VIRTUAL *UNREAL*ITY: EXPLORING ALTERNATIVE VISUALIZATION TECHNIQUES FOR VIRTUAL REALITY

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Virtual Reality (VR) offers new ways to perceive and interact with virtual content. Apart from photo-realism, VR can be used to explore new ways of visualization and interaction. In this contribution, we describe two student projects, which focused on creating innovative concepts for an artistic VR experience. We provide a review of sources of inspiration ranging from standard NPR-techniques through movies, interactive artworks and games to phenomena of human perception. Based on this wide collection of material we describe the prototypes, and discuss observations during implementation and from user feedback. Finally, possible future directions to use the potential of VR as a tool for novel, artful and unconventional experiences are discussed.

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1 INTRODUCTION

From the beginning, the ultimate goal of computer graphics has always been to achieve photographic quality when rendering. The virtual camera model, which forms the foundation for virtual image generation, represents a simulation of a real camera — even parameterizations such as aperture, focal length and artefacts like lens flare or motion blur have been established as standard techniques in the field of computer graphics. Over time, artists and scientists questioned this dogmatic approach and developed the field of non-photorealistic rendering (NPR, cf. Fig. 5) as counterpoint. Gooch and Gooch argue that NPR offers several advantages for visualizing information by emphasizing specific aspects. They use the example of a picture of a sailboat: "From such a photograph a viewer can infer a vast amount of information such as the time of day, the weather, wind direction and speed [...]. However, such an image would be of little use to someone attempting to build a sailboat." (Gooch and Gooch 2001). They argue that NPR brings together art and science by using abstraction methods to emphasize the message communicated by an image. This makes NPR a valuable tool for both scientific visualization and artistic expressiveness. Especially when trying to achieve an artistic look and feel of computer generated imagery, NPR techniques, mimicking traditional painting effects such as brush, ink or pencil strokes, are applied as "post-process" to the rendered image.

With the current excitement about Virtual Reality (VR), especially in terms of its applicability on the mass market, the underlying rendering techniques again focus on achieving photorealism. But virtuality is capable of more than just the plain reproduction of reality. Using VR, we can create illusions, manipulate the user's perception, play with expectations. Virtual environments do not necessarily need to simulate real world physics, instead they can go beyond the boundaries of these rules, simply following the imagination. Regarding alternative rendering techniques, the question arises: What happens if we apply the ideas of NPR to VR? Usually, NPR techniques resemble the methods, look and feel of classical painting and sketching disciplines and are applied to 2D imagery - the imitation and the original are structurally comparable. With computer graphics you can apply these painterly effects not only to stills but also to animated or even interactive imagery. This reveals specific characteristics that are unique to NPR, e.g. the dynamics of brush texture in an animation (Meier 1996, Gooch and Gooch 2001, Hertzmann and Perlin 2000). If we enter the interactive three-dimensional space, what additional

effects occur when using these inherently two-dimensional stylistic elements? What happens if techniques like NPR or multi-perspective rendering are used in VR? How do users perceive an interactive abstraction of the real world? How does it feel when specific elements of the environment are hidden from the users (visual) perception? Can we use sensory illusions to build surrealistic experiences?

In the following, we describe two student projects which aimed to explore the potential of NPR techniques, abstraction and sensory illusions in the context of VR, especially when using an Oculus Rift (OculusVR 2015). The first project focused on the applicability of stylistic elements derived from visual patterns utilised in comics, such as Cel Shading, text and speech visualization or motion lines. The second prototype explored the effect of a reduced visual perception of a realistic environment by presenting a completely white scene, in which the user solely relies on shadows (including his own dynamic shadow) to identify objects. Based on the experiences and observations during the project we want to show some of the opportunities and pitfalls of using NPR-techniques in the context of VR.

2 RELATED WORK

The prototypes developed are basically inspired by three areas of research: *human perception*, especially spatial illusions and use of light and shadow, stylistic elements utilised in *comics* and finally concepts derived from *Non-Photorealistic Rendering* techniques. In the following section we want to give a short overview of several visual techniques and their applicability in the context of VR, which can also serve as a source of inspiration for future work.

HUMAN PERCEPTION AND OPTICAL ILLUSIONS

One source of inspiration were the spatial illusions created by *M. C. Escher* (Escher 2001). These 2D drawings use the laws of perspective and the ambiguity of 2D projections of 3D objects to create impossible objects. Therefore, these constructions only work from a specific point of view. If used in a dynamic environment where the user can change its point of view, the illusion collapses (Fig. 1, Nolan 2010). However, depending on the type of projection and interaction, the concept of spatial illusions can be employed to create spatial puzzles with unconventional effects (Ustwo 2014, Fig. 1).

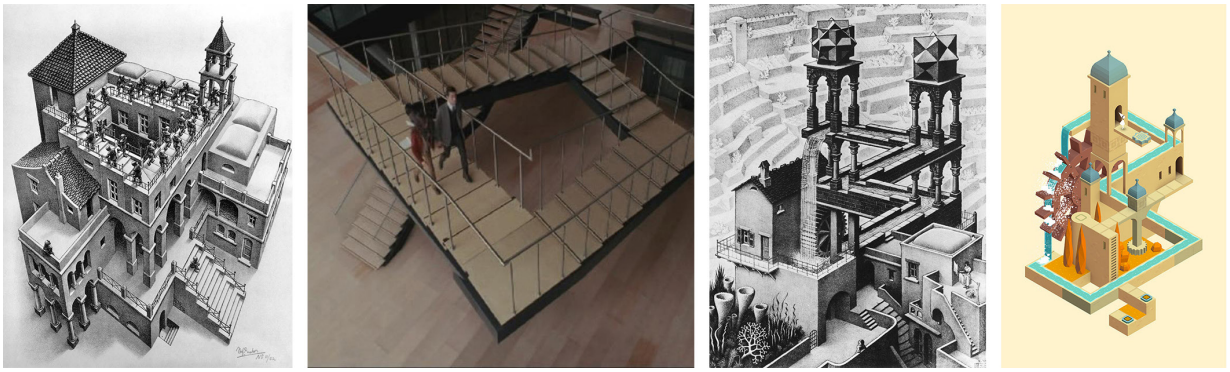

Fig. 1. *Escher* drawing of so-called Penrose Stairs (Escher 2001) and the optical illusion constructed in the movie *Inception* (Nolan 2010) (left). Impossible waterfall (Escher 2001) and its adaptation in the game *Monument Valley* (ustwo 2014) using isometric projection (right).

Besides spatial illusions, the role of light and shadow for human perception and their use in movies and interactive media were investigated. In the genre *Film Noir* the shadow is used in many ways. On one hand great dark areas provide the illusion of a safe area where the actor can hide his appearance. On the other hand, the same areas can represent danger because of the unknown that could hide in this area. Shadows are also used to predict the character's destiny, e.g. shadows of a grid on the actor's face. Shadows can also represent an actor who is off-stage (Place and Peterson 1974). Providing small lit areas during a pursuit in which shadows run through the image provide a very dynamic illusion. The shadow as *third man* can represent death, e.g. Nosferatu's shadow creeping upstairs into Ellen's Chamber (Murnau 1922), destiny (the silhouettes of both characters disappear in the fog—so their destiny remains unknown, (Lewis 1955)) or the ambiguity of characters (demonic shadows appear behind the suspect on a wall after he collapses (Siodmak 1944)).

Fig. 2. Shadow cast during a pursuit in the streets of Vienna (*The Third Man* (Reed 1949)) (left). Silhouettes of actors providing an unknown destiny (*The Big Combo* (Lewis 1955)) (center). Orloc creeping off-play up the stairs (*Nosferatu* (Murnau 1922)) (right).

Inspired by the *Film Noir* genre, modern movies like *Sin City* added highlighting and NPR to create a comic-like environment (Miller 2005). The computer game *White Night* (Osome Studios 2015) adapted those ideas and reduced the grayscale into black and white, resulting in an even more threatening environment. Regarding light and shadow, another environmental effect served as inspiration: the so-called *whiteout*. This describes a

weather phenomenon which occurs mostly in arctic or desert regions. Particles in the air (fog, snow, smoke, sand) are absorbing and reflecting light leading to an extremely low contrast between objects and background (Schlichting et al. 1980). Additionally, in arctic regions snow and low cloud cover reflect light as well. Consequently, the distribution of light seems to have no difference in a full 360° view around the spectator. The main effect is that orientation is lost and size estimations of objects are extremely difficult, which also affects depth perception. As a result, small objects near the spectator can be misinterpreted as big ones far away (Goldstein 2009).

Fig. 3. Whiteout painted with black bubbles (The Unfinished Swan, Giant Sparrow 2012) (left). Small spotlight and a black/white reduced environment (White Night, Osome Studios 2015) (right).

This effect can be employed to create new concepts to explore an unknown environment. The computer game *The Unfinished Swan* (Giant Sparrow 2012) puts the player in a completely white environment. The only way to discover surrounding objects is to shoot black ink bubbles into the void. When these bubbles collide with objects they burst and a blur of colour remains. In this way, the player can reveal the environment and is able to recognize objects, their size and find a way through the level.

STYLISTIC ELEMENTS OF COMICS

As mentioned before, the simulation of artistic patterns is a key component of NPR to render images. However, the cartoon style supports a more suggestive and stylized way of rendering and is characterized by a typically non-realistic representation, heavy outlines and Cel Shading (Decaudin 1996). In addition to the well-known cartoon shading, *McCloud* described the Comic as spatially arranged sequences, pictorial or other characters that convey information or generate an aesthetic effect on the viewer (McCloud 2001). The sequences are usually arranged to form a 2D layout, a panel or gutter, and within these spatial arranged sequences typical comic elements are placed to communicate certain activities within the frames. These comic elements commonly imply speech balloons, captions, onomatopoeia (words that mimic sound).

Fig. 4. Examples for the usage of stylistic elements from comics in the video game *XIII* (Southend 2003).

The computer game *XIII* (Southend 2003) employed the stylistic elements found in comics to create a unique experience for the user and combines the narrative 2D panel structure with 3D interaction. While the level of detail in this particular game is quite detailed, other examples may differ in line thickness, degree of abstraction, shading intensity, symbolism and proximity to real faces. Additionally, *XIII* uses onomatopoeia as gameplay element, e.g. by visualizing the movement sounds of enemies behind walls with differently scaled texts (Fig. 4). Furthermore, *McCloud* also introduced a concept of time in comics which is characterized by a single movement in a single panel. The identified categories range from moment-to-moment transitions that picture the blink of an eye over scene-to-scene transitions to illustrate significant distances of time like time skips to non-sequitur that offer no logical relationships between panels. For the perception of time and movement the layout and arrangement of panels is of great importance. The gap between the panels as well as the gap in time is filled by the viewer's mind, creating an illusion of motion and time. (McCloud 2001) Basically, time in comics is perceived spatially. The gap in time between panels varies, some transitions may be shorter while others depict a bigger time leap. Besides this, different graphics, figures and panel forms thereby affect the impression of narrated time.

NON-PHOTOREALISTIC RENDERING

Contrary to the strong trend towards photorealism in computer-generated images, Gooch and Gooch stated that images generated by artists can provide the user with information that may not have been apparent at first glance (Gooch and Gooch, 2001), which serves as motivation for the exploration of NPR techniques. A large number of publications investigates technical ways to simulate artistic styles such as pen-and-ink, water-colouring and pencil sketches as well as cartoon styles (Lake et al. 2000, Hays and Essa 2004, Tateosian 2006, Spindler et al. 2006). Especially when rich brush texturing is applied to an image, several issues with animated or interactive content arise, specifically regarding the frame-per-frame blending of brush strokes and textures

(Meier 1996, Hertzmann and Perlin 2000, O'Donovan and Hertzmann 2012). However, this effect can also be used to emphasize movement in animations (Vrellis 2014, cf. Fig. 5).

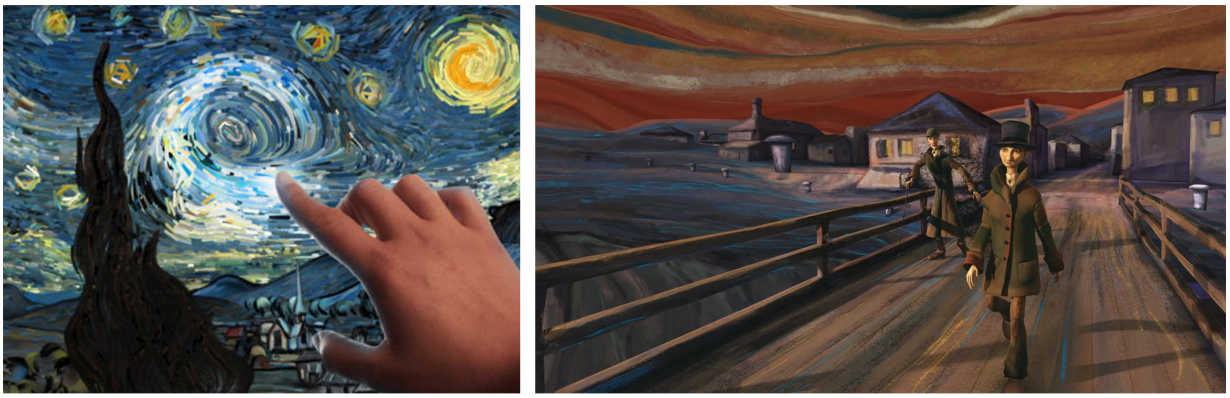

Fig. 5. Examples for animated or interactive NPR artworks. The iOS app *Starry Night* resembles the painting by *Vincent van Gogh* (Vrellis 2014) (left). The short movie *The Scream* imitates the style of the painting by *Edvard Munch* (Cosor 2011) (right).

Techniques resembling NPR are also adapted to movies, especially for intro sequences or credits, e.g. Sherlock Holmes (Ritchie 2009). One popular effect visualizes the transition from a realistic object or person to painted representation or vice versa. In interactive media, NPR has not been used extensively so far. However, there are some examples that use artistic rendering to achieve specific effects. One example is the app *Starry Night* (Vrellis 2014), where the unique style of brush strokes can be controlled by touch gestures leading to a quite psychedelic effect. Another example is a quest from the role-playing game *The Elder Scrolls IV: Oblivion* (Bethesda 2006) in which the user *enters* a physical painting. In this parallel dimension everything has a painterly look (cf. Fig. 6).

Fig. 6. Use of painterly effects in movie sequences (Ritchie 2009) (left) and as a storytelling element in games (Bethesda 2009) (right).

On the contrary, NPR techniques are employed in the context of scientific visualization. NPR can be used to emphasize specific aspects to interpret data, support orientation or find patterns or correlations in large multi-dimensional data sets. Additionally, it also has an aesthetic aspect which aims at increasing engagement and communication of complex subjects (Tateosian 2006). Biedermann and Ju found that the absence of full details and

textures is not of importance for the determination of a visual representation of an object (Biedermann and Ju 1988). The human visual adaptability to recognize objects based on simple line drawing can help to focus on important properties in a virtual scenery. To offer additional value, disturbing details may be omitted and the user can concentrate on the essentials. For instance, this approach is used in astronomic visualizations, the so-called false-colour images, where different shades of grey are coloured to make them more distinguishable and more appealing to the audience (Czolpinski and Babul 2005). Another example are volumetric models which use transparency and depth-based colouring to emphasize the spatial structure of the model (Xia, Zeng and Wang 2013).

Apart from colour and line, perspective plays an important role in virtual environments. Multi-perspective renderings, inspired by arts, offer new ways to perceive a virtual scene (Agarawala, Zorin and Munzner 2000). Furthermore, concepts employed in cubist art, use the fusion of multiple perspectives as narrative (Glassner 2004). Most of these concepts are applied to static images - the adaptation to interactive virtual environments remains an open research question.

3 PROTOTYPICAL IMPLEMENTATION

The intention of NPR settings in a virtual environment is to communicate effectively instead of focusing on the imaging process. Driven by human perception it rather creates illusions of reality than mimicking reality. The aforementioned works showcase the different opportunities to create innovative, unconventional (mainly visual) experiences. As part of a student project, we created two prototypes using the *Oculus Rift DK2* (OculusVR 2015) to explore these effects in the context of VR.

COMIC

The comic prototype focuses on the research results regarding the stylistic elements of comic and its effect on the user (cf. section 2). The basic idea was to use isolated sketches and arrange them in form of a storyboard to create a coherent scenario. We investigated how comic elements could be implemented in a three-dimensional virtual environment to create an immersive comic experience. However, the basic concept of a comic is the two-dimensional spatial combination of panels to create a storyline. Panels are the backbone of a comic and as such they should act in the implemented showcase. Being able to shift among the individual comic panels was a main objective for the interaction concept.

Theme	Concept
Sky	The main ambition was to create a non-photorealistic surrounding. Hence, most texture assets are hand-drawn in order to obtain cartoon styles. As the user steps forward, a *hole* in the ground becomes visible represented by a black panel frame to indicate being located in a comic frame.
Winter	A black border is created around the viewport to illustrate the user's fall *inside the panel* (cf. Fig. 7). When the user moves *forward* through the panels, motion lines appear. Once the user navigates backwards a fade to black effect will appear. This was incorporated to create a narrative structure to illustrate the sequential flow.
Friends	In this scenery three dimensional objects are placed and rendered with Cel Shading to emphasize their comic look (cf. Fig. 7). The user has the possibility to switch between different visualization techniques of the conversation: • 2D speech balloons connected with lines • looping speech balloons • 2D speech balloons turning to the user • 2D speech balloons with a view control • 3D speech balloons connected with lines
Desert	The user can trigger a looping 2D and control it by his view direction, highlighting the concept of spatial reading established by *McCloud* (McCloud 2001). When moving the head from left to right, the animation plays according to the view direction.
Forest	Initially, the objects are displayed as cardboard stand-ups with two-dimensional surfaces placed in a three-dimensional room. To visualize different visual effects one can switch between two-dimensional and three-dimensional objects inside this panel room displayed by a cross-fading from 2D to 3D.

Table 1. Concepts of the different rooms in the comic prototype.

Simple compounds were used for the panel transitions such as motion lines and cross-fading. Inside the panels itself simple objects are shown as a still life in 3D with simple geometric objects that offer variations and individual comic elements inspired by *McCloud* (McCloud 2001). Each panel is resembles a three-dimensional room filled with different comic specific elements and stylistic environments wherein the user can move around to explore the scenery. The different comic effects adopted in the prototype are explained in Table 1.

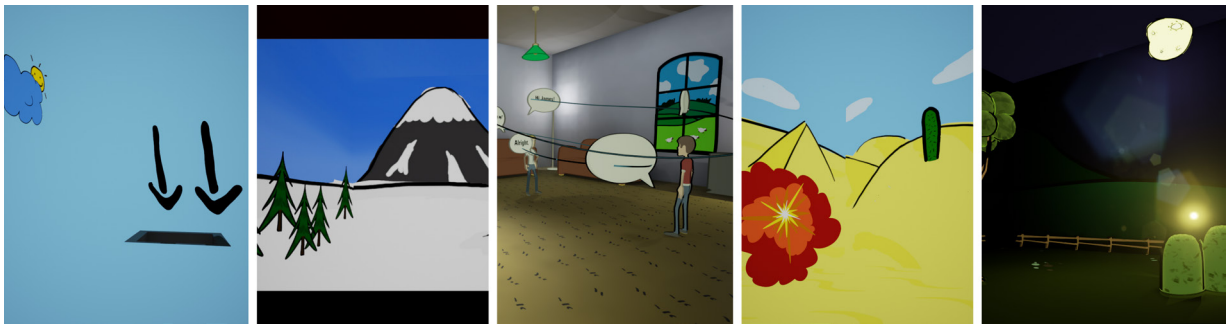

Fig. 7. From left to right: *Sky* theme with start panel. *Winter* theme with bold frame. *Friends* theme showing effects for speech balloons. *Desert* theme showing the animation. *Forest* theme illustrating three-dimensional objects.

WHITE SHADOW

White shadow is an explorative game in which the user discovers his environment and solves puzzles in a perceptionally reduced scenario. The name was chosen to illustrate its two main concepts. Initially, the user is put into a complete white world resembling the whiteout phenomenon mentioned in section 2. All objects (walls and obstacles) are white and don't cast shadows, resulting in an *overexposed* visual experience. The second aspect includes the shadow cast by the user or specific objects that represent the only available source of information about the environment. Therefore, the only possibility to navigate and explore the environment is the interaction of the shadow with the surrounding objects. Using the shadow, obstacles can be discovered, identified and avoided. Applying this method of interaction, the user navigates through his surroundings, gradually building a mental map of his environment, and tries to reach a predefined target area.

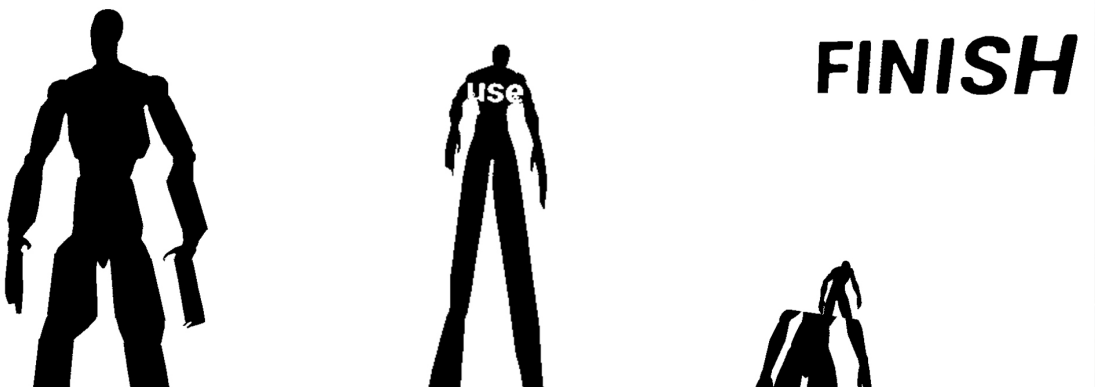

Fig. 8. Players shadow deformed by stairs (left). Hidden messages can be detected by exploring the environment (center). The finishing area of a level is blocked by a pit. The user must interact with obstacles to reach the other side (right).

We investigated several variations of the concept by modifying the shadow and its characteristics. One concept is using the *Oculus Rift* as input to control the shadow (*Oculus Controlled Shadow*). The shadow moves according to the head movement and rotation, similar to a light source positioned near the user's head. When leaning forwards, the shadow becomes shorter,

when leaning in the opposite direction, it becomes longer. Another concept is to control the shadow with an external input device (*User Controlled Shadow*), comparable to a light source behind the user which can be moved and rotated in any direction and changes the direction and length of the shadow the user is casting. In this concept, the user is able to create the shadow and modify its characteristics at any time to facilitate the perception of the environment. The third concept was to manipulate the shadow due to the user movement through the world (*Environment Controlled Shadow*). Shadow casting light sources are placed at different positions in the level. Length and rotation of the shadow depends on the position of the user relative to the light source. This interaction provides an intuitive interaction with the environment because the shadow cast acts in the familiar natural manner. Using environment-controlled shadow offers additional benefits. Using multiple light sources allows for play with penumbras, shadow intersections, different intensities of light sources and shadows as well as movement of light sources and shadows, e.g. a shadow cast by a swinging (and maybe rotating) lantern. This leads to several unusual effects to be discovered by the user.

White Shadow is divided into several levels, in which the user can explore different aspects of interaction. All levels have fixed boundaries to avoid the user getting lost. At the start of each level the environment is lit normally. Via a dolly shot from the finish to the starting point the user can see the route to the target area. When the camera arrives at the starting point the visual representation changes into the whiteout and the user has to find the way to the finish. Additionally, hints are hidden in-game, e.g. when the user has to find a passage through a wall on the right side of the room, a small text message is placed on the left wall saying »try right«. The user can reveal these hidden messages by interacting with his shadow (cf. Fig. 8).

The initial level contains a mace the user can explore. The main idea is, that the user has the opportunity to adapt to this unknown situation. Therefore, walking and looking around are the only possible interactions. Small hints appear when the shadow is cast onto specific objects, like small instructions or arrows to facilitate the task of finding the exit of the maze. The subsequent levels have a more sophisticated design and feature different variations of the core concept:

- obstacles to avoid (static or moving)
- small passages within a wall to find
- platforms to jump on (static, moving, need to be activated)
- objects to move in order to cross a pit

TECHNICAL CONSIDERATIONS

Both prototypes are using the *Oculus Rift DK2* (OculusVR 2015) to create an immersive experience in a virtual environment. Therefore, typical interaction concepts were implemented such as view control to trigger certain actions to obtain an even more immersive effect. As of the lack of movement possibilities at the time being, a simple gamepad control was used.

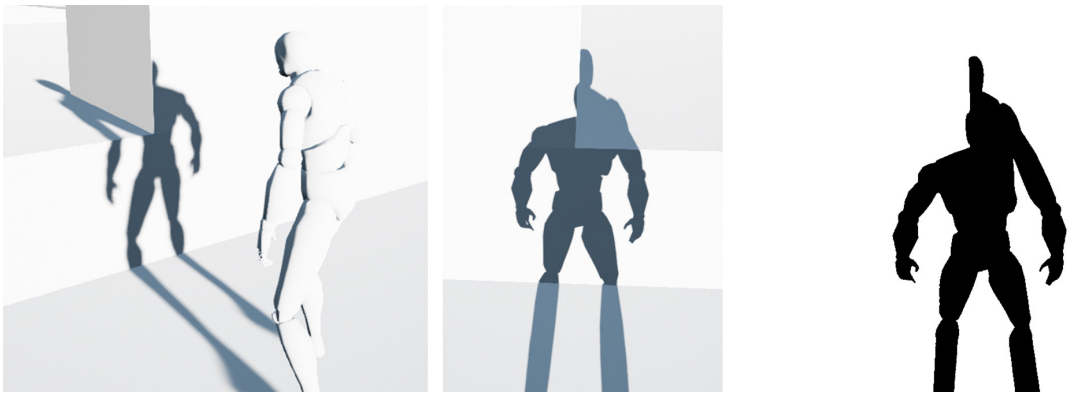

Fig. 9. Implementation of white shadow. White lit environment, with contours still visible (left). Same scene from player's view (center). Same scene with after post-process (mapping different shades of grey to black and white) (right).

The prototypes were built using the Unreal Engine 4 (UE4), a Game Engine developed by Epic Games (Epic Games 2016). UE4 can be used as rapid prototyping platform to quickly visualize concepts and for easy definition of interactive elements and events. It therefore is well suited to experiment with different ideas, especially due to visual debugging, excellent tracing capabilities and by proving a convenient interdisciplinary workflow between designers and programmers. The seamless integration of the Oculus SDK, numerous learning resources and extensibility with C++ plugins offers a wide range of tools for developing an immersive interactive environment. On the contrary, Blueprint graphs and material networks can become very complex and confusing, especially when scripting complex sequences or working with unconventional materials.

As most commercial graphics engines, the UE4 is focused on photorealistic real-time rendering. Material definitions, illumination, camera models and simulation of physics are optimized for this goal. Although modifications are possible, some of the concepts were difficult to implement. Whereas techniques like Cel Shading are quite straightforward to realize, effects such as a complete whiteout and hard shadows required some rather unconventional approaches (cf. Fig. 9). In order to realize effects like distorted, curvilinear or even multi-perspective rendering it would have been necessary to manipulate parts of the core rendering process which is simply not feasible for a student project.

In conclusion, post-processing effects are quite comfortable to develop, especially if the basic underlying concepts of computer graphics are considered. More sophisticated modifications which affect parts deeply integrated in the rendering pipeline, such as custom perspective or projection rules, are difficult to achieve.

4 DISCUSSION

The main ambition creating white shadow was to explore the opportunities for game design and interaction when manipulating specific aspects of human perception. In reaction some negative aspects were suspected: disorientation and resulting sickness, anxiety or panic. Also difficulties in adapting to the new situation: problems using the shadow as orientation or detecting and recognising the objects were expected. However, most users easily adapted to the new environment and started to explore their unknown surroundings. Also motion sickness represented only a minor problem. Providing minimal optical stimuli prevented the users from recognizing movements conflicting between the real and the virtual environment. An interesting effect can be observed, when the user misses a platform or passage and falls to the ground. Due to the complete white surrounding, the effect of falling down is simply not perceived. Motion lines could be used to solve this issue as in the first prototype. However, in *White Shadow* the whiteout effect is simply switched off so the user can see the world. Using a safe route, he can go back to the starting point, where the whiteout effect is activated. Using this system, the user can always return from failure and start over; the game does not contain a classical “game over”. This decision was made to underline the experimental character of the game. In terms of enhancing the core principles, persistent shadows are a viable option. When a shadow is cast on an object it could stay for a specific amount of time and fade out slowly. Using this method, the recognition of the environment can be facilitated. Also a persistent shadow represents a viable option. When the shadow hits an object, it is printed on it and will remain there. As a variation, light sources and the resulting shadows can be switched off at some points, therefore enabling different views on the environment, which have to be mentally combined by the user to navigate through the environment.

As for the comic prototype it was important to emphasize the comic-looking experience. The use of motion lines between the panels in some cases caused motion sickness since the camera was detached from the user and moved independently. Especially the observations of the interaction by head movements were promising. Controlling the flow of conversations, or in general

of sequences of actions, contains a lot of potential. It can be utilized to circumvent the traditional trigger approach in interactive media. Usually events are triggered when the user enters a specific area (e.g. stepping through the door). One drawback of this approach is that the user can miss important information if he is focusing on another aspect of the environment. Especially in VR, where the surroundings can be explored in all directions, it is sometimes difficult to guide the user's attention in the right direction at a specific time. With this kind of *time travel*, the user can replay actions and events on demand. Panels and the navigation between them can be used to convey a specific perception of spatial arrangements that differ from traditional structures known from real 3D space (e.g. nesting panels, opposite or parallel frames) or to combine different layers of time or space in one visualization.

We discovered that using virtual phenomena and NPR-techniques to create scenarios in VR is a feasible way to discover alternative ways of interaction. Using disorientation, reduction of perception and 2D look-a-like rendering in a 3D environment result in unconventional interactive experiences. Providing a first person view facilitates the adaptation to the new scenario and offers the opportunity to discover new aspects of perception. Using 3rd person view, fixed cameras or dolly shots sometimes result in motion sickness, and should be used sparingly. However, in specific scenarios these techniques can offer several advantages. As NPR has been mostly applied to flat images, a number of questions arise regarding their applicability to stereoscopic imagery, especially in respect to human perception and interpretation of imagery.

5 CONCLUSION

VR offers a wide range of opportunities to create appealing, unconventional and innovative experiences. Apart from the concrete implementation, VR opens a playground for visualization and interactive arts. Traditional phenomena, like the frame of an image, relations between objects and basic image characteristics (like the horizon or verticality) disappear or can be hidden from the user. Effects on the perception and new ways to engage the user or arouse curiosity should be investigated. On the other hand, there is always a connection to the real world, no matter how deep the user is immersed in the virtual world. At least with current technology, gravitational and acceleration forces cannot adequately be simulated using VR. The interesting question is, whether an immersive presentation using as many

modalities as possible can *override* the perception of these conflicting stimuli. From our observations, a more or less authentic simulation of a rollercoaster induces at least some kind of imagined acceleration and gravity, showing how intensively an immersive visual representation affects other elements of perception. To further explore the deviation from existing principles, virtual phenomena and the absence of common laws of physics can be used to create unconventional experiences and realize more or less unconventional ideas: different projection parameters, abstract geometry or non-euclidian spaces can lead to new ideas using Virtual Reality. VR can combine interaction with parameters we cannot change in reality, e.g. mapping colours of the environment to the current movement speed (Kortemeyer 2013), distorting the space around the user based on his viewing direction, movement or other interaction paths, moving through the environment ignoring gravitational forces. By experimenting with the wide range of available options without relying on constraints of the real world we have the chance to explore VR from a different, naïve and maybe a little reckless point of view. A deeper investigation of unusual and unapparent aspects of Virtual Reality offers the opportunity to reveal more of the potential of this technology. VR can be used as a tool to explore the borders of our imagination—or even to go beyond.

REFERENCES

Agrawala, Maneesh, Denis Zorin, and Tamara Munzner. "Artistic Multiprojection Rendering." In *Rendering Techniques 2000: Proceedings of the Eurographics Workshop in Brno, Czech Republic, June 26-28, 2000*. Edited by Bernard Péroche and Holly Rushmeier, 125 — 36. Eurographics. Vienna: Springer, 2000.

Bethesda Softworks. *The Elder Scrolls IV: Oblivion*. Novato, CA, Paris, France, Rockville, MD: 2K Games; UbiSoft; Bethesda Softworks, 2006.

Biederman, Irving, and Ginny Ju. "Surface versus Edge-Based Determinants of Visual Recognition." *Cognitive Psychology 20, no. 1 (1988): 38 — 64.*

Chelsea, David. *Perspective! For Comic Book Artists: How to Achieve a Professional Look in Your Artwork*. New York: Watson-Guptill, 1997.

Cosor, D. "The Scream." Accessed February 1, 2016. https://vimeo.com/33976373.

Czolpinski, Anna, and Arif Babul. "The Art of Physics: Visualizing the Universe, Seeing the Unseen." *Pi in the Sky* 9 (2005): 4 — 8.

Decaudin, Philippe. "Cartoon-Looking Rendering of 3D-Scenes." *Syntim Project Inria* 6 (1996).

Epic Games, Inc. "Unreal Engine 4." Accessed February 3, 2016. https://www.unrealengine.com.

Escher, M. C. *M.C. Escher: The Graphic Work*. Cologne, Germany: Taschen, 2001.

Giant Sparrow, S. C. *The Unfinished Swan*. Tokyo: Sony Entertainment, 2012.

Glassner, Andrew. "Digital Cubism." *Computer Graphics and Applications* 24, no. 3 (2004): 82 — 90.

Glassner, Andrew. "Digital Cubism, Part 2." *Computer Graphics and Applications* 24, no. 4 (2004): 84 — 95.

Goldstein, Eugen B. *Sensation and Perception*. 8. Ed. Belmont, Calif.: Wadsworth Cengage Learning, 2010.

Gooch, Bruce, and Amy Gooch. *Non-Photorealistic Rendering*. Natick, Mass.: A K Peters, 2001.

Hays, James, and Irfan Essa. "Image and Video Based Painterly Animation." In *Proceedings of the 3rd International Symposium on Non-Photorealistic Animation and Rendering*, 113 — 20. New York, NY: ACM, 2004.

Hertzmann, Aaron, and Ken Perlin. "Painterly Rendering for Video and Interaction." In *Proceedings of the 1st international Symposium on Non-Photorealistic Animation and Rendering: NPAR '00*. Edited by Jean-Daniel Fekete and David Salesin, 7 — 12. New York, NY: ACM, 2000.

Kortemeyer, Gerd, Philip Tan, and Steven Shirra. "A Slower Speed of Light: Developing intuition about special relativity with games." In *FDG '13 Proceedings of the International Conference on the Foundations of Digital Games*, 400 — 402. New York, NY: ACM, 2013.

Lake, Adam, Carl Marshall, Mark Harris, and Marc Blackstein. "Stylized Rendering Techniques for Scalable Real-Time 3D Animation." In *Proceedings of the 1st international Symposium on Non-Photorealistic Animation and Rendering: NPAR '00*. Edited by Jean-Daniel Fekete and David Salesin, 13 — 20. New York, NY: ACM, 2000.

Lewis, Joseph H. *The Big Combo*. With the assistance of richard Conte, Jean Wallace, and Cornel Wilde. 1955.

McCloud, Scott. *Understanding comics: The Invisible Art*. 1. HarperPerennial ed. New York, NY: HarperCollins Publ., 1994.

Meier, Barbara J. "Painterly Rendering for Animation." In *SIGGRAPH '96 Proceedings of the 23rd Annual Conference on Computer Graphics and Interactive Techniques*. Edited by John Fujii, 477 — 84. New York, NY: ACM, 1996.

Miller, Frank. *Sin City*. With the assistance of Mickey Rourke, Clive Owen, and Bruce Willis. New York, NY, 2005.

Murnau, Friedrich W. *Nosferatu — Eine Symphonie des Grauens*. With the assistance of Max Schreck, Greta Schröder, and Ruth Landshoff. Berlin, 1922.

Nolan, Christopher. *Inception*. With the assistance of Leonardo DiCaprio, Joseph Gordon-Levitt, and Ellen Page. Burbank, CA: Warner Bros, 2010.

Oculus VR, LLC. "Oculus Rift Development Kit 2." Accessed February 1, 2016. https://www.oculus.com/en-us/dk2.

Osome Studios. *White Night*. Santa Monica, CA: Activision, 2015.

O'Donovan, Peter, and Aaron Hertzmann. "AniPaint: Interactive Painterly Animation from Video." *IEEE transactions on visualization and computer graphics* 18, no. 3 (2012): 475 — 87.

Place, J. A., and L. S. Peterson. "Some Visual Motifs of Film Noir." *Film Comment* 10, no. 1 (1974): 30 — 35.

Reed, Carol. *The Third Man*. With the assistance of Orson Welles, Joseph Cotton, and Alida Valli. London, GB, 1949.

Ritchie, Guy. *Sherlock Holmes*. With the assistance of Robert Downey Jr., Jude Law, and Rachel McAdams. Burbank, CA: Warner Bros., 2009.

Schlichting, C. L., S. M. Luria, J. A. Kinney, D. F. Neri, S. W. Kindness, and H. M. Paulson. "Aids For Improving Vision In White-Out: Research Work Unit MF 58.524.013-1039." Unpublished manuscript,

Siodmak, Robert. *Phantom Lady*. With the assistance of Franchot Tone, Ella Raines, and Alan Curtis. New York, NY: Universal Pictures, 1944.

SouthEnd Interactive. *XIII*. Paris, France: UbiSoft, 2003.

Spindler, Martin, Niklas Röber, Robert Döhring, and Maic Masuch. "Enhanced Cartoon and Comic Rendering." In *Proc. Eurographics*. Edited by D. W. Fellner and C. Hansen, 141 — 44. Geneve, Switzerland: Eurographics Association, 2006.

Tateosian, Laura G. "Investigating Aesthetic Visualizations." Dissertation, North Carolina State University, 2006.

Ustwo Fampany Ltd. *Monument Valley: An Illusory Adventure of Impossible Architecture and Forgiveness*. London, UK: Ustwo Fampany Ltd., 2014. http://www.monumentvalleygame.com.

Vrellis, P. *Starry Night Interactive Animation*. 2014. http://artof01.com/starryNight.html.

Xia, Yong, Libing Zeng, and Kuanquan Wang. "Non-Photorealistic Volume Visualization with Color Distance Gradient and Two-Level Volume Rendering." In *Computing in Cardiology Conference (CinC), 2013: Volume 40; 22 - 25 Sept. 2013, Zaragoza, Spain*. Edited by Alan Murray, 1159 — 62. Piscataway, NJ: IEEE, 2013.