopic film and virtual reality stories. Many of these unique concepts are often not discussed early enough in the film process (if at all), increasing the likelihood of a, less than ideal, film experience for the end viewer. This work assembles the challenges faced by directors unique to creating these types of film, and presents
solutions to allow for fast, expressive, real-time sketching both stereoscopically and in virtual reality, without impeding a storyboard artist’s speed and abilities. This in turn allows for fast, easy, real-time collaboration and discussions between the director and film teams.

1.3 Dissertation Outline and Contributions

The remainder of this document is organized in the following manner, with the contributions stated by chapter:

Chapter 2

This chapter summarizes the relevant background information needed to discuss the work and approaches used with this research. The topics outlined in this chapter cover concepts in areas that include the creation of storyboards, animatics, previsualization, stereopsis and other depth cues.

Chapter 3

This chapter summarizes relevant research. Due to the uniqueness of the approaches presented in this work, many of the cited works are in adjacent areas; however, works in the areas of storyboards, virtual production, stereoscopy, stereoscopic images, sketching in 3D, painting, animation, pen interaction, and virtual reality are discussed, which all have some overlap with the work presented in this document.

Chapter 4

This chapter explores the method in which storyboard artists work, concepts that enable them to perform their task, and key considerations when designing a tool for this user group. It continues by exploring concepts that are different for stereoscopic film compared to traditional 2D film. This work outlines some of the key factors that should be discussed at the storyboard stage of film design, and why these factors are important for discussion. The chapter concludes by introducing a conceptual approach of stereoscopic 3D depth planes to handle the challenges of the artist, yet enable them to create content in stereoscopic space, enabling discussion of the key challenges.
The contributions of this chapter include quantifying the key considerations to support storyboard artists while they work, enumerating key concepts that should be discussed at the storyboard stage when creating a stereoscopic movie, and the introduction of stereoscopic 3D depth planes.

**Chapter 5**

This chapter presents and discusses the creative tool “Storeoboard”, and how the implementation enables the use of stereoscopic 3D depth planes. It discusses the functionality of this tool, and how it supports artists with their fast, fluid and flexible creative workflow for drawing stereoscopic storyboards via 2D pen input. This chapter continues by presenting a thorough evaluation of this technique through individual user studies, focus groups and finally a discussion regarding the deployment of the tool on the full-length, 3D Lumière award winning feature film “40 Below and Falling”.

The contributions of this chapter include the presentation of the implementation of stereoscopic 3D depth planes, and the thorough evaluation of the tool and technique for its intended purpose through individual user studies, focus groups and the deployment on a feature film.

**Chapter 6**

This chapter explores techniques for filming in virtual reality. A series of semi-structured interviews were conducted to elicit information regarding planning for virtual reality productions. This chapter discusses the different ideas and concepts that were revealed, in these interviews, which are unique to virtual stories, as well as different audience-camera-narrative styles currently employed by directors. These concepts form the basis of the requirements of a storyboard tool for VR.

The key contributions of this chapter are the results of semi-structured interviews with professionals in the VR film making community; a summary of different audience-camera-narrative styles for virtual reality used today; and highlights of the different factors that should be discussed while planning for virtual reality compared to traditional film. This chapter also introduces the concept of concentric sketch cylinders to support content creation in a 360° immersive space.
Chapter 7

This chapter explores a dual-device system (tablet & head mounted display), that implements the concept of concentric sketch cylinders. Building on the Storeoboard system for the tablet based interface, new VR related concepts are introduced, as is a VR companion system to support viewing of the immersive storyboard sketches. This tablet/VR system also enables dynamic collaboration through different artist-director workflows. These workflows, along with the features presented in this early, two-device prototype system are discussed in detail. The chapter concludes with feedback from professionals in the industry regarding the feasibility of the workflow presented with this system, and a reflection on some of the presented innovations.

The key contributions of this chapter are the implementation of an early VR storyboard system, a reflection on the different possible workflows for creating storyboards for virtual reality, and feedback from professionals regarding the proposed approach.

Chapter 8

This final chapter concludes the exploration in this text, highlighting key observations, outlining potential areas of limitations, and proposes future work pertaining to the material presented in this document.
Chapter 2

Overview of Techniques and Tools

The visual narrative that we refer to as a movie has been around for over a hundred years. In this time, the medium has grown and advanced to the complex process that result in the stunning films we see today. However, to enable these stories to be told, there is a significant amount of planning and forethought put into each scene that one sees on screen. The detail and accuracy of these plans help determine the success of a production team, in successfully assembling a movie in an organized manner, on time and within budget. Many of these planning tools, such as storyboards, are used by numerous teams in the production pipeline to help ensure that the full team is working towards the same goal.

Though this industry has been in existence for some time, not all of the tools used in film are as mature. Some of the techniques used for planning film - such as storyboards – have been around since the early stages of film, and are well defined. Other techniques – such as previsualization – are new in a filmmakers’ toolkit, and exist thanks to the advances in computers and technology. Virtual reality introduces a whole other set of possibilities, of which we are still trying to figure out how to use for film, not to mention the tools to help with planning and development. Many of these areas are still being explored, standards are still being developed, and many of the innovations in these fields are being kept in-house by the companies that provide these services. Even some of the older techniques are being upgraded and adapted to account for the new abilities provided by computers. Though many companies keep their technology exclusive, there is still some published research in the many different areas.
The following pages provide a quick overview of the general disciplines of creating storyboards, animatics, and previsualization, and the rules governing these disciplines. This is followed by the basic concept of stereopsis and other depth cues that are involved with understanding the placement of objects in our environment.

2.1 Storyboards

One of the earlier techniques (used since the 1930’s) for planning a film [Whitehead, 2004], is an artifact known as a storyboard – the creation of a comic book like representation of a movie script. Storyboards have been so useful, that they have been adapted for many other disciplines - everything from software design and games to advertising, laser shows, theme parks and industrial design [Simon, 2006]. Storyboards are very stylized with each artist having his or her own style and is usually broken down into two stages – thumbnailing, and clean up. A director often picks his storyboard artist based on the look, energy, and feel of the drawings. Storyboards are quick to make, with thumbnailing often taking anywhere from a few seconds to no more than a couple of minutes to draw. Clean up usually takes longer, but usually remains under 20 minutes per panel. A film will often only use one or two artists, and these boards are used to communicate ideas and transfer the vision that the director has in his mind onto paper in the form of pictures. This helps ensure that everyone working on the project is working towards the same goal – since “a picture is worth a thousand words”, a significant amount of detail and information can be relayed with these images. A storyboard serves several purposes: first, it is used as an early planning tool; it allows the creative team to visualize a scene before committing to the needed resources; it allows the director to consider and find interesting camera moves and angles, and set the look and feel of the scene; and it is used as a communication tool between departments - used to direct the overall process. Storyboards are often photocopied and distributed to the different crew members working on-set.
Being an art form, there are many different variations that a director and producer may use to approach the storyboard phase of a film, but in general it works similar to the following: Once a script has been selected and a director has been picked, a director will choose a storyboard artist that he feels captures the essence of the story being told. The director and artist will sit down and discuss the film one scene at a time, shot-by-shot. During this phase the storyboard artist will create “thumbnails” to capture the director’s vision and the look and feel of a scene (in some cases the director will do this phase by themselves). After this step (usually for live action film – this step is not always done for animations), the storyboard artist will take the thumbnails and spend time on each panel, creating better looking storyboards that are more accurate and visually pleasing (known as a “cleanup”), that are then used during the filming of a movie (see Figure 3).

When creating storyboards, the artist is often expected to help and/or figure out balanced shots, layout, and camera angles for the moment being discussed. Often it is the job of the storyboard artist to extract the details of the image that a director has in his “mind’s eye”. Due to this fact, there are numerous rules that artists follow. For instance, one such rule is the “Rule of Thirds”, where a scene is divided both horizontally and vertically into 3 parts. Focal points of a scene should be found at one of the 4 points where the 1/3 division lines and the 2/3 division lines intersect (see Figure 4). Another such rule is the “180° Rule” (sometimes referred to as “Breaking the Line”). For this rule, there is an imaginary straight line drawn through the scene. All camera shots should stay on the one side of the line, or on the line itself.
Moving a camera to the other side of the line can cause confusion as it will appear to the audience as if the actors have switched positions (see Figure 5). Another consideration is the location of action within a scene – for example, should an item be in the foreground (FG), mid-ground (MG), or background (BG) of a scene (see Figure 6).

Other considerations that the storyboard artist must keep in mind are factors such as the framing of the image for a specific shot. For example is it going to be a “close-up shot”, a “medium shot”, or a “full shot” (see Figure 7). Each type of shot is used in different circumstances to create different effects and emotional response. Further the “shot angle” needs to be considered. Are they using an “over the shoulder” view, “worms eye” view, “point-of-view (POV)” shot, or “straight on” shot – to name a few. At the same time, the artist needs to consider things such as lines of symmetry and balance.

Finally, storyboards have advanced to a point where they have their own language to indicate different actions that occur on screen. There are symbols for camera moves, dollies, and pans; arrows to indicate character and object motion; and frame symbols to indicate things such as a camera shake or tilt (cantor). Examples of these symbols can be seen in Figure 8.

Though storyboards are a powerful tool and allow the director to “see” the film before it is made in an inexpensive manner, communicate a unified vision with others and allow for early planning of sets, costumes and props, storyboards do not solve all problems. One of the biggest problems with storyboards is that there is no sense of timing or pacing. One cannot be sure how long it takes an actor to walk from one point to another, or how much time a stunt actor needs to get out of the way before
a building comes tumbling down. Further, it does not provide any camera specifics such as camera position or the type of lens to use for a scene. As well, since these scenes are not tied to reality the shots created in a storyboard may not actually be possible in real life.

2.2 Animatics

To deal with problems of timing and pacing, a technique known as an animatic (or a “Leica Reel”) was introduced. This is the technique of taking the storyboards and possibly other footage and compiling together the video sequence, often with a voice track and possibly a soundtrack. Depending on the use of the animatic, coloured versions of the storyboard panels may be created, and at times further assets are required to better animate the ideas being portrayed. Through this crude animation method, artists are able to bring their drawings “to life”. Though this helps with determining some of the problems of timing, physical limitations are still not tested, nor are any camera specifics provided.

2.3 Previsualization

Traditionally, previsualization (or previs) referred to any technique used to create some visualization of the film before beginning to shoot a movie. This could refer to storyboards, cardboard models, the use of action figures, clay models, or any other technique one can image.
that would allow some type of visualization of a scene within the film to help the film team understand and plan a shot. This broad definition of previs has changed in recent years to reference a new technique that has replaced the traditional definition and is now what is meant when using the term previsualization. This new definition refers to the technique of using computers to create simple crude 3D animations of a scene. These lightweight models allow the director to play with the camera, virtual actors, and layout of a scene before committing to an idea. This is similar to the old technique where production teams used toys such as Barbie’s and G.I. Joes with “lipstick cameras” to block out scenes. The use of computers has introduced possibilities that were not possible before.

Previs is different to storyboards in that it often uses teams of 4 to 12 people who will work on a single scene for anywhere from a week to a few month. The scenes that are created, though 3D, lack the artistic stylization that an artist introduces to the process with storyboards. Due to the length of time it takes to create previsualizations, directors use previs more sparingly. In contrast, it is not uncommon for a director to storyboards a full film. Previs is often used for more complex shots, such as mass crowd scenes, scenes with expensive or complex setups, fight sequences and special effects shots.

Previs is actually an umbrella term used to refer to a larger set of virtual production techniques. These techniques include “Pitchvis” – used to illustrate a project before it is greenlit; “D-vis” (or “Design visualization”) - used to help with early in-depth collaboration on design; “Technical previs” – incorporates lighting, cameras and scene layout – often used to figure out physical logistics, constraints and challenges - such as the amount of track needed for a dolly camera, the amount of green screen needed for a shot, or whether a camera crane will fit within the desired space; “On-set vis” – a technique of creating real-time visualization of a digital environment while filming on-set to help the director, VFX supervisor and crew evaluate captured imagery. Generally this means that actors are fitted with motion tracking suits and their performance is recorded in virtual 3D – as well, directors often use cameras that are tracked by motion tracking markers and are equipped with a display that is setup to show the digital environment rather than the real environment in front of them; and “Postvis” - the digital creation of a scene used for direction with effects houses, early editing, and early feedback (See Appendix A for the official definition of these terms as defined in “The VES Handbook of Visual Effects: Industry Standard VFX Practices and Procedures” [Zwerman, 2014]).
Previs is an amazing tool for determining the technical and physical restrictions of a scene, provides exact measurements and allowing a director to “play” with a camera to discover new shots. Previs helps directors with setting the timing and pacing of a scene; they can better figure out their shots; they can pre-place the cameras, even before they are on-set; it allows them to figure out what exactly is needed on-set before they arrive; determine location of actors before they are on-set (i.e. if there will be 1000 actors at a shoot); allows directors to figure out the details of a complex shot; and it allows stunt coordinators to calculate logistics and timings. This can help improve the production process immensely.

Unfortunately, the turn-around time for a previs shot is comparatively long (to storyboards), and needs a large team of people to create the shots. Further, it lacks the stylization seen from the personalization of a traditional artist who creates the scenes with pencil and paper. Due to these restrictions, the length of time and number of people involved in creating previs, it is a poor choice for exploring ideas, getting one’s ideas down on “paper”, and discussing early stage concepts (ideation). Previs is best as a next-stage technique to refine ideas already captured with a storyboard for complicated, challenging or expensive shots.

2.4 Stereopsis and Other Depth Cues

Movies, in general, are a series of sequential images each slightly different than the last which results in an illusion of motion. There are, however, other attributes that can partake in the look and feel of a film. Factors such as the image quality (i.e. high definition or IMAX), the type and location of sound (i.e. Dolby Surround or Atmos), and the techniques to create a unique visualization (i.e. stylized animation, stop-motion photography, photorealistic rendered 3D animation, or stereoscopic movies) all contribute to the look and feel of the movies that are created today.

Stereo in film has had a resurgence in recent years, and its introduction is often compared to the introduction of colour in film. People often ask, “What does 3D add to a film?” In the VES handbook of Visual Effects [Zwerman, 2014, p397] it addresses this issue stating:

*Stereo adds a new level to a film’s visual design. In its purest form, 3D gives the viewer a palpable connection to the images of a film. An actor looks real and alive. It is intimate,*
sensual, tactile, and immersive. In its raw form, 3D is not subtle and it is not ambiguous, but with good design, both of these qualities can be introduced as needed and used with great precision. [...] The stereo effect can also be exaggerated or twisted to defy reality.

This paragraph hints at interesting possibilities yet to be explored and as such, this text will explore manipulating stereoscopic imagery.

Stereoscopic images work by displaying slightly different images to each eye. Each image is shifted slightly to the left or right of the other image. In fusing these images together, there are two factors that work together, vergence (the angle your eyes rotate to see an object) and accommodation (your optical focus). Using these two factors, our brains provide the illusion of an object being in front of, on, or behind the screen. To have an image appear in front of the screen, one needs to shift the image for the left eye to the right and for the right eye to the left. When the convergence of your eyes is such that the points for the left eye and right eye

Figure 9. Apparent position of screen objects due to horizontal displacement. (A) image that appears in front of the screen (B) image that appears on the screen (C) image that appears behind the screen
Figure 10. Depth Cues: A) Retinal Image Size, B) Linear Perspective, C) Interposition, D) Aerial Perspective, E) Light & Shade, F) Textural Gradient, G) Motion Parallax, H) Accommodation & Convergence, I) Disparity, J) Stereopsis
overlap, the image will appear in front of the screen. If one moves the image for the right eye to the right, and left eye to the left, the image will appear behind the screen (see Figure 9). Note that the accommodation stays constant, on the screen, regardless of the angle your eyes move to view an object. This is different from how your eyes work regularly where the two factors usually change together. This is one reason some people believe viewers get eye fatigue and consequently headaches from stereoscopic films, though this reason is often contested.

The visual cue that this technique uses is referred to as stereopsis and is responsible for images appearing to extrude from or recede into the screen. Unfortunately, 3 to 15 percent of people suffer from what is known as “stereoblindness” due to various visual complications [Freeland, 2012]. However, stereopsis is just one of many factors that contributes to an image appearing to have depth. In his book “Foundations of the Stereoscopic Cinema” [Lipton, 1982], Lipton lists multiple factors that contribute to the appearance of depth. He lists them as follows:

- **Retinal Image Size.** Larger retinal images tell us that the object is closer. (Figure 10A)
- **Perspective, or Linear Perspective.** This cue is based on the notion that objects, often man-made, diminish in size as they recede from the observer. For example, parallel railroad tracks seem to converge at the horizon. (Figure 10B)
- **Interposition, or Overlapping.** One object in front of another prevents us from seeing the one behind. A teacher in front of a blackboard cuts off part of the view of the blackboard and must, therefore, be closer to the student than the blackboard (Figure 10C)
- **Aerial Perspective.** On a very hazy day, mountains are barely visible in the glare of the haze illuminated by the setting sun. The haze intervening between the subject and the mountain make it look far away. Atmospheric haze provides the depth cue of aerial perspective. (Figure 10D)
- **Light and Shade.** Cast shadows provide an effective depth cue, as does light coming from one or more directions (Figure 10E)
- **Textural Gradient.** A tweed jacket seen up close has a coarse texture that is invisible from a great distance. The leaves of a tree are clearly discernible up close, but from a distance, the texture of the leaves becomes less detailed. (Figure 10F)
- **Motion Parallax.** This cue is a post-Renaissance discovery, probably discussed first by Helmholtz [Helmholtz, 1925]. A dramatic example of motion parallax is the rapid
movement of nearby foliage as one rides in a car, while the sky and the distant hills seem to remain relatively fixed in position. (Figure 10G)

- **Accommodation.** Just as the camera lens focuses by moving closer to or farther away from the film, the lens of the eye focuses images on the retina by actually changing shape as it is pulled by muscles. The muscular effort involved in focusing could provide feedback for gauging depth. (Figure 10H)

- **Convergence.** The lens of each eye projects a separate image of objects on each retina. In order for these to be seen as a single image by the brain, the central position of each retina must “see” the same object point. (Figure 10H)

- **Disparity.** When the eyes converge on an object in space, it is seen as a single image, and all other objects, in front of or behind the point of convergence, can be seen to be doubled. (Figure 10I)

- **Stereopsis.** Stereopsis is the only depth sense that depends on our having two eyes. Stereoscopists use the term interocular to describe the distance between the eyes, usually 65mm for males and 63mm for females. Physiologists call this the pupillary distance, or P.D. The distance between camera and projector lenses is called the interaxial. Although it is a separate depth sense, stereopsis depends on the other depth cues in order to form a visual impression of the world. This ought to come as no surprise, since the entire perceptual process is a cooperative effort on the part of the various cues. (Figure 10J)

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**Figure 11.** Image demonstrating perceived depth, based on different depth cues. Object on left shows simple geometry; Object on right shows a 3D scene. Both images use the same amount of depth (depth budget).
2.4.1 Perception of Depth

Stereopsis is an interesting depth queue as, though the position of objects within the scene is technically consistent, the perception of the depth created from the image is not. Depending on the placement of the objects, without a reference (such as the screen edge), it can be difficult to tell where in space the scene is located. Further, depending on the composition of the scene, the image can appear to have more or less depth. For example Figure 11, shows two scenes with the same depth. The image with simple geometry looks much shallower than the one that also has other depth cues, such as retinal image size, linear perspective and textual gradient, that providing further depth information.

2.4.2 Floating Windows

The concept of a floating window is one unique to stereoscopic films based around the principle that the audience only knows the location of the edge of the screen based on the fact that it is illuminated by the displayed image. Due to this fact, the image can be manipulated so that the screen itself appear to be in front of the physical screen, or behind its actual, physical location. By treating the edge of the screen as if it were

*Figure 12. Example of floating windows. Top image shows regular window; middle image shows shot of window floating in front of the scene; bottom image shows shot of window floating behind the scene.*

*Figure 13. Example of a "tilted" frame.*
an actual object within the film, by offsetting the edge of the image for one or both eyes (Figure 12), it can be made to appear as if the screen edge is in front of, or behind the actual physical screen location. Through variations on this process, one can also create an image that looks twisted, bent, or tilted (Figure 13) either vertically or horizontally.

These “floating windows” are traditionally used to correct mistakes, or to accommodate physical restrictions that are difficult to handle when working in stereo (such as a character moving towards the front of the screen, but needing the character to stay behind the border). One can, however, also use these floating windows for visual effects, to help with the mood of the scene. For example, assume one is composing a scene where a character is looking up at a very tall building that is supposed to feel foreboding. This feeling is usually achieved by having a character look up at the building from the ground, and having the building recede into the distance. However, with the use of floating windows, the director can also compose the shot so
that the frame of the window itself is tilting forward, “leaning” over the audience. Through simple tricks such as this, the window can be used to add to the atmosphere of the scene to help set the tone of a moment.

### 2.4.3 Edge Violations

An edge violation is a term used to describe a situation that causes a conflict of depth cues. For example, Figure 14 shows a situation where the figure on the left should be in front of the frame. However, due to the fact that his head is being cut-off by the frame, there is a visual conflict. Stereopsis tells us that the character is in front of the screen, but occlusion tells us that the character is behind the frame. This artifact is one that is known to cause visual discomfort and potentially headaches. The solution in this case is shown by the image on the right, where a floating window has been used to move the window in front of the frame so there is no conflict. Figure 15 shows another similar example. In this case, only the side of the frame with an edge violation is adjusted to correct this issue. This one-side solution is not possible with the previous example since the violation happened in the middle of the frame, and for stereopsis to work the offset is only in the horizontal direction. There are many ways to correct edge violations.

Another edge violation and solution are shown in Figure 16 through Figure 18 below; where a lamppost is only visible in the right eye. Figure 16 shows the stereo-image with edge violation. Figure 17 shows the left and right eye image separately, and Figure 18 shows a solution to this problem where the left edge of the screen is occluded in the right eyes so that the conflict no longer exists.

*Image © B.Block & P.McNally*

**Figure 16.** Another example of an edge violation. The lamppost on the left is only visible in one eye.
Figure 17. The left and right eye image of the previous scene. Notice the edge violation caused by the lamppost, missing in the left-eye image.

Figure 18. The previous scene with the edge violation removed. The left border has been extended in the right-eye image to occlude the lamppost from that eye.
The following is a review of some of the literature that has been generated discussing ideas and research in the areas ranging from storyboards and virtual production to sketching, animation, pen input and virtual reality. Storyboards and virtual production are still largely an art form and still rely heavily on drawing and painting. As such, one of the goals of the work presented in this text is to involve the traditional artist (the artist who is accustomed to paper and pencil – opposed to mouse and keyboard). For this reason, the following section outlines research in many areas including computer sketching and painting, and the efforts to transfer these approaches to the realm of stereoscopic and 3D representation.

3.1 Storyboards

In computer science, there are many different ways to approach a problem. The use of computers for creating storyboards is nothing new and software to support this art from already exists. Two commonly used programs for creating storyboards are StoryBoard Quick [StoryBoard Quick], which is generally used by amateurs and directors, and uses libraries with a drag-and-drop interface, and Toon Boom’s Storyboard Pro [Toon Boom Storyboard Pro]. Storyboard Pro is the preferred tool used by storyboard professionals, as it allows for the creation of content by real-time sketching on a drawing tablet and has a sophisticated asset management systems. It also allows one to import virtual environments and 3D assets into the 2D sketch editor. However, the creation of 3D content has to be completed using an external 3D modeling tool, and the 3D rendering of the end result is a time-consuming process. This means that these tools are poor
candidates for live editing and real-time collaboration. Often artists will use Photoshop [Adobe Photoshop] and SketchUp [SketchUp] to augment their work created in these programs. However, it is not uncommon for the thumbnail process to still be done on paper, after which a digital version is often created through scanning, for the purposes of creating cleanup images and for planning.

Beyond its usage by cinematographers and animators, storyboards are also common instruments for quick user interface prototyping [Greenberg, 2011] or even characters’ interactive behavior [Rea, 2014]. Many of the research papers regarding storyboards focus on user-centered design and are not very generic or applicable for film and television. One of the more generic and cross utility papers include “Draw Me a Storyboard: Incorporating Principles & Techniques of Comics…” by Haesen et al. [Haesen, 2010]. In this paper, they explore user centered design but in a more generic fashion. They look at the problem in the sense of “graphical narratives” as a common language, focusing on techniques used for comic books to facilitate transfer of information. They create their own system (COMulCSer – or Collaborative Multidisciplinary user-Centered Software engineering) and provide an evaluation. This system allows users to draw full scenes, or add drawings on top of existing photographs.

Approaching storyboards with a similar methodology of mixing existing images and drawings, can be seen with the papers “Longboard: A Sketch based Intelligent Storyboarding Tool for Creating Machinima” by Jhala et al. [Jhala, 2008]. Machinima is a technique of creating animations through the use of game engines and 3D environments. For example, one might “act out” a scene in the popular virtual world Second Life [Second Life] to create these animations. These programs are used to create action sequences that are filmed by the user, and then edited together to create a crude 3D animated movie. In their paper, they present a system that allows users to follow a workflow similar to some movie making processes, and allows users to draw storyboards and load 3D environments to help express their visual intentions. The program is organized with tabs for each step of the design process (i.e. script, storyboards, picking sets and actors, etc.). Once a story is planned, a game engine renders a film following the crafted outline.

In an attempt to better integrate 2D sketching environment and 3D graphics environment, Mao et al. created “Sketching-out Virtual Humans: From 2D Storyboarding to Immediate 3D Character Animation” [Mao, 2006]. In this paper, they explore a process of creating character animations
by creating stick figures over top of their storyboard panels. These stick figures are “fleshed-out”, then skinned to create the 3D characters viewed in the animated scene. Though this paper focuses on the user interaction for manipulating the skeletons created from the storyboards (and refers to another paper for the details on how the stick figure is fleshed out and skinned), this demonstrates a more explicit attempt to address the needs of transferring content from storyboards to an animation context.

Another use of storyboards is to use them to guide camera shots in a virtual environment. A technique of applying constraints to setup a virtual camera in a virtual environment is explored in the paper by Bares et al. [Bares, 2000], where a storyboard representation of a moment is used to provide constraints to a system to match the virtual camera. “StoryCrate: Tabletop Storyboarding for Live Film Production”, by Bartindale et al. [Bartindale, 2012] is another paper that uses storyboards to convey information for a shot; however, this is done through providing information to a film crew. This paper discusses a prototype and approach with a more practical focus and has actually been used on a film set. In this paper, they have created a tangible interface and collaborative tool that uses storyboards as the unifying element to help bring the different players on-set together in creating the scene. Their tool is carried in an industrial equipment-packing box and is easily transported onto a live set. The paper, which introduces this tangible system, is a bit different than other storyboard papers, as it uses an already created storyboard to help drive and coordinate on-set collaboration. Further, it helps manage the recordings as they are being created. Though this paper discusses storyboards, and storyboard frames can be added during the process, the storyboards are a means to an end. They are a navigation feature to help aid in the collaboration and creativity of a project, rather than a tool to help design the scene before starting the actual film shoot.

In fact, there are a numerous papers that explore the use of storyboards as a navigational tool. For instance, Barnes et al. explore representing a full film as a continuous tapestry of images in “Video Tapestries with Continuous Temporal Zoom” [Barnes, 2010]. In this paper, they explore capturing the key moments of a film given a time duration, and present these images as a collage from which a user can zoom-in or -out to see a more select period of time, or a broader range. This allows for fast visual navigation of the film and leads to a faster understanding of what the user is seeing. Likewise, in “Schematic Storyboarding for Video Visualization and Editing” [Goldman, 2006], Goldman et al. explore visualizing a film sequence by creating a still image
with storyboard symbology. This is evaluated against professional storyboard artists and the boards that they would generate for the same sequence. Further, they demonstrate a technique to scrub through a sequence using these storyboard representations as the sequence selector. Finally, Choi et al. [Choi, 2013], explore dynamically creating different storyboard layouts for the purposes of navigating 3D character motion data. This scenario is different due to the fact that it allows for the user to be unaware of the angle and duration of the sequence they are trying to explore ahead of time. Using this paper’s method, one can explore a shot by choosing different angles and different levels of detail when they are working with the data, instead of ahead of time – as is traditional. Depending on the action taking place at the desired moment, the preferred viewing length, and the camera specifics, their system generates an appropriate storyboard for the provided constraints.

3.2 Virtual Production

At the other end of the film planning and design process, there is virtual production, which includes previs. Very few books and papers have been written at this time about previs in its current incarnation, as this technique is a relatively new area. Most information about this topic comes from web videos and interviews with professionals in the industry. Some videos of note include the collection of videos on the “Screen Industries Research and Training Centre” website [SIRT], which has provided videos from a previs conference that they hosted in 2011. As well, the Previs Society [Previs Society] in conjunction with Autodesk [Autodesk], have created two promotional videos discussing the uses and benefits of Previs [Art of Previs, 2013] and Postvis [Art of Postvis, 2013].

There are a few commercial software packages that are used for previsualization, but many are developed in-house by previsualization companies. The main programs that are used are Autodesk’s Maya [Autodesk Maya] along with Motion Builder [Autodesk Motion Builder], which is usually used by professionals, and FrameForge [FrameForge] - a drag-and-drop package more traditionally used by amateurs. Some artists will use other programs such as SketchUp [SketchUp], Pixologic’s ZBrush [ZBrush] (a 3D model sculpting tool), and Photoshop [Adobe Photoshop] to augment their work.
There are, however, a couple of papers that have started to explore this area. The first, and main paper to note, is a white paper [Patel, 2009] written by Maurice Patel of Autodesk, discussing Virtual Production, what it is, how it is changing the approach to film making and basic techniques involved with virtual production. It covers topics from applications of virtual moviemaking to camera systems and previsualization. This paper is a start, trying to outline what is currently accomplished and how these tasks are performed in the industry and where the industry might be going. There is also a paper by Northam et al. called “RTFX: On-set Previs with UnrealEngine3” [Northam, 2011], where they explore using the UnrealEngine3 [Unreal Engine] to create a system that generates live-time previsualization by motion tracking individuals and directly mapping the user’s movements to an avatar on a screen. This is similar to work done in-house by many previs companies, but this is the first publication that explores this approach and tries to develop an affordable framework. As well, there is a paper titled “Storyboarding and Pre-Visualization with X3D” [Jung, 2010] where Jung et al. use scripting and a notation that was created called “Director Notation” to provide blocking and camera effects to a previs scene. This approach requires scripting and a strong understanding of their notation; however, provides the ability for effects such as depth-of-field and strong control over factors such as camera lens selection. As well, “The director’s lens” is a paper by Lino et al. [Lino, 2011] that discusses a system that provides suggestions to artists and directors on image composition by combining position information from a motion-tracked “camera” device along with previous shot compositions. Through this on-set type previsualization, the system can help amateur artists use better shots and learn better framing techniques.

3.3 Stereoscopy

Stereoscopy has been around for almost 200 years. The first major exploration of this phenomenon was published back in 1838 by Charles Wheatstone, titled “Contributions to the Physiology of Vision – Part the First. On some remarkable, and hitherto unobserved, Phenomena of Binocular Vision” [Wheatstone, 1838]. In this article, he discusses his observations of providing slightly altered images to each eye, the effect of our brain to interpret these discrepancies, and some of the physiological constraints in this process. In this article, he also outlines a contraption he created called the Wheatstone mirror stereoscope. Though many of the factors he discusses are now well understood, the concept of stereopsis was unknown at the time,
and people were unsure how the brain would handle two simultaneous conflicting images. An interesting point of note is that this work was published before the first practical photographic process was available, and therefore all of the images he used had to be drawn. Understanding the visual system, however, is an ongoing task and research is constantly being conducted to try to better understand these mechanisms. The paper by Valkov et al. [Valkov, 2011], for example, is but one of many recent works to better understand how our brains handle stereopsis. In this paper, due to an image being split into two to create the stereoscopic effect, there is uncertainty as to where to touch if trying to touch the object. They therefore, attempt to understand where a user wearing stereoscopic glasses reaches, when attempting to grasp a stereoscopic image being displayed on a see-through screen.

There are multiple ways of viewing stereoscopic content: one can use a lenticular overlay or a parallax-barrier over top of an interlaced image; one can use a contraption such as the Wheatstone stereoscope, or a view master to provide separate images to each eye; one can use a virtual reality rig – such as the Oculus Rift [Oculus Rift]; or one can use anaglyph glasses, linear or circular polarized lenses with supporting projectors, or active shutter system to view these images that take advantage of stereopsis. Regardless of the approach, all of these methods work on the same principle – by providing an image viewed from a slightly different angle to each eye respectively.

Other approaches to provide 3D images include devices such as a volumetric display. Some research that has been done regarding these displays is seen in the work by Grossman and Balakrishnan [Grossman, 2006], where they attempt to determine whether these displays aid perception while viewing 3D scenes. They found that there was an improvement for both depth judgment tasks and collision judgment tasks compared to perspective images, and regular stereo images. As well, Vishwanath and Hibbard [Vishwanath, 2013] published a study where they observed participants assessing images, where they reported seeing the effect of stereopsis, though they viewed the provided images through only one eye. Though they conclude that viewing a scene with two eyes provides a more compelling three-dimensional experience, participants were presumably, non-the-less, able to view depth with one-eye.

There are a few papers that explore various considerations and concerns with stereoscopy. The paper “Binocular Depth Perception of Stereoscopic 3D Line Drawings” by Lee et al. [Lee,
Kim et al. in their paper “Stereoscopic 3D Line Drawings” [Kim, 2013a], look at a different issue. In this paper, they discuss two different ways of creating stereoscopic images. One method is a “center-eye” method, where an image is simply shifted to the left and right (for the respective eye) to create the effect of stereo. The other method is an “each-eye” method, where the image for each eye is generated separately with the correct image perception for the given eye. This “each-eye” approach is achievable when trying to replicate reality or when generating images from 3D models. This paper explores the problem that with an “each-eye” approach, it is possible to have images where the lines for one eye do not necessarily have a matching counterpart in the other eye. This leads to ocular disparity, which causes discomfort to the user. They present a technique to resolve these discrepancies as well as a study showing how their approach works with images rendered with several different line styles.

Stereoscopic representations are found in more than just drawing applications. Another area that has been identified where a stereoscopic approach is useful is in the design of dashboards for cars. Often the displays on new cars have some form of parallax. Designing for these displays is, however, challenging. To explore this area, Broy et al. looked at two different approaches to try to help with this design issue in “FrameBox and MirrorBox: Tools and Guidelines to Support Designers in Prototyping Interfaces for 3D Displays” [Broy, 2014]. In their setup, they examine a clear acrylic box with slots in it to insert physical media (such as clear sheets or cut-out paper) to achieve a parallax presentation, as well as a rig that has semi-transparent mirrors slanted at an angle with UI elements drawn on transparent film sitting on the mirrors. This rig sits on top of an iPad, which acts as back lighting for the contraption. Though the subject matter of this paper only loosely relates to computers, this demonstrates yet another use case scenario where a tool to designing for stereoscopic environments would be useful.
Another use for stereo is with augmenting hardware. In their paper “TouchMover: Actuated 3D Touchscreen with Haptic Feedback”, Sinclair et al. [Sinclair, 2013] augment a screen by mounting it on an actuated arm. This allows the screen to push forward or recede from the user depending on the contents of the screen and the interaction being performed. Through this means, the authors explore presenting objects with different 3D shapes and objects with different weights. With the actuated arm and tracking the user’s location of touch, they are able to do things such as have the screen move forward and backwards as the user traces the contour of an object (say a sphere) to provide the sense of touching a 3D object rather than a flat screen. They can also provide more resistance when the user is pushing an object that should appear to be made from a heavier material than another (say stone versus wood). The paper concludes with the results of a user study where they observe that using the 1D haptic channel can successfully help with the identification of simple shapes.

Finally, stereopsis has been introduced into multiple environments, such as the semi-spherical cave as seen in the one page short “Hyve-3D: A New Embodied Interface for Immersive Collaborative 3D Sketching” [Dorta, 2014]. In this paper, they discuss a collaborative drawing system where each user has a tablet that is tracked in 3D space. This tablet has a proxy represented as a plane in this 3D stereoscopic environment. Through these proxies, the users are able to draw lines and add content to the scene being drawn. Since the system is able to track more than one user, multiple users can work together collaboratively to build up a 3D scene.

3.4 Creating Stereoscopic Images

The effort to easily creating stereoscopic content has been explored in more than just immersive environments. A technique for stereoscopic computer painting is explored in “WYSIWYG Stereo Painting” [Kim, 2013b]. In this paper, they introduce a tool that allows users to create computer generated stereo drawings that are stylized in such a way as to appear to have been painted. They achieve their stereoscopic effect by introducing 3D geometry then projecting their 2D strokes onto these surfaces. Further, the user is presented with depth brushes and displacement brushes to help manipulate the environment while sketching.

Stereoscopic Cel Animations [Liu, 2013] conversely explores creating stereo images with an automatic approach. In this paper, the computer separates an image into various regions, and
then using T-junctions creates a predicted depth ordering to infer depth layers and automatically
builds a depth map. They further use adjacent frames to attempt to clean up some of the noise in
the data. Using this depth map, the program is able to apply stereoscopic layers to the original
image automatically creating a stereoscopic cel.

As more stereoscopic content is created (using drawing programs and cameras), other tools to
manipulate these images are needed. In Stereoscopic 3D Copy & Paste by Lo et al. [Lo, 2010],
the authors examine the challenges of performing copy and paste operations for a stereoscopic
image. They recognize that there are added constraints such as introducing proper Z-order,
proper image splitting, and generating proper shadows that do not exist with regular cut and
paste, and ideally need to be handled if simple operations such as these are to be included in
modern stereoscopic programs.

3.5 Sketching

Since Ivan Sutherland created his sketchpad system [Sutherland, 1963], there have been many
projects to extend its basic functionality. Sketchpad III [Johnson, 1963] endeavored to extend
Sketchpad to create actual 3D objects, while The Rand tablet [Davis, 1964] focused on creating
the hardware to support such interactions, by introducing an early digitizing tablet for drawing.
Herot’s work [Herot, 1976] on the other hand, had a much more ambitious task of training a
computer to try to help it recognize aspects of the drawing and compressing the information. As
more programs for drawing came to exist, techniques to help make the drawings look neater
[Pavlidis, 1985] and more like paper drawn sketches [Bleser, 1988] were developed. Techniques
for helping CAD drawings were also being developed [Lamb, 1990], as well as different
techniques for generating 3D models [Turner, 1999]. Further, through the 1990s, techniques for
working with digital white boards were being explored and developed [Pedersen, 1993; Moran,
1995], as well as explorations with collaborative drawing [Tang, 1990].

Along with interpreting line drawings, the look of the brush strokes has also been an area of
interest to researchers. Both Whitted [Whitted, 1983] and Strassmann [Strassmann, 1986] have
explored different way to improving the look of brush strokes to attempt to make it appear more
natural.
3.6 Sketching to 3D

Sketching in 3D is a difficult task as one is missing depth information. This results in an ambiguity with most lines that needs to be resolved before an image can properly be shown in 3D. Due to this fact, researchers have tried different approaches to resolve this missing depth information, including Clark back in 1976 [Clark, 1976]. Kokichi Sugihara presents a thorough discussion of interpreting 2D line drawings to construct 3D shapes in his Machine Interpretation of Line Drawings book [Sugihara, 1986]. Yet ever since then, new techniques continue to be introduced. The efforts of Rivers et al. [Rivers, 2010] explores creating cartoons by using a 2.5D approach. In their method, a user builds up an image by creating drawings from several different perspectives. Based on these images, the location of each stroke is placed in a 3D space. From this 3D information, they are able to interpolate the look of an object and place the parts of the image correctly based on the position and orientation of the camera in the scene.

Kallio [Kallio, 2005] takes a different approach and explores a technique for adding natural drawings to a 3D space by mapping a user’s 2D drawings onto a deformable 3D grid. The program maintains the original 2D drawings and allows for manipulation of the grid to achieve the 3D look and feel. Similarly, Napkin Sketch [Xin, 2008] allows for drawing 3D images through the addition of 2D planes. In this work, a tablet is used as a drawing “window” looking at a 2D “napkin” sitting on the table. Where Kallio looked at moving a plane around in 3D space, the user of Napkin Sketch is able to create virtual planes that are anchored on the napkin and add content to these planes, slowly building up a 3D scene drawn with the tablet’s pen.

Another unique technique for creating 3D models through sketching is explored by Igarashi et al. in “Teddy: A Sketching Interface for 3D Freeform Design” [Igarashi, 1999]. In this paper, he discusses his approach to create 3D models based on an initial closed sketch shape. This shape is given volume based on how thick the closed object is at a given point. Once the initial object has been created, the user can cut the object, and add extrusions and dents. Further, he provides the ability to redefine the contours of the image by providing guidelines with the pen for the deformation to follow.

The approach of creating 3D models starting from a sketch (either directly or indirectly) has been explored by numerous papers with different approaches. In “Structured Annotations for 2D-to-
3D Modeling” [Gingold, 2009], Gingold et al. explore creating 3D sketches by sketching 2D primitives that introduce a volume to the drawing space. These primitives provide control handles that can deform the volume of the object or change its orientation in 3D space. Through several easy to use controls, the artist can add more primitives, building-up, visually pleasing, and soft-edged 3D models.

Similar to Gringold’s work, Shtof et al. create 3D models from sketching out primitives on a drawing surface in their paper “Geosemantic Snapping for Sketch-Based Modeling” [Shtof, 2013]. This work uses annotated vector sketches as the base for creating the models. Once the underline vector sketch has been annotated, basic primitives are dragged onto the sketches and through imposing geosemantic constraints (such as concentric and coplanar constraints) the primitives snap to an appropriate location and alignment to create the desired 3D models.

In “SMARTPAPER: An Interactive and User Friendly Sketching System” [Shesh, 2004], Shesh and Chen create a tool that incorporates both direct sketching as well as gesture based sketching. This tool combines a number of methods explored in previous works allowing for 2D sketching, sketching on 3D models, 3D transformations, and CSG cutting and joining operations.

Another approach can be seen with “Sketching Reality: Realistic Interpretation of Architectural Designs” by Chen et al. [Chen, 2008] where the user starts by defining a horizon and then sets vanishing points along this line. From this point, as the user draws strokes, the computer calculates likely edges and groups similar faces, while providing feedback to the user; this allows them to adjust their model as they draw. 3D geometry is then fit to these line drawings to create a cleaned-up 3D model. Once a surface has been draw, the user can sketch a pattern, which will then be matched to a library, and a texture will be added to a surface.

Following the approach of creating content by producing initial guidelines, “Analytic Drawings of 3D Scaffolds” by Schmidt et al. [Schmidt, 2009b] shows an approach where the user interactively creates scaffolds to help define precise 3D sketch curves. In “ILoveSketch: As-Natural-As-Possible Sketching System for Creating 3D Curve Models” [Bae, 2008] and “EverybodyLovesSketch: 3D Sketching for a Broader Audience” [Bae, 2009] both by Bae, Balakrishnan and Singh, the authors explore design based curve sketching by introducing an approach to provide accurate guides to help with drawing – aimed first at professional designers and then modified for a broader audience. In these two papers, numerous interface techniques are
explored including 2D and 3D view navigation, multi-stroke NURBS curve creation, tick-based sketch plane selection, arbitrary extrusion vectors, an interactive perspective grid and a gesture vocabulary to support an artist drawing. This work is supported by user studies with professionals and students using the tool to create compelling examples. More recently, there has been an effort to re-introduce line drawing into 3D modeling programs as can be seen with Blender’s [Blender] grease pencil tool [Leung, 2015].

Another paper that focuses on 3D curve sketching that attempts to emulate drawing on paper is “Just DrawIt: a 3D sketching system” [Grimm, 2012]. In this paper, they explore using a context aware pen-based menu rather than gestures, and 3D geometry with shading cues to help place curve networks in 3D space.

However, since we as a community are attempting to computerize the art of paper drawing and design, this would suggest a need to understand the natural workflow used by artists and how they sketch on paper and paint on canvases. Augmenting a surface to allow 2D techniques to work in 3D can be challenging and has led to several papers trying to understand how the user draws to better address this problem. With “On Expert Performance in 3D Curve-Drawing Tasks” by Schmidt et al. [Schmidt, 2009a], a study is performed exploring how artists handle drawing curves in foreshortened situations, their accuracy and perceived biases. In “Where do People Draw lines?” by Cole et al. [Cole, 2008], they aimed to create a mathematical model based on which lines artists drew to represent a given shape, including its lighting and surface geometry. They explored the consistency of the strokes drawn to represent a shape as created by multiple different artists. In “Animated Construction of Line Drawings” by Fu et al. [Fu, 2011], the authors attempt to explore the order that artists add lines while creating drawings. With this knowledge, they attempt to create a computer system that animates an image being drawn in such a way that it is plausible that it was actually a recording of an artist drawing.

Dorsey et al. [Dorsey, 2007] took a different approach, to try to maintain a natural hand drawn feel in an augmented system. In this paper, they looked at using sketches made by architects to motivate the creation of 3D models. Rather than interpreting and trying to use the existing drawings, their tool allows architects to place their drawings in a 3D space, add appropriate 3D planes, create the appropriate strokes, and then fuse the images into a set of 3D segments. In this system, planar surfaces and strokes act as the available primitives.
3.7 Painting

The concept of painting on textures is not a new. In the early 1990’s Hanrahan and Haeberli [Hanrahan, 1990] applied a WYSIWYG painting technique for texturing 3D shapes. There have also been efforts to mimic painting. Though many of these papers fall into the area of non-photorealistic rendering, it seems at least one such paper should be mentioned. In particular, “OverCoat: An Implicit Canvas for 3D Painting” [Schmid, 2011] is interesting as the technique they introduce is expandable to a stereoscopic model and was adapted to help with the WYSIWYG [Kim, 2013b] paper. In the “OverCoat” paper, Schmid et al. explore a technique to apply 2D painting principles to a model in 3D space. In their approach, they allow the artist to paint a surface in 3D space above an underlying model that maps the paint strokes to the curvature of the given surface. To further help the process, they provide tools to sculpt the underlying model to better achieve the desired depth and look.

Another technique that has explored painting as an approach is in the “Light with paint” approach [Pellacini, 2007], where an artist can “paint in” the light of their scene, and the computer solves how to achieve the desired look. In this paper, they have even applied it to an animation system to show its functionality.

3.8 Animation and Film

Animation has been performed on computers since the late 1960s [Baecker, 1969]. Since then many different techniques have been explored on computers. TicTacToon [Fekete, 1995] looked at the animation pipeline to explore how computers could be used to aid in the overall animation process. Similarly, “A multimedia system for authoring motion pictures” [Baecker, 1997] looked to help amateurs create simple movies through an interactive system. More recently, there have been many advancements that have allowed the animation workflow to be explored in further detail. Many papers have looked at using different algorithms to help artists with everything from maintaining proper volume with their 2D drawings [Di Fiore, 2002] and assisting with drawing in-betweenes [Kort, 2002] to defining a proper depth order for different segments of a drawing [Sýkora, 2010]. Igarashi et al. explored a multi-modal interaction technique for animating with “As-Rigid-As-Possible Shape Manipulation” [Igarashi, 2005], where a user can use their fingers to deform a shape, which is then redrawn according to an algorithm that finds a
best-fit end result based on the minimization of an internal triangle lattice. Further, users can “pin” locations of the closed shape to create more controlled motion.

Full animation solutions have also been developed, including “Video Puppetry” [Barnes, 2008], which allows users to draw on paper and cut out their creations. By placing these pieces under a camera, the components are imported into the computer system and linked together. The user can then act-out their scene under the camera by manipulating the paper-cut outs and the resulting motion is translated to the pieces computerized counterparts. Alternately, “K-Sketch” [Davis, 2008] examines a more traditional animation style. Having assessed the most common animation techniques for 2D animation, they propose a widget that allows novice animators to quickly and easily add motion to their computer drawn creations. Another approach is explored in “Direct Space-Time Trajectory Control for Visual Media Editing” [Santosa, 2013] where the user can create and edit directly on top of videos, slide presentations, or 2D animations. Through providing easy controls to create and edit content across space and time, visually appealing animations can be quickly created. Finally, Kazi et al. have created a system that allows users to create interactive illustrations in “Kitty” [Kazi, 2014a]. This system allows users to take an illustration and add visual elements that animate as a user interacts with control points in the picture.

Even though there are many more works in the area of animation, it was felt that these papers cover some of the most basic concepts currently being researched, and those that have shaped the direction that research is currently taking for 2D and 2.5D animation.

Another interesting area that has overlap with animation is exploring techniques that allow for quick and simple movement. One approach for this is introduced with “Draco: Bringing Life to Illustrations with Kinetic Textures” by Kazi et al. [Kazi, 2014b]. In this paper, they explore providing the artist with tools that allow for quick augmentation by adding motion to a still image. The user is able to draw a few example strokes to define a small sample patch. This patch can then be used as the base for animation effects. The user is given tools to have this patch start from an emitter, move along a drawn path, oscillate along a given curve, change speed, and change size according to position. Further, the user is given the ability to create granular motion within the patch for further effect. This approach results in still images seeming alive, using natural motion or “Kinetic Textures”.

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Finally, “Motion Doodles: An Interface for Sketching Character Motion” [Thorne, 2004] is an interesting approach to give users a simple way to choreograph a bipedal character model’s motions through simple line drawings and gestures. In this paper, they discuss fitting a basic skeletal structure to a drawn model and then mapping this model’s motions to a series of drawn lines. They introduce line patterns that allow for the character to walk, tiptoe, stomp, shuffle, moonwalk, jump, perform flips and more. Through a fairly simple interface, they create a rich library of character motion that is easy to implement by amateurs.

3.9 Pen input

Many different input devices have been created based on models such as the one presented by Buxton et al. [Buxton, 1990]. Pen interaction is one such device that has been of interest to many researchers. When the WIMP interface was introduced, pen interaction was essentially lumped in with all the other input controllers such as the mouse and keyboard. In 1998 the paper “Sketching in 3D” [Zeleznik, 1998] starts to question the utility of treating all input devices in the same manner. Whether pen should be treated like a mouse and whether bimanual interaction may be superior in some situations. A decade after this article, Zeleznik et al. explores pen specific uses and highlights areas in which pen interaction may be superior to WIMP interfaces in the article “Applications and Issues in Pen-Centric Computing” [Grosky, 2008]. Articles such as these have helped fuel the exploration of other ways to interact with interfaces using the pen. CrossY [Apitz, 2005] explores a unique way of selecting items using a drawing interface, by having the user cross through the items with the pen to select them. In this paper, he demonstrates the way crossing motion can introduce a fluid and continuous interface using the pen. Pens also support many different interaction styles and modes. Ware et al. [Ware, 1989] demonstrate six different useful variables that can be read from a pen to help interpret an artist’s intent. Different techniques for mode switching using pen are compared and explored in “Experimental Analysis of Mode Switching Techniques in Pen-based user Interfaces” [Li, 2005], where the authors compare the speed and accuracy of five different techniques. In the work by Brandl et al. [Brandl, 2008] different bimanual interaction techniques are compared, looking at pen and pen, pen and touch, and touch and touch as interaction modes, finding that pen and touch is a superior input mode for bimanual interaction. Further, in the paper by Hinckley et al. “Pen + Touch = New Tools” [Hinckley, 2010], they examine explicitly combining pen and touch
interactions and find that these interactions provide a completely new set of interaction options. However, this still leaves the question regarding which actions should be used when interacting with pen and touch.

Frisch et al. explore what users feel different input techniques should be for this pen and touch interaction [Frisch, 2009] having participants perform gestures that they feel are natural for 14 different interaction tasks. Hinckley et al. continue exploring the pen and touch interaction space [Hinckley, 2014], introducing a whole new set of interaction options when the system is equipped to determine how the user is holding and interacting with the pen and tablet hardware used during pen interaction.

However, creating systems with pen interaction is a different problem then discerning different input techniques. Hong and Landay try to make pen interaction more accessible through their toolkit “SATIN” [Hong, 2000], where they introduce different techniques to leverage pen interaction. Finally, the two papers written by Hinckley et al. [Hinckley, 2005, Hinckley, 2007] explore two systems that implement pen interaction in different manners. The first explores different delimiters for accessing marking menus to allow for continuous fluid pen interaction; the second explores a whole notepad system, integrating different applications and gestures to fluidly complete different tasks all based around pen input.

3.10 Virtual Reality

Virtual reality belongs to a spectrum of mixed realities as presented by Milgram et al. [Milgram, 1994]; but there are many different styles of VR, be it fully immersive as is experienced with devices such as the Oculus Rift [Oculus Rift], 360° surrounding environments [Chen, 1995; Google Cardboard], or using head tracking and a computer monitor in what is known as fish tank VR [Ware, 1993]. Virtual reality can also be presented at different formats and sizes, be it a full room (or cave) [Cruz-Neira, 1992], a small mobile device [Fitzmaurice, 1993], or a viewing surface attached to an arm that can be moved around a specified area [Tsang, 2002]. Viewing scenes through these techniques is still considered virtual reality. Further, though VR is commonly used by a single user, multi-user VR environment have also been explored [Blanchard, 1990]. Regardless of how VR is presented or how it is used, VR has many unique challenges.
Due to these challenges, it is not a surprise that there is a large body of work on different aspects of VR. Some have tried to classify different interaction styles [Mine, 1995; Bowman, 1997; Ibayashi, 2015] or propose solutions for specific control challenges such as movement [Mackinlay, 1990; Ware, 1990; Stoakley, 1995] or simply manipulation of objects [Bolt, 1980; Pierce, 1997]. Despite these efforts, it has been noted that interactions in VR is still an ill-defined problem [Glueck, 2011].

Despite this issue of definition, people have still been researching interaction techniques for different applications, and drawing is no exception. Direct drawing in VR has been seriously explored for over two decades [Butterworth, 1992; Deering, 1995], and have even been enhanced to provide techniques to paint in VR [Keefe, 2001]. Numerous systems use a 2D plane as a mode of interaction for constructing in the 3D environment [Angus, 1995; Ens, 2014] whether it is a virtual 2D plane, or a physical drawing tablet represented in the 3D space [Bowman, 1998]. LaViola et al. [LaViola, 2011] provide a summary of different techniques for drawing in VR. Similar to drawing, writing in VR has also been explored [Poupyrev, 1998; James, 2015].

Finally, understanding people’s perception and performance with VR is an area of interest to many researchers. Papers may look at how people judge space in VR [Thompson, 2004], the effect of lag in VR systems [Ware, 1994], or how a user performs with a specific type of VR [Arthur, 1993]. Regardless of the specific interest, there are many works trying to understand the human condition with regards to virtual reality.

3.11 Conclusion

While exploring research in the areas of film and television, it quickly became apparent that there was very little work in Human Computer Interaction investigating storyboards for film, animatic and previs. Further, there was surprising little exploration involving stereoscopic renderings, specifically when it came to drawing. At this point, it can be seen that most storyboard research focuses on user-centered design, and while the art of previs itself is still being defined, the previs research is very preliminary. It also quickly became apparent that most previs research and innovations seem to be in-house and not available to the public.
Creating strokes in a 3D environment was another focus that was investigated, and most methods seem to approach the problem by creating a reference framework, or referring to an existing plane within the scene. With using stereopsis to try and augment modeling and drawing, very few methods can be seen, and none of them are easy to use, quick and render in real-time. Most stereoscopic systems require significant overhead to setup a scene before starting to draw or paint to achieve the desired effect.

As a general comment regarding the different user interfaces for the systems reviewed, it would appear that, rarely, is an easy to use UI a priority in the research, and rarely does it focus on the end user to help make the process simple and fast. The few automated methods are probably the easiest and fastest, often focusing on the line junctions and at times requiring user intervention. It would appear that the research space concerning stereoscopic and VR drawing, and creating storyboards for non-traditional film for these medium have only lightly been investigated, and that there are still many opportunities and interesting avenues to explore.
Part 2

STEREOSCOPY
Chapter 4

Storyboards for Stereoscopy

The use of storyboards is well established in the movie making industry, having roots in the days of Walt Disney [Whitehead, 2004, p47] and still being used for many current day films. Storyboards are not necessarily used with all movies, but ultimately depends on a directors’ style. Some directors do not use storyboards at all; some create storyboards, but use them simply as an ideation tool, therefore do not use the boards on set, or frequently change the plan while shooting a scene; and other directors create storyboards, and try to stay as true to this captured visualization as possible while filming. Regardless, storyboards have become a mainstay for many directors and help not only with ideation, but also with communication amongst the members of different departments on a film.

To understand how to create a tool for applying storyboards to a stereoscopic production, it is first important to understand how storyboards are used and the different considerations needed for stereo filming. This section outlines the concepts needed to understand storyboards, and how they apply to stereoscopic 3D movies. It continues by introducing stereoscopic 3D depth planes that conceptually build on the foreground, mid-ground and background planes used in cinematography, and stacked layers used in cel-animation. The approach presented here, addresses key HCI challenges tied to sketching in stereoscopy.

4.1 Domain Analysis

To better understand the authoring process of storyboards, and their role in the production pipeline, informal interviews were conducted with six professionals: two storyboard artists, two
directors, one film and television instructor and one director of technology. Their experience ranged from three to 30+ years in film and/or animation production (2D & 3D). The information gathered from these interviews, along with the information obtained from texts forms an outline of what might be considered a typical workflow for a director and artist in various contexts.

It should be noted that creating storyboards is an art form, and as such, there are many different ways of proceeding to accomplish the task. Despite this fact, the following is what is generally considered a standard approach, though most artists will probably have variations on some of the specifics of this process.

Storyboards are essential planning and coordinating tools at all stages of movie production [Hart, 2013; Simon, 2006]. When a director starts working with a script, he explores the story one scene at a time, and starts thinking about how to break the scene into a series of shots. Through this process, he forms his own vision of the scene which needs to be communicated to the rest of the team—a difficult process through words alone.

Alternately, a director could spend time during the shoot trying different approaches until the look of the shot is satisfactory. This would, unfortunately, underuses the storyboard - a tool to help the director find his vision, notice mistakes before the shoot, and communicate with all departments.

4.1.1 The Storyboard Workflow

The storyboard process starts when the director calls upon a storyboard artist’s drawing skills to concretize his vision with illustrations. The two collaborators can either work closely together or discuss the scenes remotely.

When collocated, the director and storyboard artist organically explore the director’s vision using pens, pencils and/or markers and a pad of paper, sticky notes and/or note cards. A scene is examined by creating a panel to capture each key moment, each moment being divided into foreground, middle and background layers. With each panel, an artist may try different visual designs, camera angles, and layouts. This process of externalization aims to help the director clarify and refine his vision, and results in a collection of rough thumbnails (one thumbnail for each panel) that each serves as a visual description of a key moment of the film. The artist then
takes these sketches to create a “clean-up” version on paper or digitally (Figure 3). For the “clean-up” versions artist often redraw the panels with better perspective, detail, and shading; often using different grays, colours, or line thickness to convey depth in 2D [Block, 2013; Mendiburu, 2009].

Alternatively, the director and the storyboard artist do not meet in person. The artist is given the script, and may have a discussion with the director on the phone. This distance yields less organic input with the sketching process. This results in one of two workflows: the artist works with traditional tools (pen and paper), then scans the sketches to create digital assets; or the artist works directly with digital tools. In either case, the digital files are used to communicate the latest idea on which the director can make notes and return the feedback to the artist. This process of refining the sketches is repeated until the director is satisfied.

The panels resulting from either one of these approaches are put together (mounting them on a corkboard, or digitally side-by-side) to create the storyboard. This provides a visual story of the entire film and acts as a critical communication tool between all production departments. This visual representation ensures that everyone is working towards the exact same goal that the director envisions. It is therefore critical that the information contained in each panel accurately conveys the information needed for that moment.

4.1.2 Design Considerations

Storyboards are both an important visual communication tool, and the primary medium of dialogue between the director and the artistic team. Depending on the artist and her working context, digital tools come into play at different stages of the storyboard creation process. They may be used at the beginning of the planning process to simplify ideation; they may be used while planning a scene enabling separate layers to help sort out complex blocking; or they may be used to allow different departments to create a personalized version to help figure out department specific needs, such as set components and props. The interviews revealed that the main reason for using digital tools later in the workflow was because most of the current professional tools do not yet afford the simplicity and convenience of pen and paper while capturing the director’s vision. From this analysis, a set of general design considerations for a
storyboarding tool were distilled, beyond it being a lightweight communication tool centered on sketching. A tool for creating storyboards ideally needs to:

1. **Be non-intrusive**: The interface needs to mimic pen and paper, a medium familiar to artists, and be clear of distractors. Artists indicated in the interviews that menu items and drop-down menus distract from the overall sketching process, and require extra time for selection.

2. **Be quick for authoring**: Sketches need to be quick and easy to edit. Ideally, tool switching should be minimized, and content is automatically saved.

3. **Provide instant feedback**: The tool needs to give real-time feedback avoiding techniques based on off-line and post-processing.

4. **Show an overview**: Being a tool to enable the creation of storyboards, the tool needs to support an overview of all the drawn panels, and provide the ability to navigate quickly through, and rearrange a storyboard sequence.

### 4.1.3 S3D Artistic Considerations

Even though as a viewer, traditional 2D movies and stereoscopic 3D film appear very similar, the movie industry recognizes that S3D movies are not just movies with perceived depth, but that there is a whole new set of rules, techniques, and understandings needed to create compelling stereo movies [Atkinson, 2011; Block, 2013; Mendiburu, 2009; Mendiburu, 2011; Pennington, 2012; Robertson, 2008]. It has been noted, “*When you are looking at a 2D picture, you look at a flat object defined by the edges of the screen. When you are looking at a [stereo] 3D picture, you look at objects... through a window*” [Mendiburu, 2009, p79]. Stereo is now standard enough that guides such as the VES Handbook for Visual Effects [Zwerman, 2014] include whole sections dealing with stereoscopic concepts. Apart from the above general design considerations, a tool that addresses stereoscopic design needs to include support for factors unique to this presentation style. Based on a literature review and interviews with experts, key concepts unique to S3D movies were distilled. They are discussed here:

**Object Placement** – the location of objects in stereo space. While the notion of placement exists for 2D storyboards, it has a more profound effect in S3D as audiences
are aware of exact placement of objects in the stereo 3D space, and the location as well as empty space between objects has far more effect on the audience.

**Plane Separation** – the amount of space between planes. Similar to *object placement*, plane separation affects how the audience feels: too much space between planes causes an uncomfortable feeling; planes that are too close feel crowded and busy.

**Convergence Location** – the elements in the scene that appear to be on the surface of the movie screen. To achieve a stereo effect, images are created with a left and right eye component that are horizontally offset from one another. The fusing of these two images in the brain creates the effect of objects protruding or receding into the screen; the further the offset, the greater the distance an object appears from the screen surface. The convergence plane is where there is no separation between the left and right image, and consequently is the easiest for the audience to process. See section 2.4 for a discussion on the mechanics of stereopsis.

**Parallax Position** – the position of objects in front of, on, or behind the screen. Along with what should appear on the screen itself (i.e., the convergence location), the director must decide which objects should be placed in negative parallax, or “audience space” (i.e., in front of the screen where the audience sits), and in positive parallax or “screen space” (i.e., behind the screen). Parallax placement in stereo space has a profound effect on how immersed the audience feels. If done badly, it can disconnect the audience from the film experience, reminding them they are in a theater (e.g. the traditional gimmick where an object flies out of the screen at the audience, is now recognized as one to be avoided). If done well, the use of parallax can further draw the audience into the film, creating a deeper sense of immersion.

**Depth Budget** – the distance between the front-most and back-most plane of a scene. Depth budget is used to control the sense of immersion and emotional involvement of the audience. The progression of the depth budget has the biggest impact in stereo film and is discussed with a depth script.

**Depth Script** – a chart depicting the change of depth and parallax position from one panel to the next—often compared to a musical score showing the “orchestration” or use
of the depth budget throughout a scene [Pennington, 2012; Robertson, 2008]. It is common
for a depth script to contain the progression of the convergence location, front most
plane, and back most plane (and thus the depth budget). A depth script is used to ensure
consistency and smooth transitions throughout a film, to help minimize discomfort, and
to properly plan so the audiences’ eyes have time to adjust to depth variations. A depth
script is an excellent tool for catching mistakes such as sudden jumps in depth, depth that
bounces around and flat, crowded panels.

**Floating Window** – the impression of the movie screen being in front of or behind the
physical screen (Figure 19). In stereo films, the border of the screen acts as a window
through which the audience looks. Consequently, it acts much like a separate object in the
film and can, itself, be manipulated to make the screen appear closer, further away, tilted
forward, backwards, bent or even twisted. This can be used both as a special effect to
help set the mood of a scene or to correct mistakes such as edge violations (see below).

A 2D equivalent of a floating window is to change the perceived aspect ratio of the
screen, creating a false border. By projecting onto this surrounding border, an object
appears to move “outside” the physical screen. This effect, which is appealing in 2D, can
be astounding in S3D, especially if the object moving outside the frame gets closer to the
audience.

The concept of using a floating
window for artistic purposes is a new
tool in the director’s toolkit, and
therefore not often considered by
directors at the early stages of film
design. Yet, there is a growing body
of knowledge suggesting that aspects
of this technique may be useful to set
the mood and feeling of some scenes
(see section 2.4.2 for more detail on
floating windows).

![Figure 19. Floating windows example - in front of the movie screen and behind, both stereoscopic and simulated](image)
**Edge Violation** – a visual artifact close to the edge of the screen resulting in ocular disparity and visual discomfort. This error usually occurs in one of two ways. First, discomfort and uncertainty arise when an object that stereoscopically should appear in front of the screen is occluded by the border or edge of the screen. Since the edge of the screen is technically behind the object, the brain is uncertain where to place the object; stereopsis tells the brain that the object is in front, and occlusion indicates that it is behind. The second way this violation occurs is when an object is visible with one eye, but not the other. As a result, the brain is not sure whether the object exists or not, causing visual discomfort and disorientation. Edge violations are usually corrected using floating windows (see section 2.4.3 for more detail on edge violations).

### 4.2 Current Stereoscopic Planning Approaches

With current practices for filmmaking, there is no standard way to plan for a stereoscopic film. The decision to make a film stereoscopic can happen anywhere in the production pipeline from early inception through post-production. It, however, is strongly believed in the community that the sooner the decision is made to design a stereoscopic film, the more likely the film will have success with the stereo aspects of the project. This is generally due to the fact that there are techniques and approaches used with traditional 2D film that do not work in stereo (e.g. a rapid succession of transitions – as is often seen in chase sequences). Since it is critical to ensure that one does not employ a technique that will cause an unpleasant experience, it is important to catch stereoscopic errors early in the process – fixing them in post-production can be both timely and costly; unfortunately many errors do not get fixed in post due to the intricate nature of fixing a stereoscopic problem.

With currently available tools, previsualization is essentially the earliest that one can see a scene stereoscopically. This is due to the fact that the scenes created in previs are 3D computer models, and it is a simple exercise to introduce a secondary camera, slightly horizontally offset from the first camera, to allow for rendering an image stereoscopically. Though affective, often many key decisions have already been made by the previs stage, and previs is usually only used for a handful of scenes – ones that are complex or expensive, or ones that require extensive technically planning (e.g. complicated stunt scenes, or scenes that require a significant amount of
hardware such as camera rails and blue/green screen). Therefore, previs is better as a “next stage” tool rather than one to depend on at the ideation stage.

Unfortunately, there are no earlier stage tools for planning stereo in films. If a director wishes to plan stereo at the earliest stage while creating storyboards, they are required to use a technique such as line thickness, line shading, or colour to indicate different depths (i.e. Figure 1 & Figure 2). These techniques only provide a vague notion of the depth as the images are still 2D and someone regarding a storyboard created in this manner is still left to infer where he or she believes the depth is actually placed. This does not allow artists and directors to properly talk about stereo concepts such as object placement, plane separation, parallax position, and depth budgets; and so, many of the existing problems remain undiscovered at this stage.

As another approach, one could consider tools for 3D sketching [Bae, 2008; Dorsey, 2007], but these are typically targeted at 3D modeling, an approach that is inappropriate for the purposes of storyboards. Further, many 3D drawing programs require the user to draw in the air [Lakatos, 2014; SANDDE] – which requires cumbersome instrumentation. Ideally, a functional system should be simple, easy to setup and easy to carry around.

4.3 Bringing Stereoscopy to Storyboards

To assess the needs for planning a stereoscopic movie, a field analysis was performed. The results of the analysis along with the derived design considerations were combined to create a proposal for bringing stereoscopy to the storyboard authoring workflow, allowing artists to easily augment their sketches with depth cues, and visualize the resulting stereoscopic panels in real-time, as they sketch. To achieve this goal, the concept of *layers* was leveraged and extended, a mechanism already familiar to artists when abstracting cinematographic scenes down into the foreground, middle, and background layers for compositing. Enabling the artist to seamlessly try different effects and assess their impact on the stereoscopic view in real-time not only helps one to foresee difficulties inherent to S3D, it also brings a full new dimension to the storyboard as a communication tool, now supporting spatial thinking related to film staging.

The fundamental question “*how to bring stereoscopy to the storyboard authoring process?*” is twofold. First, how does one enrich the sketching process with a depth dimension without
increasing the artist’s cognitive cost, so as not to distract her from her primary creative task? Second, how should users interact to control such stereoscopic visualization while creating content? Two interlocking key challenges were identified pertaining to adding stereoscopy to a creative digital sketching activity:

**Fluid depth-cued content editing.** Sketching in space using 2D input is a difficult problem that researchers are still trying to address (see section 3.5). While working with layers has the advantage of limiting the problem of 3D sketching to a 2.5D sketching task, i.e., by adding essential depth cues to strokes instead of creating fully formed volumes; it also adds to the complexity of the problem in that this depth information must be fully integrated to the creative process so as to maintain fluid and flexible editing during collaborative discussions. UI design necessitates answers to questions such as how does one maintain live-editing performance while navigating, drawing and changing focus in stereoscopic space (see e.g. [Lo, 2010])?

**Depth-enabled visualization.** Another key aspect concerns visual feedback during the creative and collaborative workflow. More specifically, adding depth to a 2D sketch raises the question of perception [Kim, 2013a; Lee, 2013]. While displaying three-dimensional content on a flat display is bound to reduce the impression of depth, enabling stereoscopic vision during the sketching process introduces unique new challenges from a user-interface design perspective. Practical questions include, for example, depth-viewing control: what is the default depth, and to what extent should it be interlocked with the current drawing plane? Should stereoscopy always be active? How does one cope with visual clutter of close content when focusing at a far distance?

### 4.3.1 Creating Stereoscopic Sketches with Current Tools

With the above concepts and questions in mind, one can examine the ability to create stereoscopic sketches with existing tools. Online search results lead one to many tutorials for creating anaglyph images with mainstream professional software such as Adobe Photoshop [How: Anaglyph a; How: Anaglyph b; Making Anaglyph] and Adobe Illustrator [How: Anaglyph c; How: Anaglyph d]. These processes were evaluated by following the tutorials to create a few
stereoscopic images using Photoshop – an industry standard for digital image manipulation. Note that tools other than Photoshop rely on similar procedures.

The authoring of a simple stereoscopic artifact using Photoshop can be achieved through a tedious repetitive process. First, the artist needs to create a new layer, and draw the content she would like on that layer. To create the anaglyph effect, she duplicates the layer, selects the properties of the first layer to turn off the red channel. The same operations needs to done on the second layer, this time, turning off the green and blue channels. Depth control is achieved by nudging one of the two layers a certain number of pixels in one horizontal direction, and nudging the other layer the same distance in the opposite direction. The latest operations (select; nudge; select; nudge) must be repeated until the layers display the image at the desired depth. The artist repeats the entire process for every additional depth layer.

More than just being tedious, this process violates the design considerations constraining both expressivity and creativity along the storyboard authoring workflow.

4.3.2 Introducing Stereoscopic 3D Planes

As a suggested approach to address the outlined challenges, one could employ an approach based on pen interactions on a tablet display that maintains the drawing experience as close to sketching on paper as possible, but augmented with stereoscopy.

Since storyboard artists are accustomed to a layered compositing approach using foreground, middle, and background planes, the suggested approach treats each panel as a 2.5D stereoscopic drawing volume, parallel to the viewport of the tablet display. This stereo volume can be divided into a stack of transparent stereoscopic 3D planes (Figure 20) which can be seen as a natural

![Figure 20. Illustration of the suggested approach: stereoscopic 3D planes are stacked to form the right hand image](image-url)
extension of the (z-ordered) layer notion used for 2D image compositing. Each of these planes acts as a drawing canvas at a specific depth in the stereo volume.

In contrast to existing sketch-based modeling tools [Olsen, 2009] (discussed further in the section 3.5 and “Related Work” below), this approach strictly constrains the virtual planes to match the physical viewport of the device. This alleviates the need for explicit manipulation techniques for the orientation of objects and 3D planes while drawing. It also does not force the artist to have a pre-conceived notion of the layout of the 3D scene before starting one’s sketch as is necessary when drawing in perspective on ground grids.

Given that a panel is meant to be viewed in stereo, the drawing plane must always correspond to the zero-parallax image plane. To add content in front or behind a plane, one can stack and re-assign plane depths in the stereoscopic space. The content of one plane will be perceived at a different depth than that of another plane thanks to the stereoscopic visualization.

4.4 Related Work

Many computer-assisted sketching programs have been developed to facilitate storyboard authoring, such as Power-Production’s Storyboard Quick [Storyboard Quick] and Toon Boom’s Storyboard Pro [Toon Boom Storyboard Pro] (see section 3.1 for more detail). However, these require the creation of 3D content on an external 3D modeling tool, and the 3D rendering process of the end result is a time-consuming process making these tools poor candidates for live editing and real-time collaboration.

As an alternative, there are techniques such as previsualization (see section 3.2 for more information). Unfortunately, due to the length of time and number of people involved in creating a previs scene, renders it a poor choice for exploring ideas, getting one’s ideas down on “paper”, and discussing early stage concepts. Previs is best as a next-stage technique to refine ideas already captured on paper for complicated, challenging or expensive shots.

Beyond its usage by cinematographers and animators, storyboards are also common instruments for quick user interface prototyping [Greenberg, 2011] or even characters’ interactive behavior [Rea, 2014]. However, such ease of usage does not easily translate to 3D and new idioms are
required to express depth information. Existing research has addressed such issue by providing alternative methods to create stereoscopic content and pushing the limits of digital sketching.

4.4.1 Stereoscopic Authoring

Using physical devices, Broy et al. [Broy, 2014] explored stereoscopic design for S3D UI prototyping, where the user could try different depth arrangements of UI elements, rearranging physical layered planes. This works nicely for design; but, it is too slow and not fluid enough for the needs of planning a film.

Other techniques for creating stereo images include Kim et al.’s WYSIWYG system [Kim, 2013b], which explores painting in stereo space, layering “paint” on existing underlying structures. Though effective, systems that use “underpinning” [Cohen, 2000] are inappropriate for storyboards, as one needs an understanding of the scene a-priori, to create underlying structures. Storyboards are exploratory, and artists often do not know what they will draw ahead of time, requiring storyboard techniques to be spontaneous, fluid and unstructured. Post-hoc techniques that interpret existing drawings to determine layers and depth to stereoscopize cel animations [Liu, 2013], while inspiring, are not suitable for real-time sketching in stereo.

In fact, it has been noted [Lo, 2010] that tools and techniques used in stereoscopic environments need to be reconsidered; to be more than just an existing technique transported from a 2D environment onto the 3D canvas; that in fact there are nuances and issues (such as scale and occlusion) that result in the stereo canvas being different from its 2D counterpart.

4.4.2 Sketching in 3D

Digital sketching of 3D objects dates back half a century, to Sutherland’s seminal sketchpad system [Sutherland, 1963] (see [Olsen, 2009] for survey). A large body of research deals with interpreting a collection of 2D strokes as a 3D object represented using a network of 3D curves. Tools such as ILoveSketch [Bae, 2008], True2Form [Xu, 2014], and analytic 3D drawing [Schmidt, 2009b], infer 3D from 2D using a mix of regularity constraints that define geometric relationships between the curves in 3D. Curves are often inferred as cleanly drawn 2D strokes projected onto appropriate 3D planes in these approaches. Another thread of research, exemplified by the organic shape modeler Teddy [Igarashi, 1999] and its successors [e.g.
Gingold, 2009], builds the surface of a 3D object through the sketching process by inflating or extruding sketch strokes. As an ideation-stage sketching tool, 3D objects are both overkill and distract from the primary goal of story layout. This work makes no assumptions on the nature or meaning of the user’s 2D strokes (the presented approach is a free-form sketching interface in the spirit of [Dorsey, 2007]), but are restricted to planar curves parallel to the view plane following the foreground, mid-ground, and background cinematic concept.

Sketching research has also focused on drawing and control of curves explicitly projected onto a virtual 3D plane [Tolba, 1999] (e.g. 3D6B Editor [Kallio, 2005]). Researchers have explored physical ways of defining the projection plane’s position and orientation: Napkin Sketch [Xin, 2008] tracks a physical support, the “napkin”; similarly, Hyve3D [Dorta, 2014] is an immersive virtual environment where the drawing plane is mapped to the 3D position and orientation of the tablet held by the artist; 3D Tractus [Lapides, 2006] mounts the drawing display on a physical rack to constrain the plane’s motion to a depth value. These techniques are complementary to the work presented here, where controlling depth of a stereoscopic sketch plane, is but one operation of the proposed approach.

Creating strokes directly in space has also been explored via 3D input (e.g. [Grossman, 2003; Keefe, 2007]). The SANDDE system [SANDDE] uses this in-air drawing technique to create compelling stereoscopic drawings, which have been used for animations [Page, 2003]. These techniques, however, in addition to lacking precise control, move the artist away from the familiar sketching on paper paradigm that was a goal of the proposed system. The goals are in fact similar to 2.5D modeling [Liu, 2013; Rivers, 2010], as the focus was on the essential depth cues to create a stereoscopic effect (such as with stereo painting [Kim, 2013b]), rather than fully formed 3D volumes. Most 2.5D techniques decouple the act of sketching from the depth labeling process. The proposed technique seamlessly integrates depth manipulations into the drawing workflow.

4.5 Conclusion

This chapter explores a traditional storyboard workflow, and examines and quantifies key design considerations for supporting storyboard artists while they work on creating storyboard assets – a tool needs to be non-intrusive, quick for authoring, provide instant feedback and give an
overview of the scene. Key concepts that can and should be discussing at the storyboard stage for stereoscopic films is also enumerated in this chapter – these include object placement, plane separation, convergence location, parallax position, depth budget, depth scripts, floating windows and edge violations. This chapter concludes by introducing the concept and approach of treating the drawing volume as a stack of transparent sheets, or stereoscopic 3D depth planes. The following chapter proceeds by exploring an implementation of these concepts, constraints and approach.
Chapter 5

Enabling Stereoscopic Storyboards (Storeoboard)

The previous chapter explores basic design considerations when designing a program for storyboard artists. It also introduces key stereoscopic concepts, such as object placement, plane separation, parallax position and depth budgets, which can and should be discussed during the ideation process with storyboards for stereoscopic productions. Unfortunately, current tools do not allow artists and directors to easily discuss these concepts.

Therefore, the previous chapter outlines an approach for treating the drawing volume as a stack of transparent sheets to enable artists to work with the drawing space as a 2.5D volume, which enables the creative team to discuss these stereoscopic principles.

The following chapter outlines a tool that was created to fill the gap in the filmmakers’ toolkit, by contributing the first stereoscopic storyboard system that allows the director and artists to explore both the stereoscopic space and concepts in real-time. Storeoboard’s design is the result of a distillation of S3D cinematographic principles and issues corralled from loose descriptions in cinematic text, interviews with professional filmmakers, and other anecdotal sources, as outlined in the previous chapter. Support for these principles unique to S3D are built into the stereoscopic storyboards by design, and demonstrate a fluid and flexible enough interface to support creative flow, while providing rich interactions for depth specification.
A thorough evaluation including focus groups, user studies and successful deployment on the 3D Lumière award winning feature film, “40 Below and Falling”, suggests that Storeoboard responds to a real need in the S3D filmmaking industry.

5.1 Initial Approach

A simple stereoscopic sketching prototype was initially developed that was presented to different participants – visitors and colleagues, to collect initial feedback. Users were provided with red-cyan anaglyph glasses to achieve a stereoscopic view – low-cost hardware that is easily obtained. 

Influenced by the physical strategy employed in 3D Tractus [Lapides, 2006] and Napkin Sketch [Xin, 2008], the spatial location of a tablet was tracked — using a VICON system — for the purpose of navigating inside a drawing volume divided into 20 discrete planes. From the user perspective, it resulted in moving the tablet device towards or away from oneself to access a drawing plane closer or farther away in space. Sketching on one of these depth planes was performed by drawing on the tablet placed at the corresponding physical location. Given the goal was to focus on the

Figure 21. Rotoscoped image of a cottage, used as an example

Figure 22. Nature scene rotoscoped and used as an example
conceptual approach, a minimalist user interface was used: a single panel (defined by a border line within a white canvas) and the strokes drawn on each plane were all represented by non-aliased single pixel lines. The stereoscopic effect was created by drawing each line representation for the right and left eye, with red and cyan respectively, at the offset appropriate for the depth of the line. While wearing the anaglyph glasses, the image resolved to a stereoscopic one. The depth of the zero-parallax was accommodated to 70 cm corresponding to the average distance of a person holding a tablet in his hand while sketching. To help participants familiarize themselves with the stereoscopic effect before they started creating their own content, they were shown images created by rotoscoping existing images to generate stereoscopic pictures (see Figure 21 & Figure 22).

A second interaction variation was also attempted for depth selection. Similar to the above approach, with a scene subdivided into 20 discrete planes, instead of moving the tablet, tick marks were introduced along the edge of the storyboard frame that corresponded to the locations of the available planes (see Figure 23). Users could tap on a tick mark to select the desired plane. The tick mark associated with the current plane had a different appearance to the others to assist the artist with identifying their currently selected depth plane.

Around 40 people from a variety of backgrounds voluntarily tried the system during lab visits (a fourth of the participants were artists). Each person used the system, on average, for a couple of minutes each. Feedback was collected through observation and informal discussions. The users adapted quickly to the stacked planes approach and found the stereoscopy extremely compelling for sketching. The feedback regarding stereoscopic visualization was highly positive,
demonstrating value in using this display technique for interpreting line drawings. The navigation restriction to 20 discrete planes was, however, limiting. The initial thought was that pre-defined discrete planes would facilitate an artist’s needs; however, artists expected continuous navigation of the depth planes, which in turn would enable more control over the depth instead. Participants also experienced issues when trying to get back to a given plane, as it was difficult for them to recall the depth at which a given stroke resided. Finally, participants found moving the device to navigate among planes to be entertaining, but cumbersome and tiring when used for long periods of time. This preliminary feedback provided valuable insights to proceed in the design, approach and validation of the process presented below to bring stereoscopy to sketch storyboards.

5.2 Storeoboard System

In light of the insights gained during the initial exploration, Storeoboard was created – a stereoscopic sketch-based storyboard authoring tool grounded in a thorough analysis of moviemakers’ creative workflow, as well as concepts exclusive to stereoscopic movies.

5.2.1 Design

The visual interface was designed on a few key principles, while trying to accommodate as many of the necessities identified in the previous chapter. The main principles are fairly straightforward. First, the look and feel should be similar to that with which artists are already comfortable and familiar. Second, menus and hotkeys should be avoided when possible; all items should be based on a graphical interface driven by direct manipulation. Third, since this is an artistic tool, no assumption should be made on the exact nature of the order a user will perform tasks, or how a user will interact with the system. In other words, avoid imposing arbitrary restrictions – providing feedback that artistic decisions are correct or incorrect also falls into this category and have been purposely avoided. Fourth, give results in real-time.

For the interaction design, since using a tablet, the goal was to keep as many interactions available as possible. To help facilitate this goal, touch and pen were viewed as different input modalities. This proved to be more challenging than originally thought. Pen and touch technically should provide opportunity for three different bi-modal input strategies: only pen,
only touch and combined pen/touch. However, due to palm rejection functionality on the tablets used, pen superseded touch, and any touch action that was in-process was terminated when the pen was detected. For example, if the user triggered a touch-down event by placing their finger on the screen, as soon as the pen was in a “hover” state above the screen, the system would trigger a touch-up event disabling any further touch events until the pen was removed; even if the finger was still on the screen. Due to this difficulty, bi-modal input strategies were kept to a minimum and, when used, were triggered by assuming the finger remained down while the pen interaction was performed. Essentially, despite the touch-up event, if the system triggered a pen-hover or pen-down event at the same time a touch-up event occurred, the touch-up event was ignored. This approach would not do well for commercial software, but was acceptable for a research prototype. Further, to let the artists focus on their main sketching task, a minimalist version of the pen and touch approach employed by Hinckley et al. [Hinckley, 2010; Hinckley, 2014] was generally followed: pen input was for sketching and content editing, whereas touch was dedicated to controlling UI elements.

5.2.2 Usage Overview

Storeoboard was designed to allow an artist to create stereoscopic storyboards quickly and easily by specifying the depth information of each stroke while sketching. When the artist launches the application, she can start by creating a new storyboard scene and its first panel, loading the previous project, or loading an even older project. Once a project has been started or retrieved, the user has access to one of Storeoboard’s three main views: the summary, or storyboard view (see Figure 25), the sketching pane (see Figure 26 & Figure 27), or the depth script view (see Figure 28).

(Image courtesy of Naseer Pasha)

Figure 24. Sample of a traditional storyboard sequence
5.2.2.1 Summary View

The summary view (see Figure 25) features a traditional storyboard layout, i.e., a sequence of panels organized in a grid (Figure 24). This view can be invoked at any time using a pinching-out gesture on the depth script window or the main canvas area of the sketching pane. Each individual panel is represented as a thumbnail, along with its corresponding depth budget bar (showing the amount of depth being used in the frame and the scenes parallax position) on the left and annotations below it. Tapping on any panel thumbnail automatically leaves the summary view and enters the sketching pane for that panel. Similarly, tapping on any depth budget bar opens the depth script view (expanded upon later). The summary view also allows one to manipulate the panels within the scene: all basic operations such as inserting a new panel (draw a vertical line between panels), copying (tap with the pen then drag a line between the selected panel and the one to be copied to), merging (copying one panel onto another existing panel), reordering (by first selecting via a pen tap, then dragging it to its new location) and deleting panels (drawing a diagonal line through the panel) are supported through direct manipulation. It is also worth noting that the summary view and all thumbnails used by the application are stereoscopic.

5.2.2.2 Sketching Pane

The sketching pane is the core component of Storeoboard, where all creative drawing takes place (Figure 26 & Figure 27). It consists of two interactive areas: the main canvas, where the artist can sketch new strokes and visualize the stereoscopic panel, and the depth slider, used to control the current stereoscopic focal depth in the panel — the active plane — and can be used to easily rearrange the 3D planes composing the panel.

As soon as the artist sketches a stroke, a new stereoscopic depth 3D plane is automatically generated and a corresponding thumbnail is added to the depth slider (Figure 26 G). The artist can keep adding strokes to the current plane, or she can move the slider with her finger to a foreground or background location. By starting to draw at a different depth, she again creates a new depth plane. As the slider is manipulated, the stereoscopic image is adjusted continuously to place the current plane on the surface of the display by changing the stereoscopic parallax.
Figure 25. Storyboard (Summary) view showing the storyboard thumbnails, their depth budget and annotations for a given scene.
Figure 26. Storeoboard User Interface (version 1 – basic interface): sketching pane with depth slider on the left and main canvas on the right
**Sketch Surface Cont’**

![Sketch Surface](image)

**DESCRIPTION**

- A) Ghost / Onion-Skin Left/Right
- B) Next / Previous Panel
- C) Undo
- D) Erase
- E) Scene’s Frame Number
- F) Depth Selector
- G) Frame Corner Depth Markers

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Figure 27. Storeoboard User Interface (version 2 – supporting floating windows): showing basic controls and frame depth controls
Figure 28. Depth script view showing the depth progression using green bars for each panel of the scene.
This is done so that the line being created by the pen always appears under the pen rather than floating above or below the pen tip position. This also ensures that drawing in the stereoscopic space feels natural. Existing planes can be easily rearranged in the slider bar through direct drag-and-drop manipulation of the corresponding thumbnails. Finally, once the artist is done editing a panel, she can move to the next panel by tapping on the right side of the interface. Tapping on the left side of the interface will display the previous panel.

An interesting fact observed while building and testing the tool was the lack of issues due to occlusion. Since one is creating images that are in front of and behind the screen, one might think that occlusion would be a problem - occlusion from the hand, the pen, or other strokes. For the most part, this was not an issue. Since, while drawing, the hand is to the side of the pen, the artist’s focus is rather on the pen tip, so the hand does not interfere with the drawing process. The pen technically could interfere with the depth perception, but with creating individual lines and the fact that the pen tip is rather small, this did not seem to be an issue. Finally, with content on the drawing canvas, the occlusion that exists from these objects is expected, as it is part of the drawing. Since one generally cannot see through solid objects, this seems natural. The one time that was observed where occlusion from the pen started to interfere, was when the artist filled in their drawings and created “solid” objects. In this case, at times the pen and the image seemed to interfere, but with the speeds that artists work, this was never for long, and never a serious concern. One could potentially change the opacity of the objects in front of, and on the screen, but this seemed unnecessary.

5.2.2.3 Depth Script View

The depth script view (Figure 28) displays the progression of the depth budget from one panel to the next and allows the artist to manipulate basic values. This is discussed in more detail in the “Depth Budget & Depth Script” section below.

Storeoboard has been carefully designed so as to support quick authoring and effective communication of stereoscopic artifacts. The following sections, gets back to the artistic considerations specific to S3D outlined earlier, and discusses how Storeoboard handles these new factors.
5.2.3 Object Placement & Plane Separation

Some of the basic stereoscopic considerations this tool needs to support are object placement and plane separation, which are addressed in the following manner.

5.2.3.1 Stereoscopic 3D Plane Control

To create an S3D drawing from a set of stereoscopic 3D planes, a mechanism to specify and control the depth of any input stroke sketched on the main canvas is here proposed. The depth slider bar (Figure 26 A) displays a laid out miniature version of all planes, with the height of the tablet representing the full depth of the scene, and the miniature thumbnails laid out in the appropriate position relative to the planes depth location in the scene. This mechanism fosters quick access, simple manipulations, and easy understanding of the scene. Though the height of the tablet constrains the manipulation of the available depth, one could potentially introduce the ability to scale the visible depth within the slider bar widget to foster more fine-tuned spacing. The depth slider is virtually segmented into three logical areas corresponding to the traditional foreground, middle, and background viewing composite for reference; but continuous navigation within and across these three areas is supported to allow artist to position planes as needed. Dragging the slider provides a continuous navigation of the overall space and existing planes, whereas tapping on a depth plane thumbnail results in a direct jump to that depth.

As the slider moves, the stereoscopic view in the sketching pane is smoothly updated to guarantee that the convergence of the active plane matches the screen depth, i.e., the active plane is shown with zero-parallax, which best suits sketching. This ensures that the line being drawn by the pen always appears under the pen tip, rather than far behind the screen, or floating above the active location. A disconnect between the pen tip and the line being drawn can be disorienting, and therefore, the scene must be adjusted to ensure that all pen lines are created on
the surface, as the user would logically expect. All other planes, located in front or behind, are perceived at the appropriate relative depth thanks to the stereo rendering. This entire rendering happens in real-time. Figure 29 illustrates this mechanism.

5.2.3.2 Editing Stereoscopic content

To change the depth of an existing 3D plane and tweak the separation between the planes, one is able to drag a plane’s corresponding thumbnail in the depth slider by selecting it using a finger-tap gesture. This operation engages a “move mode” which allows one to move all of the sketched content of the selected plane(s) either forward or backward to make depth adjustments (Figure 30).

Through direct manipulation and instantaneous visual feedback, the artist can easily experiment with different arrangements within a panel. Note, relative size of objects is maintained, i.e., moving an object further back will cause this object to shrink on the screen. Holding a finger on the canvas while dragging a plane alters this behavior by maintaining the absolute size of elements. To reinforce depth cues, the shade and width of the stroke is also adjusted according to its depth in real-time, mimicking the technique used by storyboard artists.

A double tap on a thumbnail initiates a multiple plane selection mode. Subsequently tapped thumbnails add to this selection. Beyond moving planes as a group, having multiple selected planes enables one to control plane separation by bringing them closer together in depth or push them further apart using a pinch gesture. Holding a finger on the canvas while pinching, again, maintains the absolute size of the elements.

The traditional concept of layers is also supported. These layers are displayed as a horizontal thumbnail sequence when holding a finger on top of a plane thumbnail (see Figure 31). One can use layers to separate items for animation, or simply for managing content on a depth plane. With layers, one can
perform all the basic operations such as add, move, copy and delete. Add is achieved by selecting the “+” icon at the end of the expanded layer list; move is done by tapping and dragging with one’s finger to a new location in the stack; copy is done by first selecting with the pen, then using the pen to drag the contents to a new thumbnail; and delete is performed by first selecting the eraser, expanding the layer list, then drawing a line through the thumbnail to be removed.

It should be noted, that it is possible to toggle the stereoscopic display, however, this was a hidden feature that was not mean for the artist to use. Tapping on the scene title would perform this toggle, which was added simply for the sake of discussion. However, it was found that there were a couple of situations in which this feature was useful and likely would aid an artist with her drawing. When trying to align items at different depths, it was much easier to do with the stereo turned off. In addition, one artist who tried the system had a binocular disorder where he was unable to see stereoscopically. Turning off the stereo display in this case helped him while he was drawing. Despite this fact, he was still able to create stereoscopic images due to the nature of the system and the way it presents the information about stereo placement of depth planes. Image 8 of Appendix C shows an image he created.

5.2.4 Convergence Location & Parallax Position

Storeoboard gives the artist the ability to control which plane appears as the convergence plane, which planes are in positive parallax and which are in negative parallax through the quick manipulations of planes as described above, and specification of the convergence location of the panel, materialized as a small arrow in the depth-slider area (Figure 26 H).

Recall that while drawing, the tool continuously changes the authoring convergence plane of the panel based on the location of the depth-slider. This introduced an issue as the planes are all actually in static locations positioned around the convergence – despite being constantly drawn at different locations based on the position of the slider. Originally, the system was setup so that the artist needed to leave the slider at the location where she wished the convergence to appear. This, however, did not work well as artists needed to remember to perform this last step, which was often forgotten. Artists would then need to go back through each panel and set the slider at the location that was to be the convergence plane. To deal with this issue, the concept of a
default convergence depth was introduced, indicated by the little arrow in the depth-slider. When a new panel is created, the default convergence is set at the middle point of the drawing volume. If the artist wishes to change this location, she simply needs to draw a stroke with the pen from the depth slider, onto the main canvas. Any plane that appears below this arrow will be drawn in audience space, everything drawn above, will be drawn in screen space.

Through these simple manipulations, the artist can quickly adjust depth characteristics of the panel without being slowed down or having her artistic workflow impeded.

5.2.5 Erasing

Erasing is toggled via a “hotspot” in the corner of the interface (Figure 27 D). Erasing works via a vector mechanism rather than a raster based eraser (which was deemed sufficient for a prototype). This means that to erase a line, the artist simply needs to activate the eraser and cross the line she wishes to delete. This will erase the full-indicated vector stroke. The eraser can be enabled in one of two modes: quick erase – enabled by double-tapping with the finger, which allows the artist to make one erase stroke and the system automatically reverts to draw mode; and regular erase – enabled with a single finger-tap, which leaves the program in erase mode until the “hotspot” is tapped a second time. With the erase mode activated, the artist can also draw a line through a thumbnail in the slider bar to quickly erase a full depth plane.

When erasing there remained a situation that was ambiguous. What was to happen if there were multiple lines under the erase stroke at different depths, but no lines on the active plane? Should the system erase the lines not on the active plane? What if the artist only wishes to erase strokes from the current depth plane, how can one restrict the eraser? This situation was very similar to manipulating plane depth while maintain the absolute size of the objects. Again, the logic was used to allow the tool to be non-restricted by default, and therefore erase any line regardless of its depth that appears under the eraser line. To restrict the eraser to the current plane, the user simply needs to first place a finger on the sketch surface to “restrict” the action, then erase as normal. In this case, only lines on the current play will be removed while erasing.
5.2.6 Floating Windows

The artist can manipulate the frame of a window from the sketch pane of Storeoboard. Side and corner handles, revealed when tapping on the border of the frame, allow resizing. The depth of each frame’s handle can also be adjusted individually in the depth slider (Figure 27 G), allowing the artist to change the very shape of the window, create windows that float in front or behind the convergence plane, or even have screens that tilt, taper or twist. The flexibility of floating window manipulations in Storeoboard allows for quick experimentation of effects as well as planning of viable solutions when an edge violation is detected. Through this mechanism, an artist can also change the screen ratio by pulling the top of the screen up or down, or the sides in or out (see Figure 32).

5.2.7 Depth Budget & Depth Script

Storeoboard enables the monitoring of how much depth there is between the furthest and closest point in a panel, how this depth is distributed around the convergence plane, and how this depth progresses, in two ways: through the depth budget of a panel, and through the depth script view.

Depth Budget – The depth budget of a panel is visible in the sketching pane due to the placement of the thumbnails on the depth-slider. In the summary (or storyboard) view, each panel includes a depth bar that depicts the distribution of the planes (Figure 25 C & Figure 33), showing the size and distribution of the depth budget, where it is in relation to the convergence plane, and where each plane is located in the overall space. Tapping on any depth budget bar opens the depth script view.
**Depth Script View** – The director can see at a glance how the depth of a scene progresses from one panel to the next in the depth script view (Figure 28) where a series of green bars demonstrates the distribution and location of the depth budget for each panel, and how it is centered around the convergence plane. This view is divided across the middle by a black line representing the convergence location of all scenes. Anything above this line is farther away from the viewer; anything below this line is closer to the audience. Along the bottom is a set of numbers corresponding to the panel number, and along the top are the thumbnails for each panel. A vertical line runs from each thumbnail at the top to the corresponding scene number at the bottom of the screen. Along each of these vertical lines is a green bar that shows the depth budget of that scene (the space from the closest plane to the farthest plane). This bar may be divided by horizontal black lines – one for each depth plane within the scene (not counting the top and bottom of the green bar). The green bar itself is within a light gray box. This gray box represents the total available space within the scene that could potentially be used. This space is limited due to the fact that anything drawn past this point has the potential to cause divergence of the viewer’s eyes if items are drawn at the two extremes (closest and farthest point). Dragging the bars up and down changes the location of the scene’s depth planes in relation to the convergence – in other words, moves the scene closer and farther away from the audience. By using the pen and dragging the top or bottom of the green bar, the user can “squish” or “stretch” the depth of a scene causing more or less separation between the planes. This allows directors to make better use of the available scene space, can help with transitions, and can aid in spotting errors. For instance, in Figure 28, the director can immediately spot a depth jump between panels 9 and 10 – which may better be avoided, creating a smooth progression from panels 10 to 16.

**Figure 33.** Storyboard panel showing depth bar on left. In this image, the scene is positioned completely in audience space.
5.2.8 Additional Storyboard Support

To better address the specificity of the storyboard workflow, the following functions on the main canvas are included: *onion-skinning* which allows the artist to see the neighboring panels as a semi-transparent overlay to guide successive panels; and *flip-book* functionality to play a sequence of panels as an animation.

The onion-skinning mechanism shows one previous or next frame in a series and is activated by an icon (Figure 27 A) on the top-left of the sketch surface for the previous panel, and the top-right for the next panel. Once activated, the contents of the next and/or previous panel are displayed as a lighter semi-transparent image from which the artist can iterate. Though visible, the artist cannot erase or otherwise affect the contents of the non-active panels as they are only meant as a reference. The artist would need to go to the previous or next panel to make changes to the contents of that moment. The depth-plane thumbnails for the activated ghosted panels are also shown in the slider bar, beneath the active panel’s thumbnails, to help the artist align her work along the depth axis. However, since the current panel’s thumbnails can obscure the location of the ghosted thumbnails, these ghosted images are offset to the left for a previous panel, and to the right for the next panel.

To view a sequence as a flip-book animation, once the panels are drawn, the artist can hold the left (previous) or right (next) side of the screen for a few seconds, and the program will automatically flip between panels, “playing” the flip-book like animation at 12 frames per second – an industry standard for simple animation known as "Shooting on twos" (versus the traditional 24 frames per second often used with live action). Initially a feature to set the speed of the animation was included. This was accomplished by having the user tap on the “next panel” or “previous panel” hotspot multiple times to set the desired speed. The average length of time between taps was calculated when three or more taps were detected, and this average was used as the flip speed. This, unfortunately did not work as users had difficulty achieving speeds faster than about eight frames per second through tapping. An interesting observation regarding perception was that while the user was actively flipping the scene, this speed seemed acceptable; however, when the user held their finger down to watch the animation (and thus were not tapping), this speed seemed too slow. The assumption is that this occurred due to the fact that
when a user is tapping, they are actively involved with the process, but when the user is holding down their finger, they are more aware of the passage of time as they wait for the next frame in the sequence. Due to this constraint, this feature was removed.

5.2.9 Unused Stereoscopic UI

A couple of alternate UI techniques were also tried to take advantage of the stereoscopic nature of the system. An attempt was made to present both the drawing frame as well as the slider bar stereoscopically; however, these did not work as expected and caused visual strain, so were removed.

The initial intent with the drawing frame was to leave it at the default convergence depth. In this manner, the artist would have further feedback regarding their current drawing offset from that of the convergence plane. It was found that this worked fine when the offset was minimal, however, as the discrepancy approached the visual extremes, (e.g. the default convergence plane was at the front-most depth and the artist was drawing on the back-most depth), the artists eyes needed to strain to be able to see both depths comfortably (e.g. Figure 34). Usually the frame would not be visually fused, rendering the frame useless. As well, as one drew further away from the frame, it became difficult to be sure of whether the strokes being added to the surface were actually within the frame, or if they drifted outside of this space.

An attempt was also made to display the slider bar stereoscopic to match the depth location it was representing – i.e. the part of the slider bar that represented a depth closest to the user, was
visually closest, and the part of the bar that represented a depth furthest away from the user, was visually further away. Unfortunately, as with the drawing frame, the extremes of the bar were difficult to visualize at the same time. Further, since the offset between the left and right eye image of the bar had to be constantly adjusted to correspond to its depth in the scene, being drawn close to the edge of the screen caused a problem. As the offset increased, more screen real estate was needed to the left and right of the slider bar to correctly draw the corresponding image. This space was significant enough to impact on the available area for drawing. However, along with the difficulty in viewing the bar properly when presented in this manner, it was deemed that the gain of the visual representation was not worth the discomfort and loss of space within the program.

5.3 User-Centered Design & Validation

Storeoboard, is the result of an iterative, user-centered design process. On three separate occasions, throughout the project, a professional storyboard artist came in to give feedback. Each session was about two hours long, during which he helped refine Storeoboard’s techniques and workflow. Many design decisions were guided by the regular feedback from the artist. For instance, an early prototype “flipped the page” when moving from one panel to the next. Though a fast animation, this slowed the artist, breaking his pace and workflow. He helped determine such issues, resulting in a more streamlined process. He created 66 panels (some of these are featured in Figure 27 and Figure 30) over the course of the project. This expert will be referred to later as S0.

5.3.1 Evaluation Protocol

To better understand the potential of the approach as a creative planning and conceptualization tool and assess professional artist’s acceptance, Storeoboard was evaluated through multiple sessions, with different groups selected based on their level of expertise, and the methods in which they use storyboards. First, all three validation sessions conducted are described, then a synthesis of the results is presented.
5.3.1.1 Session 1: Focus Group

The first validation session consisted of a focus group with a set of expert storyboard artists – the main target users of the prototype. A workshop with nine participants was held (aged 21-60; 5 female) at Sheridan College - a local arts college. The group consisted of seven students in their 3rd and 4th year of training as storyboard artists and two instructors – both professional storyboard artists. The purpose of this session was to assess the usability of the tool and evaluate the tool’s suitability for a director and storyboard artist to discuss stereo aspects of a film (the prototype version at this stage did not include depth budget and depth script functionalities). The group was shown the tool by means of a quick tutorial and given about one-and-a-half hours to freely explore the prototype in small groups – there were three tablets for the entire group, and anaglyph glasses for everyone. Participants answered a questionnaire before and after using the tool, and participated in a group discussion to conclude the session. This three-hour focus group resulted in 36 panels with six sequences and seven individual panels drawn. Figure 29 is an example artifact created in this session. These experts will later be referred to as S1_{1-9}. (more results are shown in Appendix C)

5.3.1.2 Session 2: Semi-Structured Interviews

The second validation session consisted of semi-structured individual interviews with three directors who work or have worked with stereo films, two technical directors and one stereographer, for whom storyboards is a critical reference and communication tool. The goal of this session was to assess whether professionals, familiar with S3D film making, would use stereoscopic storyboards, and at what stage(s) in the filming process. The overall feedback regarding the prototype was the focus of these sessions and its use in the production pipeline. Participants were asked to fill out a questionnaire on their current working practices with storyboards and stereoscopic-related tools (i.e. depth budget, depth script, floating window). Then the experimenter demonstrated Storeoboard and its different functionalities (all functionalities were present), after which the participants were asked to answer questions on the tool’s different aspects. These participants will later be referred to as S2_{1-6}. 
5.3.1.3 Session 3: Deployment

Finally, the program was successfully deployed as the only storyboard tool on the full-length feature film “40 Below and Falling” over a four month period (Dec. 2014 - Mar. 2015). For this film, the director worked with a storyboard artist to help explore his ideas and communicate with the other departments to ensure a smooth understanding while filming (the stable version deployed at the time did not contain the depth budget, depth script, nor floating window features). Figure 25 and Figure 33 display some examples from the film (more examples can be found in Appendix C). The director was debriefed through questionnaires and a phone interview following the filming of the movie. The director will be referred to as S3 in the following text.

5.3.2 Feedback and Discussion

Valuable insights were gained from the feedback collected during the different sessions conducted with professional experts. These insights are synthesized in the following text.

5.3.2.1 Usability and Usefulness

All interviewees commented on the program’s usefulness as a communication tool. It was noted that “there really isn’t a language to convey ideas in stereo… [Storeoboard is] the first of its kind” (S0) and “Nice to be able to see stereo at the storyboard stage […] it makes a lot of sense” (S24). Many of the storyboard artists also commented positively about the simplicity of the interface, saying things like, “I really like how the interface is simple and intuitive […] it reminded me of drawing on note cards” (S15).

When asked about how enjoyable and easy to use Storeoboard was on a 7-point Likert scale, seven out of the nine artists (focus group S1) rated their experience with a score of 6 or greater (1 = not enjoyable to 7 = enjoyable; and 1 = hard to use to 7 = easy to use). The film director (S3) also commented on the ease of use and stated that the program allowed him to “work at the speed of thought”. Every participant who tried the tool commented on finding the program fun to use.

All groups were questioned about Storeoboard’s usefulness for planning and design. All participants agreed that the tool would be useful for some aspects. One participant asserted that he “would use it for ‘what ifs’ and ‘one off’ creative discussions” (S24) another observed that it
would allow “studio execs... to ‘view’ images thanks to the anaglyph” (S21), though it was noted by the stereographer (S21) that he would want to “work with a storyboard artist”.

Another question that was asked on multiple occasions was in regards to people who cannot see in stereo for various reasons; whether this tool is still useful, or if it would not work for them. It is documented that as much as 13% [Freeland, 2012] of the population may have some trouble seeing stereo properly, so this is an important question. What is nice about the suggested approach and implementation is that a user does not need to be able to see stereoscopically to make use of the tool. The slider bar gives information about plane depth (by the depth planes location on the slider bar), plane separation (amount of space between thumbnails on the slider bar), depth budget (the amount of space between the front most and back most thumbnails in the slider, and the scenes parallax position (based on the thumbnails distribution around the convergence plane indicator arrow). This allows an artist or director who is unable to see stereo properly to still discuss stereoscopic concepts when planning a shot. This was further supported by the fact that participant S12 was unable to see in stereo but was still able to contribute in the discussions and create stereoscopic assets while trying the system.

5.3.2.2 Focus on Stereoscopic Functionalities

Only participants of session 2 were exposed and interviewed about the depth budget, depth script and floating windows functionalities. All the industry professionals liked the concept of the depth script and the ability to play with it, though the stereographer (S21) did comment that the storyboard artist should not be the one deciding the depth. Rather, he suggested a workflow where the stereographer provides a high-level depth script parameter, which could “clamp” the storyboard artist’s drawings. The director and stereographer could then adjust the depth of the images at a later time. He also noted that a depth script needs to be flexible as it can change constantly through the production process. He found this implementation accommodates this need for flexibility.

Feedback on the concept of floating windows was interesting as it is a new tool in the film industry and people are still figuring out how to use them. Currently, floating windows are only accessible to people working in post-production, and it is used mainly for correcting mistakes. The artistic use of floating windows is still largely unknown to most directors and its uses are
still being discovered. Hence, most professionals felt the ability to play with floating windows in early stage planning, was “somewhat pre-mature” (S24), but, that the ability “should be in the toolbox” (S21). A participant stated that “Any tool that can be part of the live process is useful; [but] if it slows [the process] down, it’s no good” (S24).

5.3.2.3 Issues and Opportunities

Storeoboard was met with very positive feedback, though the different groups did note some features that were potentially missing or could cause problems. One aspect that was very apparent with the focus group was that each user has a very personalized way of using the tools with which they work. Therefore, the ability to customize the interface and look is a necessity for artists. As well, multiple users commented that it would be nice to have more control over the look of the brush stroke. Currently, there are no controls for the thickness or opacity of a stroke; the system simply uses pressure to control the thickness of the line. Artists felt that there was a use and need to provide controls for both brush thickness and opacity, specifically when creating storyboards. Comments were made such as “[the system needs an] adjustable brush size. Different shades of black” (S14), “[consider] adding tones or mattes” (S15) and “grayscale level [was missing]” (S12). Another idea that was suggested by the different groups was the ability to load an image into the background. This was proposed for both providing reference material in the form of an image or an alignment grid. It was also suggested that having the ability to “cut-out” parts of the background image and move these regions to different planes could drastically speed-up some of the planning processes (especially for film conversions).

Another concern that was raised related to the use of anaglyph glasses. Artists did not mind wearing them for a period of time, but were skeptical about wearing them all day to draw a full storyboard. One artist even commented that “[it] hurts my eyes at the end” (S17). Participants in the focus group suggested that possibly drawing the image flat then “popping” it into stereo for discussion might be an alternate workflow. This idea was supported by the fact that some artists seemed to be able to draw most images without glasses, and would use the glasses at the end to “tweak” the final results. Since anaglyph is only one method to achieve stereo, it is likely that using a passive system would be less abrasive to the artist, but less accessible to individuals without the specialized hardware (such as producers).
5.3.2.4 Deployment on a Live Feature Film

According to the director of the film (S3), the tool was well received; it “worked exactly as expected” and that it “achieved exactly what was needed”. Before, obtaining the tool, they tried using the pre-visualization tool FrameForge Pre-viz Studio [FrameForge] which was perceived as too cumbersome and slow during the brainstorming phase. He stated that in the course of using FrameForge, it would take the better part of an evening to explore one scene and he would often forget ideas by the time they managed to commit the first idea to paper. This slow process really impeded exploration of ideas and did not work well for ideation. He estimates that, in the end, Storeooboard saved the production hundreds of hours and thousands of dollars while filming; that it “allowed things to flow so much easier between departments”. “It was a big thing, especially for crews that haven’t worked with 3D and don’t really understand, what should [be done]…it allowed them to see right away rather than on set”. Regarding its use, he would sit down with the tool and play with different ideas, until he found something that he thought he liked. He would then have his storyboard artist create a nicer, cleaner version of his idea that would then be used for discussion. He stated that the Storeooboard was used in “preproduction... by all departments... sound, lighting, production design”. Further, it “allowed departments to better understand [the scene], especially lighting and production design because they knew where the world was already going to be”. This meant that the film team would arrive on set, and everyone was able to quickly setup for the shot, as everyone knew exactly what was expected and where everything needed to be placed. Finally, he noted that at first, people would ask “the point of [stereoscopic storyboards]? And then when they start to understand what you can do with that, it just made sense”. When asked about future projects he stated that he would “use [the program] again in a heartbeat”.

In January of 2016, “40 Below and Falling” went on to receive a prestigious 3D Lumière award from the International 3D Society for their 3D work done on the film beating movies such as “Star Wars VII – The Force Awakens” and “Inside Out”. This is an award that, in the past, has been given to directors such as James Cameron, Ang Lee, and Martin Scorsese.
5.4 Limitations & Future Work

Though Storeoboard was well received and accomplished the intended goals, there are some limitations that are worth noting. Due to the approach of using stacked planes, the images created with this system suffer from an artifact known as “cardboarding” – the look that all objects are drawn on a piece of cardboard and placed in the drawing space; i.e. none of the objects had volume. Since this tool is meant for ideation, this was not really an issue per se. However, a few situations were noted where this effect could impact discussions. When talking with the Stereographer, it was mentioned that one of the jobs of a stereographer is to try to play with the volume of a scene. Since all the objects in the scenes created with this tool are flat, this makes this tool less effective for the stereographer. Another side effect of this “planes” approach is, unlike traditional animators and storyboard artists who are trained to draw via layers, classically trained artists may find the technique difficult. Often with traditional art, one starts by creating sight and perspective lines. One can create these lines on a background plane in Storeoboard, however, these lines are unable to go from the foreground to the background. Some artists that tried the tool felt that this made it very difficult to accomplish the desired task. With training, this can be addressed, but shows an opportunity for future work – to allow for drawing across the existing planes. Also, this tool is designed as a line/wireframe drawing tool. What is meant by this is that the objects one draws are see-through. To make an object opaque, one must fill it in. However, an artist may wish the inside to be white. Therefore, it would be useful to explore the ability to fill in objects to obscure the lines in the background. Along with filling in these objects, the potential to assign a three dimensional shape to an outline could be explored.

Finally, as proposed above, it would be good to explore the workflow where a stereographer first creates a depth script, which then clamps the artist’s work. As well, in its current iteration, planes and layers exist or they do not. It would be nice to explore the ability of setting the visibility of a layer and thus turn it on or off.
5.5 Conclusion

The contributions of this chapter include the presentation of a tool called Storeoboard that implements stereoscopic 3D depth planes, floating windows, onion-skinning, flip-book animation, interactive stereoscopic storyboards, and interactive depth-scripts. Along with these features, a thorough evaluation was performed of the tool and techniques for its intended purpose through individual user studies, focus groups and the deployment on a feature film. The method for sketching stereoscopically and the feedback mechanism to show how the space is used, both show promise as approaches for achieving fast iterative sketching in stereoscopic 3D space.
Part 3

VIRTUAL REALITY
Chapter 6

Storyboards for Virtual Reality

Head-mounted displays (HMDs) for virtual reality (VR) have evolved over half a century from research prototypes [Sutherland, 1968] to consumer products [Google Cardboard; HTC Vive; Oculus Rift]. The entry of VR technology into people’s homes has caused a surge of interest in the medium among developers, filmmakers, and storytellers. Major film festivals, studios, and technology companies [Frost, 2016; McNally, 2014; Trenholm, 2016; Oculus Story Studio] have created teams specifically targeted at VR stories: where live-action, or animated narratives occur in a fully immersive environment, where the viewer experience is uniquely intimate.

VR is characterized by a quality known as presence – the feeling of actually being at a location in a story rather than experiencing it from the outside [Slater, 1994]. This new medium provides a unique opportunity for viewer engagement and the exploration of novel storytelling, but requires the development of new cinematic constructs and film language [Pausch, 1996].

Creating a movie for VR is not as simple as taking a regular script and going through the well-developed film making process. The unique properties of VR require directors to consider concepts such as presence and peripheral vision, and use them effectively. Directors also must address the challenge of guiding an audience through a narrative, while leaving them free in a fully immersive environment, to look or move in any direction, and even trigger events within the environment. Traditional cinematic principles of cuing and staging can help solve this problem, but need to evolve with the immersive use of spatial visual and auditory cues.
Through multiple interviews, it was learned that, no one currently knows how to properly plan for immersive narratives. Traditional storyboarding and planning tools are shallow and restrictive given the full extent of the environment that needs to be discussed. Communicating ideas between individuals is further impeded, by the experiential quality of VR. Film teams thus rapidly model, collect, and assemble assets that are viewable in VR, simply to form the basis for team discussions, so everyone can understand and plan for the unique challenges being faced by the project.

To help address this unique set of problems, the workflow specific to the needs of professionals creating storyboards for VR and the related challenges were examined, with the purpose of enabling teams to conduct initial explorations and collaborate at/near the speed currently possible with traditional film.

To facilitate this goal, a series of semi-structured interviews with a variety of film professionals was conducted, to fathom these design and technical challenges. The interviews gave insight on how experts regard the space of VR narratives relative to traditional filmmaking, and the processes and tools to plan for immersive experiences, in use today.

This information was used to design a two-device interactive storyboard system for tablet and VR: that leverages both the speed and skills of a storyboard artist, and allows a director to experience the results in VR simultaneously.

A number of issues were addressed in a working prototype of this collaborative multi-device storyboard design: ensuring homogeneity between the different viewing environments, supporting quick authoring, fast navigation, and a proper overview of the fully charted story. This prototype was presented to VR film professionals and feedback was elicited on different aspects of the design, its ability to address the needs of planning narratives in VR, and to assess if the proposed workflow was worthy of further exploration.

6.1 Formative Study

To properly understand current planning processes, and the differences between traditional and virtual reality film creation, discussions were held with a variety of professionals who each had at least 10 years of experience working with film, television, and VR. These interviews were
held either at the lab where this work was performed, or at the professional’s work environment. Specifically the conversations were focused on extracting fundamental information on the specific challenges of early stage planning, as well as the hurdles while creating VR productions. Therefore, the discussions were led with open-ended questions encouraging the individual to explain their process, the challenges they had faced, and the different factors they viewed as important while planning and working with VR versus traditional or stereo3D film. These interviews were conducted with no time restriction, so that the interviewee could share as much information as they deemed was appropriate. Distilled here are the result of these semi-structured interviews with three producers, four directors, one executive creative director, one technical director and one storyboard artist.

6.1.1 Stories in Virtual Reality

Unlike movies that are projected on a silver screen, VR films can intimately engage audiences. These films are often referred to as stories in the industry, reflecting a looser terminology used by professionals. VR stories will henceforth be referred to as VRSs. As well the terms “story” and “narrative” will refer to the content being told (as is used by the interviewees), while “VR experience” will refer to what the audience consumes.

Further, it is important to define what is meant by VR, as there are different styles (or methods) for displaying VR – whether it is a fully immersive environment in which the user can move about, or simply a 360° panel that wraps about the user, different groups can have different meaning when discussing VR. For the purposes of this text, VR refers to any system where the visual environment is completely replaced by visuals (computer generated, or captured by camera) that are different to the actual surrounding space. This could be through any means, such as a head mounted display [Google Cardboard; Oculus Rift], or even through some, as-of-yet- undiscovered, future technology where the stimuli are wired straight into the optic nerve or brain. The important factor is that the environment is replaced by one that is not actually there.

6.1.1.1 Relationship of Story and Audience

At a high level, a film experience can be formulated using three components: the audience, the camera, and the narrative (or story). The narrative is a collection of moments presented in some
predetermined order. These moments may be temporally sequential, or non-linear, and they may be told within a continuous environment, or jump from one location to another. The audience is a group of one or more individuals who experience the story being told. The camera is a mechanism with which to control this experience: framing shots, camera movement, stereoscopy, and field-of-view (FOV) are all variables in aligning the audience with the narrative.

With traditional film, the director is usually in complete control of the narrative and camera, with the audience generally experiencing the story from outside the movie’s environment. In VR, this arrangement is not as clear. With a VRS, the narrative remains in the director’s control, but the audience is part of the story, so that the narrative occurs all around them. The notion of a camera is also less definite. The camera is loosely the viewer’s field-of-view (typically frameless) that the audience controls, though a director controls intrinsic camera parameters e.g. stereoscopy and lens filters (color, shading, graininess), and can subtly or explicitly guide or control audience gaze throughout the narrative.

Directors are actively experimenting with various configurations of this audience-camera-narrative model in VR:

- virtual movie theatres; immersive environments where the viewer can look anywhere, but the narrative is focused in one primary place; environments where multiple narrative moments happen simultaneously in different places; a primary “stage” that slows down and eventually stops as the viewer looks away [Visionary VR]; camera concepts where audiences attach themselves at any time to any character to follow that character’s story arc [Bishop, 2015]; and the ability to teleport anywhere, to follow a story as much or as little as desired are all examples of techniques that are currently being explored.

These techniques allow for different levels of interaction. Therefore, it is here proposed that a narrative shifts from a VRS to a game when a viewer’s interactions change the outcome of the story being told (e.g. a character dies as a result of a viewer’s choice). This work focuses on VRSs, where the viewer control is limited to their consumption of the narrative, not its outcome.
6.1.1.2 Making VR Stories: Key Considerations

Though many of the concepts and approaches used for creating a VR experience are similar to conventional cinema, others are more akin to live theatre and plays. This interplay results in many new concepts that one must consider that are unique to authoring these experiences.

Presence – One of the biggest differences from traditional film is a concept that is referred to as presence [Slater, 1994]. Presence is the feeling of being inside a scene rather than looking at one from the outside. For instance, looking at a family vacation photo may cause you to remember your experience of being there, but is unlikely to invoke a similar feeling in an outside observer. VRSs evoke a sense of being there, that is not captured by 2D/stereoscopic imagery.

Active Experience – Movies have generally been passive, static experiences for the audience, allowing one to sit down and be taken on a journey as the story is told. VR experiences allow audience participation, where viewers can actively look and potentially move around to explore the immersive setting, while following a narrative.

No Framing – With traditional film, the viewing environment is defined by a border within which a director can layout or frame a shot that the audience has no control over. As a result, with traditional film, a significant amount of attention and effort is used to properly plan and design a shot. VR typically has no border and no guarantee where a user will look. Framing is thus harder, even conceptually, which changes how a director approaches the planning of a shot.

Blocking – With VR, the space all around the audience can be used to stage a film. For this reason, the concept of blocking, the process of deciding what will be where, where objects and people will move, and the composition of a scene as a whole within the set changes. “How much of the film will happen in front of the user?”, “What will happen behind the user?”, and “How should one guide the viewer’s attention from one area to another?” are just some of the considerations needed while planning the blocking for VR.
Peripheral Vision – Since VR creates the sense of actually being on location, the director needs to think about the viewers’ lines of sight. In the past, things that would have been off-camera can now be seen peripherally.

Audience Attention – Keeping the audience focused on the narrative is an added directorial burden in VR. Sound or staging cues, lighting and movement can all be used to draw the user’s attention; however, as an interviewee noted, these actions must be used sparingly, as an audience is quickly desensitized and will ignore these techniques if used too often.

Limited Transitions – With traditional movies, directors rely on cuts, fade in/out, wipes and other shot transitions to keep the story engaging and to move the narrative from one moment to the next. In VR, transitions are more jarring and potentially disorienting, as they involuntarily “teleport” the audience. Interviewees indicated that VR directors have generally found that limited use of fades are the best way to transition between scenes. Due to this effect, many stories are told in one environment, effectively eliminating the need for transitions. Live theater has a similar constraint, not due to disorientation, but the inability to quickly or easily change physical sets or move the audience around.

Screen Format – A director has a wide choice of spatial staging formats in VR, from a virtual screen to a completely immersive environment.

Stitching – Current fully immersive VR video capture rigs mount multiple cameras omnidirectionally, to immersively capture a live scene. Stitching these multiple camera images together often creates faint distortions and discontinuities along the seams. While future imagery may be seamless, current directors need to plan their shots to minimize viewer focus in the vicinity of seams.

Optics – A director’s choice to present their movie mono- or stereoscopically has a different dimension in VR. Stereoscopy is the effect created from each eye being shown a different image; one horizontally offset from the other, creating an illusion of depth through stereopsis. Leaving the picture monoscopic, a director relies on depth cues like retinal size, overlap, and aerial perspective [Lipton, 1982].
Duration – For the near future, VR films will be fairly short in length, both due to the complexity of authoring content and viewer fatigue from sustained viewing in VR.

“You” as the Camera – with the camera direction usually being controlled by the viewer’s head, the audience is often treated to an experience where they act as the physical camera within the scene.

Layer Alignment – Since the camera often moves with the user’s head, the different layers of the scene rotate around the user in an apparent static manner. This appearance with VR is, however, not necessary. With a VRS, parts of the scene can appear locked to the viewer’s perspective while other can remain static with the environment.

Scene in Audience Space – with stereoscopic film, the physical screen acts as the convergence location for the scene, with some of the scene taking place in front of the screen (in audience space) and some taking place behind the scene (in screen space). With VR, however, the scene converges at it recedes into the distance (as is the case with natural vision). Due to this fact, all of the action in a VRS happens in the equivalent of audience space – in front of the convergence location.

6.1.2 Planning for VR Stories

As with any film, due to the multitude of decisions and technical challenges to create an engaging experience, directors need to plan a VRS in virtual reality itself. This ensures that everyone understands and works towards the same vision for the film and allows the film crew to organize a scene’s logistics. For instance, lighting technicians can figure out the type and placement of lights, stunt coordinators can discuss choreography and rig setup, and problems can be anticipated before anyone is on set, preventing costly mistakes. The various unique considerations for VR, however, render traditional planning tools such as storyboards and previsualization (Figure 35), ineffective in VR.

Figure 35. Previs (left) is used to plan for movie shots (right).

Image from Wee Biz Studios.
6.1.2.1 Storyboards

Storyboards, traditionally, are hand drawn sketches very similar to comic strips that outline the key moments of a shot for a scene in a film [Hart, 2013; Simon, 2006]. Typically, they are small quickly drawn rough sketches made to capture the essence of a moment in the story without the need for any underlying infrastructure. They allow a director to step through a movie to discuss concepts and moments, their relationship in the narrative, and to plan a compelling story. These boards are generally created very quickly by one or two artists. Storyboards are often distributed on a set to aid with organization.

Though great for discussing shots, traditional storyboards have disadvantages with VR. First, one cannot convey a sense of presence with a small 2D sketch. As well, since VR is mostly frameless, framing can potentially distract from scene understanding. Lines of sight on a 2D picture have an abrupt border, whereas one’s visual acuity gradually fades at the periphery in VR. VR planning further entails blocking a 3D environment around the audience, instead of a limited field-of-view shown on a 2D plane.

6.1.2.2 Previs

Previsualization, or previs, is the technique of creating (usually) a 3D computer model of a film set, populated with virtual cameras and characters to explore and refine narrative breakdown and plan shots. While directors can freely explore multiple camera angles and transitions, previs is expensive, time-consuming, and requires the creation of many digital assets early in the filmmaking process. Conceptually, previs can be used in other film contexts [Zwerman, 2014]. See Appendix A for a complete definition of these different uses.

6.1.2.3 Drawing and Painting in VR

There are some very compelling 3D tools for drawing and painting directly in VR, like TiltBrush [Tiltbrush], where users paint in the air using 3D controllers, and Hyve3D [Dorta, 2014], where drawing on a spatially tracked tablet is mapped to virtual planes in a cave-like environment. Storyboards for early stage planning and blocking, however, should leverage existing skills of a storyboard artist and support quick sketches of appropriate visual roughness, that provide a good spatial proxy for scene elements at an appropriate level of abstraction for planning a VR scene.
Neither of the above-mentioned approaches are well suited to storyboard: drawing in air interfaces like TiltBrush are too slow for prolonged use when creating a large number of storyboard panels, and have no natural abstraction that can be used for cinematic blocking. A planar sketching interface like Hyve3D provides such an abstraction, but controlling arbitrary planes in space can be overkill and thus cumbersome.

Further, while stacked planar sketching is ideal for traditional and stereo storyboards (see Chapter 4 & Chapter 5), a more natural spatial extension to VR would be drawing on concentric cylinders or spheres around the audience.

6.1.2.4 Current VR Planning Strategies

It was learned from professionals that there are currently no standards for planning VR projects, as there is no preferred or even sufficient process for discussing evolving VR cinematic concepts. Consequently, groups scramble to cobble together a 3D visual mockup (using images, projected 2D storyboard panels, 3D objects, toys, cardboard cut-outs, previs and other proxies), so presence in VR can be experienced and discussed.

For example, one group interviewed uses a workflow that combines Mettle (an Adobe After Effects plugin for 360/VR) and Adobe Photoshop. Each asset is sketched in Photoshop, imported, and manipulated onto planes in After Effects. The overall scene mock-up is then exported to be subsequently viewed using a Samsung Gear VR headset. Any iterations require the entire process to be painfully repeated, which has serious implications on productivity. The goal was thus to provide a solution of the same quality and efficiency as

Figure 36. A dual device system, implementing a tablet for sketching and HMD for viewing VR storyboards
traditional storyboarding, that leverage domain expertise (mimics pen and paper), is easy to edit by an artist or director, and provides real-time feedback in VR, which are all design requirements critical to creating effective storyboards (see Chapter 4).

### 6.2 Toward a System for VR Story Planning

There are a number of questions and issues that need to be addressed in the design of a VR storyboard system:

How does one allow for the speed and familiarity of drawing on a tablet/paper in an immersive environment? What should a VR storyboard look like? How does one abstract an immersive environment that surrounds the audience into canvases for sketching? How does one collaborate and communicate in a virtual space, when visually separated from other discussants? How does one ensure storyboard sketches provide sufficient volume to perceive depth and spatial relationships between objects in a scene?

To start, interviewees were asked if a VR storyboard would be useful. The executive creative director commented that “to [him], storyboarding in VR is the first step of tackling a big problem when creating content for the medium, and that is, all parties involved have something different in their imagination. Similar to a film, storyboarding in VR serves the purposes of getting everyone on the same page, gathering around the creative vision. Having a VR storyboard would allow for all parties involved to understand how their roles play into the larger picture.” It was also stated that “Using a traditional storyboarding method would require exponentially more drawings/work/time, and even then there would be no sense of space or scale.”

This work proposes a planning tool based on a networked multi-device system, where one can simultaneously exploit the sketching abilities of a tablet, and immersive viewing, by wearing an HMD (Figure 36). Through a “best of both worlds” approach, an artist can draw on a tablet by working with stereoscopic, panoramic sketch planes, and can instantly view the results mirrored in VR themselves (or collaboratively with a director), to experience the scene from within.

Different possible workflows enabled by this multi-device approach are illustrated in Figure 37. If the director (in a dark shirt) and artist (in a white shirt) are working synchronously in the same location (Figure 37 – a, b), they could both sit around the tablet and have a discussion similarly
to what is done for traditional film, or both view it in VR. Alternately, the director can immerse himself in VR while the artist sketches on the tablet, and see the results in real-time.

Conversely, in an asynchronous scenario, the artist could start by sketching and viewing on a tablet as is typical, or drawing on the tablet and viewing in VR. The director, working asynchronously, could at any time view the immersive VRS panels with the HMD and with the tablet add comments and notes for the artist to subsequently address (Figure 37 – c, d).

While the physical tablet is not visible in VR, with the tactile feedback of the physical tablet, and the instant visual feedback of the sketch lines and stylus in VR, sketching is not a problem for digital artists used to drawing on digitizing tablets that are physically separate from the display.

To enable storyboard artists to sketch in a fast and familiar method on a canvas surrounding the viewer, and capture the well understood cinematic concept of scene depth (see Chapter 4), the space is parameterized into a set of concentric cylinders shown as flat stereoscopic panoramic panels - a surface that is easier for artists to mentally unroll than a wrapped sphere. These panels can be rolled back into a cylinder for immersive display (Figure 38). While this depiction is best suited to a $360^\circ$ view, it is nonetheless able to quickly depict 3D scenes that can be arbitrarily navigated and viewed for general VR cinematic discussion.
6.3 Related Work

Telling stories in a virtual environment is not a new concept. In early work, Randy Pausch et al. [Pausch, 1996] identified the need for a VR storytelling lexicon (that is currently evolving), and the need for rapid prototyping in VR. The talks with current filmmakers suggest that this is still very much an open problem. Below focuses on existing tools that enable 3D sketching, and drawing in VR.

6.3.1 Sketching 3D models

Since Sutherland’s seminal sketchpad system [Sutherland, 1963] more than half a century ago, digital sketching of 3D objects has been an active area of research (see [Olsen, 2009] for a survey). A large body of research deals with interpreting a collection of 2D strokes as a network of 3D curves. Tools like Analytic 3D Drawing [Schmidt, 2009b], ILoveSketch [Bae, 2008], and True2Form [Xu, 2014], define geometric relationships between curves in 3D based on inferences of 2D strokes, using regularity constrains. These curves are often treated as cleanly drawn 2D strokes projected onto 3D geometry (like the above mentioned sketch cylinders). Other research, illustrated by the organic shape modeler Teddy [Igarashi, 1999], builds 3D objects by extruding or inflating sketch strokes.

As an ideation-stage sketching tool, 3D objects are both overkill and distract from the primary goal of story layout. Gesture based drawing systems provide rules to build 3D geometry [Ding, 2005; Forsberg, 1997; Zeleznik, 1996] or suggest plausible alternatives [Igarashi, 2001].

This work is better served by systems that mimic the fluidity of pen-and-paper [Dorta, 2014; Tsandilas, 2015], where no assumptions are made on the nature or semantics of sketched 2D strokes, save for projecting them onto concentric sketch cylinders that reflect view depth. This abstraction of view depth is akin to 2.5D modeling [Rivers, 2010], or techniques that conceptually subdivide space into volumetric layers [De Paoli, 2015].
6.3.2 Drawing in VR

Direct drawing in VR has been explored for over two decades [Deering, 1995], and has even been enhanced to provide techniques to paint in VR [Keefe, 2001]. Numerous systems use a 2D plane as a mode of interaction for constructing in the 3D environment [Angus, 1995; Ens, 2014] whether it is a virtual 2D plane, or a physical drawing tablet represented in the 3D space [Bowman, 1998]. LaViola et al. [LaViola, 2011] provide a summary of different techniques for drawing in VR.

When worrying about speed and accuracy, research has shown that sketching 3D objects in a virtual space is less accurate and more time consuming than traditional sketching [Wiese, 2010]. Given the large volume of sketches needed for storyboarding, tablet-based sketching was chosen over direct drawing in VR.

6.4 Conclusion

A formative study to assess the challenges and goals of VR storytellers was performed. The tools available today to these individuals as well as the limitations they face were studied. Following this, a workflow that pairs a sketch tablet and VR display, and allows users to sketch on stacked stereoscopic, panoramic panels corresponding to concentric cylindrical surfaces of increasing view depth was proposed. This setup leverages the domain expertise of storyboard artists and enables interactions in VR between the director and artist. The following chapter proceeds by presenting an implementation of a system that employs these concepts, constraints and approaches.
Chapter 7

Enabling VR Storyboards (StoreoboardVR)

The previous chapter explored the challenges unique to planning a virtual reality story. It laid out the different considerations and discussed current techniques used to plan for this form of storytelling.

This chapter explores a technique to better enable directors and artists to plan for virtual stories. The technique enables artists to work at the speeds with which they are accustomed, yet allows directors to see and discuss these sketches in a virtual environment, enabling discussions about concepts such as lines of sight, blocking for VR, and an image that is frameless. This two-system approach, allows for a “best of both worlds” scenario, enabling fast, live-time discussion of virtual concepts for creating virtual stories.

7.1 Working Prototype

The implementation combines a tablet-based sketching tool (Microsoft Surface Pro 2.0) to author VR storyboards, and a synchronized HMD (Oculus Rift DK2) to experience the boards immersively.

Many design innovations of the dual system were based on supporting synchronous use of the tablet for sketching, and the HMD for experiencing the VRS panels from within. Given the lack of ability to currently storyboard for VR, rather than trying to establish specific input techniques, the goal of this first prototype was to explore and assess a workflow that enables teams to
conduct early explorations, collaborate at/near the speeds currently possible for traditional film with a VR system, and to see whether storyboards are even useful at this early stage for VR.

First described below is the authoring of a storyboard on the tablet. Following this is an explanation regarding how the artist or director experiences the result in VR, and can annotate using the tablet. Finally, outlined is how the dual system supports collaborations between the artist and director (Figure 37).

7.1.1 Authoring VR Stories on the Tablet

The primary storyboarding activity consists of sketching, and viewing a series of moments (panels) that make up a narrative. The tablet presents a manifestation of the unrolled concentric cylinders, enabling the artist to sketch on the 360° environment of the VRS panels.

7.1.1.1 Sketching View

Like traditional storyboard tools, this system includes a sketch canvas, where the artist can draw content for a panel. As with Storeoboard (see Chapter 5), she can add strokes at different view depths (i.e., concentric cylinders), by navigating a slider bar, to support the director’s spatial vision. The bar is augmented with thumbnails to show the placement of the strokes that are present in the environment (Figure 39).

To maximize the drawing area, rather than presenting the entire panel unwrapped, the tablet shows a smaller portion of the current panel. Swiping left or right, the artist can access the rest of the drawing space. The canvas smoothly wraps around as the artist reaches the edge of the panorama.
As the artist develops the narrative, she can add new panels to describe new moments in the story. Tapping on the edge of the canvas, the artist can easily access the previous (left) or the next (right) panel of the VRS.

Technically, one of the main challenges of drawing on a cylindrical panorama is to provide a drawing surface that accounts for the canvas’ curvature when projecting on the drawing surface. This type of correction is dismissed in this system, i.e. it provides a flat canvas, since in practice, artists draw at sufficient viewing depths that the distortion becomes negligible.

7.1.1.2 Overhead view

An important aspect of storyboarding in VR is to visualize overall layout of the immersive scene. Drawing inspiration from a technique currently used by VR directors, the system aids with the quick placement and blocking of objects via an overhead view (Figure 40), which allows the artist (and the entire film crew), to see all sketch strokes for a VRS panel, in a target view (right) with a preview window (left).

The overhead target is divided into 30° segments with concentric circles to highlight given depths. Colored segments drawn over the circle convey the radial locations of scene content, allowing the artist to identify crowded and empty spaces, as well as distances between sketch elements in the virtual environment. The current view direction (seen in elevation in the top-left preview window) is represented by a gray wedge, similar to radar, and can be manipulated by rotating the wedge around, to update the preview window.

Flipping back and forth between panels in this view allows the artist (and director) to see how audience attention is being guided over the course of the narrative, understand the flow of action, as well as spot abrupt changes in depth and location, which can be disorienting for the audience.
Simple interactions allow the artist to quickly edit the spatial composition of the panel. She can adjust depth and location of strokes by lasso selecting with the pen (in either the overhead target or the preview window) and dragging the selected lines with a finger. The system thus leverage pen and touch interaction for different activities, supporting artistic workflow with minimal interruption [Hinckley, 2010].

7.1.1.3 Panoramic Storyboard View

As with traditional storyboards, the system provides an overview of the VRS, showing the sequence of panels as panoramic thumbnails, under which the artist can add notes (Figure 41). From this view, the artist can also quickly jump between panels for further edits in the sketching view.

To heed the VRS planning of audience attention, a concern unique to VR storyboards, the system highlights the primary area of focus for each panel (green box and gradient in Figure 41). Panoramas are aligned with respect to the view angle (see angular scale under thumbnails), allowing the artist to understand and experiment with different focus transitions along subsequent panels, and maximize the use of the stage.

With its sketching, overhead, and panoramic storyboard views, the tablet provides the artist with a rich set of perspectives of the VRS, supporting expressive authoring and providing assets for discussion between the director and crew. Transitions between the views is achieved through a simple pinch gesture, without disrupting the creative flow.

7.1.2 Exploring the Virtual Environment with the HMD

At any time during the process, the director, the artist, or any other collaborator can decide to experience how the VRS looks within the virtual environment, using the HMD. Design decisions
for VR were largely based around a philosophy that the tablet draws, and the HMD views content.

7.1.2.1 HMD as an External Observer

An external observer (the director, or any other collaborator) can experience the panels as the audience would, and view sketched content wrapped around the cylinder in 3D, while the artist continues to work on the tablet (Figure 37 – b).

To facilitate discussions around content, all changes that the artist makes on the tablet are immediately reflected in the VR environment. Meanwhile, the observer can look around at will without affecting the artist’s environment, and may even decide to experience the scene from a slightly different viewing angle, through navigation with the keyboard. Similarly, the artist can freely work in any of the views (sketching, overhead, panoramic) without affecting the VR environment. Only when the artist changes the panel on the tablet, will the observer be teleported into the new scene.

7.1.2.2 HMD as a Display of the Tablet

A single user can immerse themselves in the VRS, while using the tablet, e.g. the artist can look at their creation in the HMD, and keep editing the content on the tablet (Figure 37 – c, left); later, the director can look at the VRS immersively and make annotations on the tablet (Figure 37 – c, d, right).

While wearing the VR headset, the surrounding physical environment is invisible to the immersed user. Thus, the tablet and keyboard are less accessible. The system relies on “within arm’s reach” proprioception [Mine, 1997] and haptic cues for interactions. In practice, drawing on the tablet is not hindered, as the canvas and pen are represented by a frame widget and cursor in VR (Figure 43), which is similar to artists working with 2D digitizing tablets. In this setup, the tablet interface is reduced to pen interaction for sketching, and touch to control the view, negating the need to remove the HMD. Finger dragging up and down changes the current working depth on the sketch surface, while panning rotates the view, i.e. the VR environment is rotated to the position shown on the tablet; but the user can still look left and right. While large rotations performed via the tablet can cause vestibular discomfort [Akiduki, 2003], it is
preferable to using the HMD gaze to control the tablet view. As the tablet is used for sketching, it should be insensitive to ambient HMD head movements. Still, free navigation using the keyboard remains available, and hotkeys allow easy access to tools and the undo action.

7.1.2.3 Diorama Storyboard View

The interviews indicated that professionals were unsure what a storyboard for VR would look like. To initiate the discussion on this topic, a diorama storyboard (Figure 42) was introduced that acts as the VR counterpart of the panoramic storyboard view on the tablet. Panels are represented as a series of 3D miniatures within cylindrical discs with white backgrounds that contrast the strokes. Viewed from a 3rd person perspective, these dioramas surround the user, rather than being organized traditionally in a flat grid. The panels can be viewed from different angles and proximities with keyboard navigation. Like the panoramic board, the user can jump between panels by looking at the desired diorama and with a key switch to sketching for that panel.

7.1.3 Support for Collaboration

Collaboration is an important design requirement of this dual system, as artists and directors often work together on storyboards, and may discuss them with other film crew. To enable the workflows illustrated in Figure 37, the VRS panels are synchronized via a wireless LAN using UDP messages, supporting consistency between devices, increasing awareness between users, and facilitating discussions.

7.1.3.1 Consistency Across Devices

To establish common landmarks for all users, the system ensures consistency between the flat tablet’s view and that of the HMD. First, the tablet and VR system display the same FOV (~90°), which occupies only half the screen given the same aspect ratio (freeing the other half for other
purposes). Further, to help the director and artist mutually understand the VRS space, both interfaces contain a ground plane represented by a radial grid, and a degree scale wrapped around the environment for orientation (Figure 39 and Figure 43).

Though both devices show grid lines with the same perceptual spacing, they are not exactly the same. The HMD shows the 3D scene in accurate linear perspective. The tablet on the other hand presents the sketch cylinders unrolled into rectangles, ideal for sketching. Therefore, the ground plane projects as straight lines rather than radial lines on the tablet. This accurate depiction is disregarded for one that provides a better perception and interactive control. The ground plane grid is drawn to perceptually match the grid in VR: with the concentric circular arcs as horizontal lines (that show the depth of the sketch cylinder), and the radial lines near vertical, but converging inward. Note that, two sliver regions outside the outermost radial lines are outside the VR field-of-view. Further, a dark horizontal line is shown that moves along the ground plane to help the artist distinguish strokes above and below the ground plane (Figure 39).

7.1.3.2 Collaboration Feedback and Additional Features

Users in disparate visual spaces introduce a communication challenge, which is addressed using overlays indicating the current view, or gaze, of the other user on both devices.

While sketching on the tablet, the artist may notice a red horizontal bar along the bottom of the screen that moves to track the director’s gaze in VR (Figure 39). With this mechanism, the artist can quickly pan the sketch surface to match that of the director during discussions. A similar VR field-of-view indicator appears in the overhead view target on the tablet, as a pie wedge. Similarly, at the depth of the current sketch cylinder, an outline of the current view area of the tablet is shown in 3D on the HMD. This render overlay not only helps by showing what the tablet sees, but also defines the current 3D canvas for sketching while immersed.

Figure 43. Examples of VRS panels created with the system, as seen in the HMD. Note, in the leftmost example, the gray frame widget conveying the current tablet view.
Alternately, the tablet’s view can be temporarily coupled to that of the HMD, sparing the artist the need to actively track where the director is looking, when the latter momentarily leads the discussion. The reverse is not advised, as an external controlling source may cause nausea on the HMD.

Finally, there is support for director’s notes as a dedicated canvas (Figure 39) that is coloured purple, distinct from content on the tablet and in VR (which can be toggled as needed).

Ultimately, the system supports the production of VRSs by artists following traditional storyboard language, and enables VR explorations that were not previously possible. Integrated in a cohesive dual system, these enable new collaborative workflows between the artist, the director and overall film crew.

7.2 User Feedback

To evaluate the system, interviews with professionals from the VR cinematic industry were conducted to determine whether the dual system approach was worth pursuing. The interviews focused on high-level feedback on the dual system to assess the workflow and its ability to support the creative process rather than focusing on particular UI components.

Feedback was solicited from a producer and an executive creative director from an Emmy winning VR team (p1 & p2), as well as the feedback from a director/producer from another leading VR company (p3), and a 3D Lumière award winning director of stereoscopic and VR films (p4). Each of these professionals was invited to the lab to experiment with the system following a ten-minute demonstration of its functionality. They experimented with each context freely without any time constraint (i.e. using the tablet and HMD simultaneously, using just the tablet and then looking at the results in VR afterwards, etc.). The sessions were concluded with a semi-structured interview, where their feedback was elicited on the system as a whole as well as exploring specific points.

7.2.1 General Feedback

The general response received regarding the system was all positive, eliciting comments like “I loved it… hugely valuable” (p1) and “from a prep side, it’s a huge step forward” (p4). When asked about these responses, there was a general consensus that the judicious coupling of the
devices and the ability to see the drawings simultaneously on the tablet and in VR was the biggest contributing factor to this feeling, “the simultaneous view in the [HMD] is amazing... a hit hands down” (p2).

7.2.2 Dual System Approach

Since storyboards are usually created on a single system, the user response to the need for a tablet and a HMD was interesting. It was found that the users were happy with this setup and viewed the flexibility this introduced as a benefit. One participant noted that the two-system approach allows artists to “intuitively block things in” and that when they put on the headset, “it’s exciting to actually see [the scene]” (p2).

Participants also acknowledged that very few people can remain in a VR environment for a long period of time without feeling slightly ill. For a storyboard artist, to be immersed in a VR environment all day is impractical. It was felt that the system was a “good way to preview without using the [HMD]” (p1), and that it was actually positive that “[storyboard artists] don’t have to be in [the VR environment] the whole time” (p2).

Inquiries were made about possible problems caused by the disparity in the way viewers perceive the scene (i.e. panoramic panel on the tablet vs 3D interactive space in VR). None of the interviewees were concerned about this. It was felt that “people will start to learn the relationship between what it looks like in panorama and what it looks like in a [HMD]. Having an experienced artist using your tool, you can get pretty far just in panorama view” (p1). Further, it was stated that “once [the storyboard artists] understands the concept they can just draw, [they] don’t need to be in there.” (p4)

7.2.3 Authoring

One of the goals with the system was to allow for quick storyboard creation despite the more complex nature of VR. Participants were able to quickly generate simple content during the interviews. Figure 43 show some examples of their creations.

Inquiries were made about what users liked about the system workflow and what could be improved. General comments were positive. Abilities such as “being able to toggle back and
forth [between the panels] is awesome” (p1). It was felt, however, that there were a number of features that could be added to improve on the existing system. The thumbnail slider bar was found to be a nuisance, and that it “got in the way” (p2). The ground plane grid was found useful for a sense of spatial dimension, and similar scale feedback in the vertical dimension was suggested, as was a feature to toggle to-scale silhouettes of an “apple, person and dinosaur” (p2).

General comments about the UI included suggestions that combine interactive control of the overhead and sketch surface view. It was also noted that with complex scenes, it is difficult to isolate items in the overhead view as they often overlapped. Therefore, a “function to explode out the lines that are overlapping” (p1) would be a useful addition.

7.2.4 VR Storyboards

When starting this project, it was learned that, currently there are no such things as VR storyboards. Consequently, the system was created with both the panoramic storyboard view and the diorama storyboard view. Users seemed to prefer the panorama storyboard view: “[I] can go scene one, scene two, scene three, and just see the subtle differences” (p2) and “you can see your primary point of focus” (p1).

Several of the professionals noted that though they did not have much use for the dioramas, they could see them being useful to other departments. “I could see [dioramas] being more useful in the future… if you end up moving cameras” (p2); “I think it would be useful for other departments” (p4).

7.2.5 Collaboration

The potential for a collaborative workflow with the system was recognized by users as a significant contribution. It was felt that the system “allowed for creative collaboration where [the director and artist] were able to be in the same space and bounce things off of one another” (P4). One user stated that showing the location of the other user was “helpful ‘big time’…when you’re in the same space, it’s pretty intuitive” (p1). However, it was also noted by this user that “if you were over the phone… [it would be useful] if there were some way for a person with the headset on to stare at something” (p1) to explicitly highlight object(s) of discussion.
7.2.6 Final thoughts

The users who tried the system were very excited about its potential. Being able to try shots without having to set-up cameras for test footage, and the ability to quickly and collaboratively create and discuss ideas, were all factors that contributed to their enthusiasm. One can often measure the success of an implementation by a user’s willingness to use the system, and when interviewees were asked for their final thoughts, it was stated that, “If you had a [consumer] version ready tomorrow, we’d use it” (p1).

In some ways, the responses collected through these interviews may, at first, seem a bit simplistic, or may be perceived as if the experts had not put much thought into their responses for the questions being asked. This appearance has to do with the nature of the interviews, as the problems of early stage design for VR does not yet exist and currently has no solutions. Therefore, it is important to remember that the interviews were not conducted to determine if the approach presented was the best way, nor was it to determine what major changes needed to happen to make the system better. The primary purpose of these interviews was to validate the approach as a method that is workable, and a technique that the experts felt could be used to improve their workflow for early stage planning of virtual productions. As well, since many of the standards and rules are still being determined for working with VR, and since every studio and every project handles VR requirements uniquely, it would be difficult if not impossible to reliably suggest improvements on a system such as this through a simple demonstration and interview. The logical next steps for further evaluation would be to run a follow-up, deployment study, at which point questions on improvements to the system and UI could be discussed.

7.3 Limitations & Future Work

While the response to this prototype was very positive, there were many insightful suggestions that would improve future versions of the system, such as the following:

The system does not address the concept of stitch lines, which vary by camera-rig. Directors often film test footage to check blocking of elements. Showing stitch lines on storyboards would greatly benefit planning and layout in VR.
This system represents objects using sketch strokes. Though effective and lightweight, this approach lacks explicit mass and volume, which can be useful for planning. Combining these sketches with previs quality 3D assets is interesting future work, along with a richer set of input options while in VR. Different input techniques: bi-manual input, sketch language, augmented real 3D sketching, and visualization all provide other promising areas for future exploration.

In addition, though this chapter focused on VR stories, it is likely that this dual system approach and its planning features for 3D dynamic scenes would be useful in many other contexts such as gaming, education, architecture, and AR.

Finally, this prototype was designed with two collaborators in mind. While many of the concepts scale from two people to a full team, this system has yet to be deployed or tested in such a setting. In fact, a deployment study to observe the tool actively being used is a good next step to determine how to improve the workflow, and where to focus next.

### 7.4 Conclusion

With the consumerization of VR headsets, there is an explosion of interest in creating content for this medium. While filmmakers wish to tell stories in VR, tools to support this endeavor are next to none. Thus, this chapter contribute the first system targeted at creating storyboards for VR.

The approach that was proposed in the previous chapter was implemented and presented in this chapter. This chapter discusses this implementation and the early feedback that was elicited from professional VR storytellers on the prototype. This system was received very positively, and responses indicated that the approach provided the speed and functionality needed for early stage planning, and the artifacts to properly discuss VR films.
Chapter 8

Conclusion and Future Work

This work has explored the areas of early stage planning for stereoscopic film and virtual reality stories. The text started by establishing the fundamentals of what is involved in the art of creating storyboards, and understanding the problems with creating storyboards for stereoscopic film and virtual reality. It discussed current techniques and related work in numerous related areas. It proceeded by focusing on planning for stereoscopic film. First, differences and aspects that are unique to stereoscopic film were established, clearly defining what needs to be discussed with stereoscopic film that is often missed today. Both artistic and design considerations are discussed, followed by a proposal on how to address the problem of creating storyboards for stereoscopic productions – stereoscopic 3D depth planes. After this, an early prototype, Storeoboard, is discussed – a system that implements the concepts presented for addressing the above stated needs. The effectiveness of this system was established through validation from four different user groups, focusing on different aspects and concerns. One of these groups was the deployment of the tool on a live film production of the 3D Lumière award winning film, “40 Below and Falling”.

The stereoscopic exploration is followed by the investigation of the needs and expectations of a storyboard to discuss VR stories. The unique properties of these types of projects is elucidated from interviews conducted with professionals in the VR film making community, and films were analyzed to determine configurations of the presented audience-camera-narrative model that directors use today. From these understandings, it was apparent that a system needed to display the storyboard results in a VR setting; however, an artist needed to be able to work on a flat
surface to be able to work easily and quickly. A hybrid approach was proposed to provide a system that enabled a “best of both worlds” environment. The suggestion was to create a two-device tablet-HMD system, allowing the artist to sketch on flattened 360° stereoscopic panoramic panels, representing concentric cylinders that could thus be displayed flat, or rolled up and placed around the user. A prototype was created implementing this approach, employing a similar depth control as the one used in Storeoboard. This system was further enhanced with an overhead map similar to what is used by directors today who plan VR productions. This prototype was shown to industry professionals who provided feedback on what they felt worked, and where they felt improvements could be made; but more specifically, whether they felt this approach was workable and could improve the current systems available to them today.

Throughout this work, the goal has been to provide simple mechanisms for input and feedback to enable storyboard artists and directors to plan and discuss complex matters in early stage film for more complex environments (such as stereo enabled media). Currently, challenges specific to these modalities are often avoided or ignored during planning, as filmmakers are unaware of the problems, or are unaware of a method to discuss these challenges at the initial stages. This in turn often leads to bad decisions being made that then have to be fixed on-set or in post-production; which, consequently, all too often are never fixed at all.

8.1 Thoughts

The area of early planning for stories and film is an exciting area with much potential for different innovations and creativity. However, being an art in itself adds a layer of complexity to the challenges of planning an application to help this user group, as very rarely are there prescribed ways of doing things. This work was built on the assumption that, in fact, the more prescribed a method the more likely an artist will break the rules. Therefore, one must create and design with the goal of maintaining maximum flexibility in approach, and simply provide a mechanism to artists to envision their ideas – the more flexible the environment, the more readily it will achieve the needs of the artist. Therefore, throughout these projects, an underlying guiding principle has be to avoid a forced prescribed method of working with the tool; but rather to seek an approach so that the tool can be used as the artist or director best sees fit. The results and feedback received from the different directors, artists, and stereographers, suggests that this was the correct approach to use for the problems being solved for this thesis.
The techniques presented in this work are only first attempts at solving the problems of creating storyboards for media that is more complex than traditional film. By no means is it assumed that these approaches are the only way to achieve storyboards for stereoscopic film and virtual reality, nor are the methods used necessarily the best way to achieve the needed ends – it is simply a way that has shown to be effective, that allows for the needed discussions that are missing today. By identifying the unique factors of these environments allows one to recognize the problems that a tool such as this needs to solve, and hopefully will better help the discussions to make better films and better stories. In fact, many professionals are very excited when they see the prototypes and the potential that they promise to provide. Several directors, in fact, have asked about acquiring the product to work it into their existing pipeline.

Regardless of all the functions and features provided by these tools, in essence, the tools and these projects have been about providing a feedback mechanism for a setting that is more complex than the simple 2D environments that are easy and quick for one to use; environments with which one has become comfortable using for planning otherwise complex projects. In the case of storyboards for stereoscopic film, the slider-bar becomes a significant component to the feedback apparatus provided to the user. For this reason, an external slider (unless enhanced with a built-in display) does not achieve the needs of this situation, nor does a simple slider represented by a movable block on a vertical or horizontal line (as is common with many applications). The thumbnails in the slider provide key information, providing the feedback needed to discuss depth topics, yet allows the environment to stay essentially in 2D with which artists are accustomed to working. The VR environment benefited from a similar mechanism; however, it was found that the challenges that needed to be facilitated took a slightly different form. Despite the fact that one may need to deal with depth while working in virtual reality, it was determined by the participants that the provided feedback – the depth-slider – in VR was less useful. This seemed to be partly due to the fact that the slider-bar widget obscured part of the scene and presented an inconsistency between the world as viewed on the tablet versus the one seen while using the VR headset. In addition, contributing to this feeling seemed to be the fact that there was another mechanism presented that had the potential to, among other things, display this depth information and provide a mechanism with which depth could be manipulated. On the tablet-application of the VR project, an overhead view was introduced that allowed artist to, not only see the scene from above, but also select parts of the scene. Some of the participants
proposed that this view could also be used for depth navigation and be combined on the screen with the drawing environment. This pairing would not only allow one to navigate a scene, but also have a better understanding of the scene as a whole, since it shows the current viewing direction and the placement of all objects, including the ones not currently visible in front of the observer.

One point that was noted was that these implementations worked exactly as participants expected. Though the mechanisms are very simple, they effortlessly and effectively accomplish the task for which they were designed. One question that participants were asked was “what the tool did not do that they expected or hoped that it would do?” Numerous participants did not have anything to add, and indicated that it did exactly what they expected (and needed).

There is a question of whether storyboards will remain relevant as an art form and technique given the increased popularity and usefulness of previs. Further, the advancement in technology and artificial intelligence may one-day lead to a system that could help create images simply based on a director’s description. There are a few factors that potentially will help ensure the longevity of storyboards. Though technology is advancing at an incredible rate, it will likely still be a while before computers are fast enough and sophisticated enough to create computer sketch-like imagery in real-time based on a partial description provided by the director. For such a suggested system to be successful, it would need to work faster than an artist can capture an idea with a pencil and paper. However, providing a system is developed to interpret, search, and create images fast enough for ideation, there are other factors to creating storyboards that are still unique. The process of creating the storyboards themselves is very important, as it is very iterative with both the artist and director contributing to the discussion and adding their ideas to the determined solutions. Further, the director’s and artist’s input is based on factors that we do not yet fully understand. When creating art, all of ones’ past experiences contribute to the work being developed. Therefore, everything from an artist’s breakfast to an event in kindergarten contributes to affecting their decisions and their artistic contributions are consequently, essentially random. Many such factors contribute to the creativity of the storyboards being created, and this creativity is something we have yet to understand (not to mention replicate).

Regardless, as we become better at searching and/or generating models on the fly using a computer, drawing is still a phenomenal method to specify ideas and would provide an excellent mode of input for such a system.
Setting up a planning tool for virtual reality can be challenging since it all focuses on the experience more than the technology. Since the VR community does not necessarily, currently, understand the techniques for properly telling stories in virtual reality, it is hard to anticipate properly what is needed and what is not. Much of the film vocabulary for this media is still being defined, techniques that best capture the audiences’ attention, and ways in which to further evoke deep emotion, are all factors that are still being discovered in this relatively new experience. Yet, this fast changing modality and developing community has some very exciting potential and challenges. Since these “rules” are still being written, tools to properly discuss the needed challenges in greater depth, can help the filmmakers better understand the potential of this environment and help define further opportunities for the stories being told. While directors still find their style, and artists ameliorate their understanding to support these creative collaborations, the use cases will remain largely unknown, but still hold fascinating prospects.

In addition, the approach used with the VR system in this work treats the environment as a stack of concentric cylinders; yet this does not need to be the case. Other shaped environments could also be used. Ultimately, to use different shaped environments would require research for each of the shapes to identify the unique challenges of the suggested space; however, there are a few things to remember when discussing different environments. First, the space around the user is essentially user-centric as it radiates outwards, surrounding the user. Therefore, when using a segmented approach, shapes that have the user in the center and expand out from the middle are the most logical. This really could be any 3D shape (sphere, cylinder, cube, rectangular prism, etc.); however, the more continuous the plane of each side, the easier the space will be to work with and to understand. Second, the system is based around the idea of unwrapping the environment to make it easy for the artist to visualize and access. A cylinder was used, as it is the easiest 3D shape to visualize flat without worrying about distortion. A cube could have been used; however, the user would then have had to worry about corners due to the non-continuous nature of the shape; alternatively, a sphere or hemisphere, though continuous, would have the problem of creating an image that is easily visualized unwrapped. Yet, even with the cylinder, being able to rotate the environment might be useful, as this would make the space more diverse. For example if a scene takes place in a tunnel, a cylinder oriented along the x- or z-axis (i.e. on its side) may provide a space that is easier to use during ideation then the upright cylinder used in the current solution.
Looking forward as to how movies and stories in VR might evolve, one reasonable assumption would be a sophistication in the use of depth cues. Currently movies viewed in theaters do not respond to the individual. There is no head tracking, so the image stays essentially constant no matter where a viewer moves his or her head. Stereopsis in stereoscopic films shows a false 3D representation as the accommodation stays constant, unlike in the real world where the accommodation changes along with the vergence angle. As well, the focal length of a scene stays constant regardless of what the viewer decides to focus upon. VR addresses some of these issues, as many forms of VR provide head tracking; however, stereopsis and the focal depth remain as areas to be fully explored and developed. The techniques used in the tools presented in this work should still be applicable for media that uses new developments such as the ones listed above; however, the tools themselves would need to be adjusted to handle these new aspects.

8.2 Limitations

As with all applications, decisions were made that effect the overall functionality of each of the programs, and thus has introduced some limitations. Some of these limitations can be addressed with future research and approaches, others are inherent in the way the methods employed function.

One such limitation with both systems is that due to the segmentation of the environment, objects that are “deep”, or that span many depths (for example a gigantic whale that extends from behind the user to the far distance) is difficult to represent. This does not mean that one cannot represent these objects; it simply means that the artist must be more creative and rely more heavily on other depth cues. For example, a cube at an angle could be drawn on three different planes to give the illusion of being continuous (Figure 44). However, this is essentially a limitation of the current system.

Figure 44. An image showing the use of other depth cues to allow for the appearance of a cross-plane object.
8.2.1 Storeoboard

Storeoboard applies a method of breaking the drawing volume into a stack of transparent sheets. This works very well for providing a stereoscopic effect; it however, does have the side effect of an artifact known as cardboarding. This means that it causes images drawn on each plane to look as if they have been glued onto a piece of cardboard, which results in each depth layer appearing flat. For the sake of planning, this is not too big of a concern; however, cinematographers like to talk about volume of objects, and try to make things look as dynamic as possible. This lack of volume renders it difficult to discuss decisions that would help a scene look more continuous and full. This approach of treating the space as a stack of sheets also has the effect that one cannot draw between the planes. Though in theory, providing the ability for the artist to draw between the different planes is easy, it starts to become a larger logistical issue, as the depth slider bar is setup to mimic the information shown on each of these planes. If one starts to draw between the planes, how does one represent this “cross-depth-plane” line information? As previously mentioned in this text, not being able to draw between planes was found challenging by some artists who were trained traditionally, as their natural intuition is to draw sight and guide lines as a first step. A third limitation based on this stacked sheet approach is that one cannot change the camera angle. Since all sheets are lined up to a specific camera, changing the camera angle offsets the angle at which the lines are drawn, and consequently shows the images incorrectly. Discussion with one of the artists during an interview suggested there might be some benefit from a slight adjustment to the camera angle and position, just to provide a hint of what one might see; however, this would be very limited as an approach.

Colour is another limitation with the current decisions that have been made. First, the decision to use anaglyph limits the available colours, as many colours appear strange, cause eye strain, or shimmer (as the colour may not be visible to both eyes). Practically, this mostly limits the colours to shades of gray, with only a few exceptions (i.e. yellow is sufficiently visible to both eyes). Secondly, to help with the perception of depth, aerial perspective is applied. This means that as objects get further away, they progressively become lighter. This results in a limitation to the amount of gradient being used at any time as the colour also provides some depth information. So, one can conceivably use different shades of gray on a given plane, however, this has the potential to result in a scene where the depth is more difficult to discern due to the mixed
meanings of the gradient colour. This colour restriction is further a limitation due to the fact that storyboard artists often use oranges and blues to enhance highlights and shading within a scene, as it provides “hot” and “cold” areas to the images.

Other limitations with the Storeoboard system could be addressed with a small amount of further research. For example, the current system does not consider lens type, or take into account the effects of a specific lens. This addition could provide great value to the system while planning, as the camera lens used can make a significant difference in what a user can see, and the introduction of a lens would provide the option for depth of field (DOF) effects.

Another limitation with the current system is that it only provides one type of pen. Pen types could include factors such as different thicknesses, different textures, different shaped nibs, and different colours. This was partly by design to keep the process simple, but many of these techniques would require further research to figure out the best way to implement the tools, particularly with an anaglyph image.

The focus with Storeoboard was to enable discussions of stereoscopic content. As such, techniques to advance many different areas while creating storyboards were not overly explored. For example, the storyboard (or summary) view was kept straight forward and simple. The system shows a grid of about five panels across by three panels down. This is only one layout that is currently used by storyboard professionals. Also common is three panels across, three panels down, a freeform layout, and three panels across by two panels down. By using anaglyph, there may be unique opportunities to provide new layouts, such as overlapping images, or providing suggestions of alternate story paths. These all provide opportunity for future research.

Finally, with the approach used for this application, each panel (despite being part of a larger storyboard), is a stand-alone image. Often with storyboards, each panel is an iteration of the previous one. As such, a character that appears on one panel, likely appears on the subsequent panel. Ideally, a computer system should be able to track the different objects within a scene, and relate one panel to the next. This would allow for opportunities such as propagating colour across multiple panels, as a scene is coloured; or changing the shape of an object across multiple panels, when it is adjusted in a given panel. All these things are possible, but are a limitation of the current system.
8.2.2 Storeoboard VR

Since Storeoboard VR is built on the regular S3D version of the system, the limitations of the previous system apply to this system as well. Factors such as the lack of volume and the fact that there are no perpendicular lines across the planes (or cylinder in this case) can be considered a significant limitation. However, there are limitations that are specific to the virtual reality environment as well.

First, the system is designed for a 360° environment based around cylinders. Though this is fine for some films and devices such as Google Cardboard, not all systems use a cylindrical approach. Many programs and movies are completely immersive, meaning that a spherical environment would be more appropriate for these situations. It is likely that directors would still be able to use the cylindrical system that have been employed in this work, however, this cannot be assumed to be true. Further, since this solution supplies cylindrical walls, ideally one should be able to create a top (or ceiling) and bottom (or floor) plane. The current system does not implement these planes.

Second, due to the cylindrical nature of the presented solution, there is a curvature of all lines drawn around the vertical (or y) axis at the center of the cylinder. This is not immediately apparent, as often objects are not very wide. As well, they have been drawn to look correct from the perspective of the center of the environment. Due to these reason, the curvature is usually only apparent when the user decides to move around the virtual environment. However, even at this point, most lines are drawn at a significant enough distance from the center that the curvature is not extreme.

Third, the ground plane grid, when unwrapped renders the radial lines to appear parallel, converting the pie shape wedges into rectangles. This results in the ground plane to no longer appear as a floor surface. To aid with the illusion of the grid plane being an x-z surface, the depth lines are tapered in slightly to help with the appearance of the surface being at the given floor plane height. This does mean, however, that the alignment of the objects drawn in the scene, compared to the floor plane over which these objects are drawn is no longer accurate. Ultimately, it would need to be tested to determine if this actually causes a significant issue, as planning is
often rough in any case, but this has the potential to lead to slight distortion compared to what the artist may expect.

Fourth, another aspect that was uncovered while conducting interviews is that with stories in VR, there is the possibility of a viewer influencing the outcome of the story. It might be with something as simple as looking in an arbitrary direction at a given time, choosing to follow one character or another down a story arc, or it may take a form that is more complicated such as one might experience with a choose-your-own ending story. The current version of the system does not allow for different story arcs, or even different possible moments. The system is designed around a linear narrative and therefore, does not address this specific need. Along with choosing different story arcs, there is the concept of being able to conduct simple interactions with the environment, which can result in a change of outcome. Again, this is not currently possible with the current iteration of this system.

While using the VR headset, there were a couple of limitations that become quickly apparent. One such restriction is the ability to type while in VR. If a user wishes to add comments, or save a file, one would need to remove the VR headset, as the current VR system does not support typing in any form. One can use the stylus to write messages, but this handwriting would need to be interpreted by the system to make this a practical method for text entry. Again, this is not currently supported with this system.

Finally, a new view to discuss VR productions on a flat surface was introduced – the overhead view. An equivalent of this overhead view, however, was not included in the VR system. Whether this type of view is as necessary while in VR would need to be explored, however, the ability to view the scene from above is currently restricted to the tablet based system.

8.2.3 Fundamental Assumptions

For completeness, it should be pointed out that this work, like all work, is built upon certain fundamental assumptions. For example, it was assumed to be a truth that storyboards are actually a useful and better way to plan a production. It should be noted that not every director uses a storyboard, but for those who do, they find them very useful. Whether a storyboard is the best tool for their purpose is harder to say; however, due to the longevity of storyboards in the
industry, one has to assume that it is a useful and successful tool; one that likely would have been eliminated over the past 80 years if it had not facilitated the required needs of the many film productions that employed this technique. Many of the other fundamental assumptions used in this work are based upon artists’ beliefs. Based on artists’ feedback, this work assumes that artists prefer to work on a flat surface that provides tactile feedback, rather than waving a virtual stylus around in the air. It is also assumed that working with planes is good enough for early stage planning purposes. Storyboard artists indicated that this was sufficient, however, they also asked for the ability to tilt the camera to look at the scene from a slightly different angle. In general, it was felt that working with planes was "good enough" for the needs at the earliest planning stages.

Regarding the depth of the assets created with the Storeoboard tool, the amount of depth available to the artist was based on the discrepancies between the nearest and farthest planes. Participants never complained about the amount of depth available; however, this restriction was based on an assumption that artists would want the imagery to stay within a comfortable viewing space, where all layers can be visually fused without too much discomfort. Being an art, there is always the possibility that a director might want to purposely break this threshold, but this “purposeful discomfort” was assumed to be an anomaly rather than something that most directors would actually desire.

Finally, with the virtual reality component to this thesis, an assumption was made that it is beneficial for an artist to be able to mentally unwrap the scene and consequently the image that she is trying to create. It is conceivable that an artist could become proficient at dealing with warped volumes; however, it is felt that this would make the tool less accessible to the common user. Likewise, the VR component is built on an assumption that storyboards for VR would actually be useful. Since this is a topic that is still being explored, it is difficult to know with any certainty if this is in fact the case; however, there is a strong likelihood that this form of communication will continue to be used in some fashion based on its success and usefulness with traditional productions.
8.3 Key Lessons

This body of work has explored many different areas, attempting new innovative approaches to solve existing problems. With this type of work, there are a number of key lessons that one learns throughout the exploration. For this work, there were a number of key lessons learned for both the stereo aspect as well as the virtual reality component respectively.

Stereoscopically, it is strongly advised for a film team to start discussing stereo concepts as early as possible for the purpose of providing the most pleasing stereoscopic visual performance. Concepts such as object placement, plane separation, parallax position, convergence location, and depth budget should all be discussed from the earliest stages, which is facilitated by the work in this thesis. Similarly, storyboard artists need to have systems that work quickly, have very little setup, and provide instant feedback. The work presented in this text accommodates these needs, and the approach used (breaking the scene into a stack of transparent sheets), was one that artists learned and adapted to very quickly. Though this approach was effective, it was also found to not be appropriate for all users and situations, and some results suggest that classically trained artists who are not accustomed to dividing their scenes into regions of foreground, midground, and background may struggle more with this approach. However, it was felt by all individuals who provided feedback that the stereo storyboards presented here, have the potential to effectively enable communication for stereoscopic film concepts – something that is difficult to discuss today at the earliest stages.

Virtual reality, in contrast, has enough significant differences from traditional film that no one really knows how to plan for a VR production. This often leads teams to ask, “What would a storyboard for VR look like?” or “What is the equivalent of a storyboard in VR?”. Further, professionals are not even sure if a VR storyboard is necessary or appropriate for this medium, or whether a new type of planning tool will evolve that allows for the flexibility of a traditional storyboard. Yet, there is no argument that there are many unique VR concepts that need to be discussed and planned. Everything including, presence, blocking for a 360˚ environment, and the need to guide an audience's attention are all factors that cannot be ignored. This problem is, however, even more challenging than dealing with traditional media, due to the fact that artists and the rest of the film team have different needs. Artists like to work on flat surfaces (ideally
outside of the VR environment), while film teams need to be able to see the scene in VR as quickly as possible to make appropriate decisions. The synchronized multi-device approach developed in this work shows promise, and seems to work effectively to enable both groups of users (artists and directors). Further, it enables these team members to properly discuss the projects being developed through both synchronous and asynchronous workflows. The approach of unwrapping the VR scene into stereoscopic panoramic panels to allow for discussions involving both the 360° surrounding scene and the depth components of a production, both in VR and on a tablet surface, was deemed effective. Though this unwrapping can cause slight distortion, this was viewed as a negligible issue for early stage discussions. Finally, the diorama view of storyboard moments was viewed as an interesting approach, but directors seemed unsure how to effectively use this presentation style at the earliest stages of production. Regardless, these techniques challenge the way projects are developed today, and excite professionals with the potential the presented approaches promises for future projects.

8.4 Future Work

Since the purpose of the projects presented in this work was to establish techniques that do not currently exist – methods for quickly creating sketches to enable early discussions for both stereoscopic and virtual reality environments – the work projects presented here have only started to uncovered all the possibilities that tools such as these can potentially provide.

8.4.1 Storeoboard

With Storeoboard, basic functionality was provided; however, there are many features that are not present. For instance, since the system simply adds lines rather than geometric shapes, objects drawn by artists are consequently see-through. This fact led many artists to asking for the ability to fill in shapes and thus create occlusions. Along with this, simply being able to draw some 2D primitives could speed up the drawing process and deal with the occlusion issue. Extrapolating on this concept, one could also introduce the ability to add volume to drawings, either through 3D primitives or through a fill mechanism. Other features such as stroke neatening could also be interesting to some artists.
Another feature that could be useful is paring the stereoscopic nature of the image displayed with the presence of stereo glasses. In this manner, the artist could put on the glasses to see the image in stereo, or remove them to work with a 2D image, possibly providing the ability to tilt the device to explore the depth of the image through other depth cues such as parallax. This 3D visualization, instead of the stereoscopic version, could also help reduce visual fatigue that many users experience with stereo.

The storyboard view is another area that could be further explored. For instance, this system displays a grid approximately 5 panels wide by 3 panels high. Different artists like to work with different layouts, such as only 1 panel wide, but 3 panels high, or 4 panels wide by 3 panels high. Further, some artists will draw a larger image, then mark key panels on that larger image (i.e. Figure 8B). Supporting these different configurations has potential for exploration, as well as storing different images for a given panel (or sequence of panels).

The current system provides a crude flipbook style animation. However, this only animates the image, and requires all the in-between frames to be drawn by the artist. Progressing from basic storyboards, animatics is the next logical step, which is the process of creating crude animation from the storyboard stills. Whether this is created in conjunction with the stills, or as a process after the fact would need to be decided, but provides exiting opportunities. This would also necessitate the ability to support sound for voice tracks and potential sound tracks.

This naturally leads to a larger study on how these stereoscopic storyboards might be integrated into other aspects of film production such as sound editing, set design and cinematography. The stereographer consulted during this work noted that “currently it’s a planning tool…I’d like to see it become a delivery tool”. By this comment, he meant that there’s opportunity to further work this type of tool into other aspects of film, not just the early stage planning; but to better integrate it into what happens on-set (possibly aligning with other on-set assets) and follow it into post-production.

Finally, due to the current popularity of stereo 3D systems and this being the first early stage stereo communication tool that has been worked into an existing workflow, there are many opportunities for this technique and approach not only for film, but games and product design (e.g. Broy, 2014) as well.
8.4.2 StoreoboardVR

Many of the future work suggestions for Storeoboard apply to StoreoboardVR as well; however, there are some areas that are specific to this VR version. For instance, this system does not currently address the concept of stitch lines. These vary according to the camera rig that is employed by the director. Directors shooting live video often must film test footage to check blocking of scene elements before embarking on the actual film. Visualizing stitch lines during the storyboard phase has the potential to greatly benefit planning and layout for a VR film.

One of the unique features with VR is that a user can potentially interact with the story. This can either be directly by making a choice, or indirectly by simply looking in a given direction or walking to a specific spot. Whatever the cause of these different story arcs, supporting the ability to plan for different paths has interesting implications that would be fascinating to explore in the future. An approach to implementing this in a film-setting has already been suggested by VisionaryVR [Visionary VR], and ILMxLab [ILMxLab] has looked at systems where the viewer can follow any character in a story. Yet, there is still the problem of how one plans for these different experiences.

One design decision that was made with StoreoboardVR was to treat the environment as a stack of concentric cylinders. This results in a setup that is ideal for 360° video; however, many VR stories and films are shot for fully immersive environments. This would suggest that a sphere (or at least a semi-sphere) might be a better match for this type of environment, which has its own design and interaction challenges compared to the cylindrical solution that was presented in this text.

In addition, like with Storeoboard, this system represents objects using sketch strokes. Though effective and lightweight, this method lacks explicit mass and volume, which is potentially more of a problem in VR than in stereo. Combining the sketches with previs quality 3D assets represents interesting potential future work, along with a richer set of input options while in VR. Different input techniques: bi-manual input, sketch language, augmented real 3D sketching, and visualization all provide other promising areas for future exploration.
As well, though StoreoboardVR focused on VR stories, it is believed that the dual system approach and its planning features for 3D dynamic scenes would be useful in many other contexts such as gaming, education, architecture, and AR.

Finally, the StoreoboardVR prototype was designed with two collaborators in mind. While many of the concepts scale from two people to a full team, it is yet to be deployed or tested in such a setting. In fact, a deployment study to observe the tool actively being used is a good next step to determine how to improve the workflow, and where to focus next.

8.4.3 General

There are also numerous areas one could explore that could be applied to either system. With storyboards, there are numerous symbols that belong to the vocabulary that imparts meaning to the panels. For example, it is common for one to use arrows that overlap the border around the image to demonstrate movement of the camera. As well, one often uses arrows within the image to show movement of characters and objects. These arrows may be shown as 2D representations or 3D representations depending on the intent of the arrow. One area of possible work is: if one can interpret the action or motion of an object from one panel to the next, one could attempt to automatically annotate a scene with arrows. Likewise, if one could recognize the movement of the camera from panel to panel, one could try to annotate the camera motion on each panel.

In generally, many of these arrows and other annotations easily carry over from traditional film to stereoscopic film and VR; however, it is likely that these annotations will evolve with these new film mediums. Since these different film techniques have unique challenges, it is very likely that there are motions and actions that storyboards need to communicate that are not easily shown with current techniques. With the Storeoboard program that was used on the live action film shoot, it seemed that certain standards develop. For example, arrows to indicate camera motion were always drawn on the top most plane with the arrows breaking the storyboard sketch border. Arrows for character and object action were usually drawn on a separate depth plane, just above the object for which they were augmenting. It is reasonable to assume that small changes like these will be how the stereoscopic storyboard nomenclature starts to evolve, and in this process, new uses and needs may become apparent.
VR, in contrast, will likely continue to use many of the traditional techniques; however, the VR environment has many unique qualities that are drastically different from traditional film; factors such as the surrounding environment and the need to consider presence. As such, there is a higher likelihood that the current symbols used today do not cover all the intentions that need to be communicated. For example, how does one indicate that the user needs to turn around, or that an object is being introduced from behind the audience viewing the story? As such, this area will likely continue to evolve for the foreseeable future, while discussions and rules for this domain are being discerned.

Another area that would be interesting is, since each panel represents a moment in a scene, it may be possible to slowly build up a 3D environment based on the sketches in a storyboard, if the relationship between each panel can be determined. Through this manner, one could quickly build 3D models from the simple 2D sketches that an artist creates for the film under regular circumstances.

Expanding this work to apply it to areas such as artificial reality (AR), or other display formats such as volumetric displays should also be possible. One would need to account for factors that are unique to the different mediums; however, many of the principles would still apply. Displays such as volumetric displays would be slightly different in that the view being discussed would not necessarily be user-centric, or the shape of the viewing volume may be unique, so constraints specific to the desired hardware would need to be introduced. In principle, however, segmenting a space to discuss different depths should be applicable to these displays. With AR, the main difference would be that instead of working on a blank canvas, the artist would be working on a scene that already exists. Therefore, one would likely want to impose an image of the surrounding environment and include information that could be pulled from a depth map of the space. Further, one would likely want to introduce occlusions from the objects that already exist within the workspace. In principle, however, it is reasonable to assume that systems such as the ones presented in this work could be applied to augmented reality and other viewing formats.

Finally, in general, each of the two projects presented in this work could be expanded upon by exploring the areas of animatics – fast animations with the use of storyboard panels, as well as a more complex, “traditional” animation – providing key frames, tweening, resizing, and effects.
In addition, camera effects such as depth-of-field, and different lens types could improve the systems as it is currently presented.

8.5 Conclusion

This work has endeavored to understand the needs of the storyboard artist while creating early stage images and conceptualizations for film productions. These needs have been explored, extrapolated and expanded to include stereoscopic and virtual reality productions, based on the needs of the film medium and the directors who create content for these genres. From these understandings and constraints, feedback mechanisms were developed and tested to enable artists to work directly in virtual and stereoscopic environments at (or close to) the speeds with which they are familiar while working on regular film projects. The mechanism developed for stereoscopic film helped the film team successfully plan the stereoscopy of the 3D Lumière award winning film “40 Below and Falling”. Though not tested on a live production, the mechanism for VR has been very favorably viewed by professionals in the industry. Each of these techniques shows promise for their respective film areas and are approaches that are worthy of further development and exploration.
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Appendix A

The following is the definition of Previs as listed in “The VES Handbook of Visual Effects” [Zwerman, 2014] generated by the subcommittee on Previsualization, a collaboration between the Visual Effects Society (VES), the Art Director’s Guild (ADG), and the American Society of Cinematographers (ASC):

Previs is a collaborative process that generates preliminary versions of shots or sequences, predominantly using 3D animation tools and a virtual environment. It enables filmmakers to visually explore creative ideas, plan technical solutions, and communicate a shared vision for efficient production.

The reference to filmmakers include anyone performing visual storytelling for movies, television, games, and other related media.

The same committee recognized a number of subgenres of previs in current practices:

- **Pitchvis** illustrates the potential of a project before it has been fully funded or greenlit. As part of development, these sequences are conceptual, to be refined or replaced during pre-production. (Although pitchvis is not part of the main production process, it allows people like executives and investors to take a first look at the potential result.)
- **Technical previs** incorporates and generates accurate camera, lighting, design and scene layout information to help define production requirements. This often takes the form of dimensional diagrams that illustrate how particular shots can be accomplished, using real-
world terms and measurements. (In good practice, even preliminary previs is most often based on accurate real-world data, allowing technical data to be more easily derived.)

- **On-set previs** creates real-time (or near real-time) visualizations on location to help the director, VFX Supervisor, and crew quickly evaluate captured imagery. This includes the use of techniques that can synchronize and composite live photography with 2D or 3D virtual elements for immediate visual feedback.

- **Postvis** combines digital elements and production photography to validate footage selection, provide placeholder shots for editorial, and refine effects design. Edits incorporating postvis sequences are often shown to test audiences for feedback, and to producers and visual effects vendors for planning and budgeting.

- **D-vis** (design visualization) utilizes a virtual framework in pre-production that allows for early in-depth design collaboration between the filmmakers. Before shots are developed, d-vis provides a preliminary, accurate virtual design space within which production requirements can be tested, and locations can be scouted. Approved design assets are created and made available to other previs processes.
The programs written for this thesis were written in C++ using openGL to handle the image processing; and each of these programs draws stereoscopic images to the screen. There are many websites that discuss how to achieve stereoscopic rendering for openGL, but the main website consulted, which includes an extensive explanation, can be found here: 
http://www.animesh.me/2011/05/rendering-3d-anaglyph-in-opengl.html and was last retrieved on June 7th, 2016.

In the code, a camera class was created to handle view frustums and other camera functionality. This camera class had a number of key member variables storing environment specific values for the purpose of rendering the stereo scene. These measurements were all handled in centimeters or degrees. The member variables include the following:

- `m_near`: the location of the near plane for the given camera (i.e. 80cm)
- `m_far`: the location of the far plane for the given camera (i.e. 100 cm)
- `m_fov`: the field of view for the camera (i.e. 23 deg)
- `m_aspect_ratio`: the aspect ratio of the screen (generally [width of screen] / [height of screen] – i.e. 1920/1200 = 1.6)
- `m_convergence`: the convergence location for the stereo image (i.e. 90 cm)
- `m_eye_separation`: the inter-axial distance between the two cameras (i.e. 6.4 cm)

The following code also refers to a local variable indicating which camera was being rendered.

- `camera_left`: a boolean flag indicating whether the left or right “eye” (or camera) was being rendered. “True” represents the left camera; “false” represents the right.
The code is as follows:

```c
// switch to projection mode
glMatrixMode(GL_PROJECTION);
glLoadIdentity();

float top, bottom, left, right;

// set the top and bottom frustum location
top = (float) this->m_near * tan(this->m_fov/2);
bottom = -top;

// calculate the location of the left and right frustum plane
float a = this->m_aspect_ratio * tan(this->m_fov/2) * this->m_convergence;
float b = a - this->m_eye_separation/2;
float c = a + this->m_eye_separation/2;

float scale_factor = (float)(this->m_near/this->m_convergence);
if(camera_left)
{
    left = -b * scale_factor;
    right = c * scale_factor;
}
else
{
    left = -c * scale_factor;
    right = b * scale_factor;
}

// set the view frustum
glFrustum(left, right, bottom, top, this->m_near, this->m_far);

// translate the camera view according to left/right eye
if(camera_left)
    glTranslatef(this->m_eye_separation/2, 0.0f, 0.0f);
else
    glTranslatef(-this->m_eye_separation/2, 0.0f, 0.0f);

// switch back to model mode
glMatrixMode(GL_MODELVIEW);
glLoadIdentity();
```
Appendix C

With the development of Storeoboard (Chapter 3 & Chapter 4), validation and feedback was sought over multiple sessions from four different groups. The groups consisted of a professional storyboard artist who was consulted on three separate occasions over the development of the program (S0), a validation session was held with a focus group of 3rd and 4th year students at Sheridan College studying to become professional storyboard artists (S1-9), semi-structured interviews were held with industry professionals who work with stereo 3D film (S2-6), and the tool was deployed on the 3D Lumière, award winning feature film “40 Below and Falling” (S3).

All of the following examples are anaglyph images created using the Storeoboard system by three of these different feedback groups. These images are meant to be viewed with red/cyan anaglyph glasses.
Images

1. Participant: S0 (Professional Storyboard Artist)

![Image 1](image1.png)

2. Participant: S0 (Professional Storyboard Artist)

![Image 2](image2.png)
3. Participant: S0 (Professional Storyboard Artist)

4. Participant: S0 (Professional Storyboard Artist)
5. Participant: S0 (Professional Storyboard Artist)

6. Participant: S0 (Professional Storyboard Artist)
7. Participant: S1₅ (Storyboard Instructor)

8. Participant: S1₂ (Storyboard Instructor)
9. Participant: S1₅ (Storyboard Instructor)

10. Participant: S1₃ (Storyboard Student)
11. Participant: S0 (Professional Storyboard Artist)

![Image](image1.png)

12. Participant: S0 (Professional Storyboard Artist)

![Image](image2.png)
Sequences

13. Participant: S14 (Storyboard Student)

14. Participant: S17 (Storyboard Student)

15. Participant: S18 (Storyboard Student)

16. Participant: S14 (Storyboard Student)

17. Participant: S0 (Professional Storyboard Artist)
18. Participant: S0 (Professional Storyboard Artist)

19. Participant: S0 (Professional Storyboard Artist)

20. Participant: S0 (Professional Storyboard Artist)
40 Below and Falling – Movie

(Storyboard courtesy of 12pt Media)
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NBC Universal: Figure 3, Figure 8B, Figure 8C, Figure 8D

Ron Doucet: Figure 7, Figure 8A, Figure 8E

Wee Biz Studios: Figure 35