From 2D to 3D: A Case Study of NPR and Stereoscopic Cinema

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Abstract. Our interdisciplinary research is dedicated to exploring the boundaries of stereoscopic filmmaking from an unusual viewpoint: we aim at creating 3D non-photorealistic cinema which allows conciliating a stereoscopic pre-visualization that is oriented to ensure visual comfort with concept tests of NPR applied to a 3D film. In this paper we describe the role of pre-visualization in stereoscopic cinema and our preliminary observations and experience of combining 3D cinema with non-photorealistic rendering approaches, from the filmmakers' point of view.

Keywords: Non-photorealistic rendering · Previsualization · 2D and 3D cinema · Visual comfort

1 Introduction

The history of cinema is indissolubly linked to technological development and photorealism. Since the beginning of the digital era, technological advances have not ceased to push further the boundaries of photorealism. A good example is the huge development of special effects and 3D animation, both oriented to reach the empathic effect of a photographic image. So, in general terms, photorealism has aesthetically dominated the history of cinema through the different stages of its technological development.

In the case of 3D cinema, photorealism is even more important, at least for two factors: the promise of sensorial hyperrealism is the main commercial argument of 3D experience in movie theaters, and at the same time, it is a sort of universally accepted standard for producing a visual comfort in the viewer. Thus, hyperrealism and visual comfort seem to be two inseparable characteristics of contemporary 3D cinema, both resting on the idea of photorealism as a conventional premise for stereoscopic filmmaking. We will question this premise by exploring the possibility of a non-photorealistic 3D cinema, in a two-step research.

The first step will consist of evaluating the use of non-photorealistic rendering (NPR) filters in 2D cinema on two types of users: general public (university students) and specialized public (film postproduction professionals).

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The second step will consist of exploring the perceptual and technical problems of using NPR in stereoscopic cinema: on one hand, to understand the pre-visualization method as a way to guarantee visual comfort for the whole stereoscopic content, and on the other hand, to identify the technical and perceptual challenges of combining stereoscopic visualization with NPR.

Even though believable 3D relies on a realistic rendering model, realism is only one of the many artistic styles of storytelling and expressing emotions: choosing the proper visual style is an important aspect of art [9]. So, if we think of the aesthetics of 3D cinema as a spectrum of possibilities ranging from photorealism to non-photorealism, this idea expands the possibilities of cinematographic creativity. In this paper, we show experimental results of NPR applied to 2D cinema, and preliminary observations of NPR applied to 3D cinema. Thus, we aim at exploring the limits of merging the expressive possibilities of NPR with the narrative use of stereoscopy.

In Sect. 2, we describe visual comfort as the main perceptual challenge in 3D cinema and previsualization as a tool to achieve it. In Sect. 3, we describe the framework we have developed and used to test the role and applicability of NPR to stereoscopic cinema. Section 4 presents results of NPR for 2D cinema. In Sect. 5, we explore a two-pattern method to compare samples of stereoscopic contents processed with NPR filters. Finally, we conclude our paper in Sect. 6.

2 Visual Comfort as a Perceptual Challenge for 3D Cinema

Constant "depth scanning" is a natural characteristic of human vision. But even if the principle of binocularity is shared in stereoscopy, the 3D cinema of the 21st century still produces ocular discomfort, dizziness or headaches in many people [18]. About this aspect, in 2014 a French public agency published a series of recommendations on possible damage detected in children under 6 when exposed to stereoscopic content [1], in order to limit risks on children's health. The French agency that produced this report [2] states, however, that "given the lack of information on exposure to these technologies, the Agency considers necessary to promote new research".

The "know-how" for creating high quality stereo motion picture with stylized graphics is very limited. Even though it was shown that the mixture of stereoscopy with NPR can break 3D space perception [3], there has been little research on how to create visually pleasing NPR images or videos. Recent research focused on specific subproblems such as line drawings [4], painterly rendering [10,13] or simulating film grain effects [16]; however, a general framework to combine arbitrary styles (including post-production work that is applied in image space in 2D) with stereoscopic 3D visualization is yet to be established. In this paper we merely scratch the surface of this topic: we experiment with screen-space NPR stylization methods that are applied independently on the two images corresponding to the two eyes. Among other issues, we are interested in

how stylization influences the filmmaking procedure, including the quick generation of previews or pre-visualization ("*previz*") with a set of different styles. It is not enough to just create solutions that optimize 3D conventional processes (such as geometric or light correction applied to stereo pairs); it is fundamental to experiment with the language of 3D cinema and, in the same process, analyze the user's responses to formal innovations. To achieve this, we have shot a stereoscopic film following the rules of a "secure" stereography, which means using pre-visualization as a tool to prevent disturbing transitions between scenes with different depths. This film would be used to test with NPR processing.

2.1 The Role of Cinematic Factors in Visual Comfort

The experience of filming in 3D is very didactic to understand the concept of visual comfort from an empirical perspective. In principle, the inconvenience is ocular [6,14]: eye fatigue results from the conflict between fixed accommodation on the screen (where we focus) and mobile convergence in scenic 3D space (where we look). In the 3D experience, although we can get used to this process after a few minutes, the quality of the film does the rest. The 3D quality of a film responds to decisions of "*mise en scène*" because they simultaneously involve several components of cinematography (photography, editing, post production). We shall call these the "cinematic factors" of eye fatigue.

If we compare the "physiological" and "cinematic" factors of eye fatigue, we should assume that, as medical research, optics and neuroscience do not submit new evidence on how to reduce the impact of physiological factors, our efforts should focus on cinematic factors. By properly using conventional resources of 3D cinema, we could produce films that are comfortable for the average viewer. One of these resources to avoid eye fatigue is the stereoscopic preview or 3D storyboard. The experience of shooting in 3D, which we describe below, incorporated the use of stereoscopic preview as one of the cinematic strategies to define a shooting plan aimed at visual comfort.

In July 2014, we shot a 3D film at the residence of Spanish filmmaker Luis Buñuel in Mexico City, based on a three-dimensional model of the house. This model allowed identifying the camera axes with greater visual depth, so that the shooting could take full advantage of depth perception in that house.

Once the script and the model of the house were completed, Frameforge [12] was used to simulate the material aspects (interior and exterior of the house, furniture, lighting, characters), optical factors (photographic focus, stereoscopic variables) and cinematic factors (fragmentation of history into scenes and shots). This stereoscopic preview was useful to generate the optimal amount of material for edition, which is very useful to solve problems in 3D postproduction.

Then, there is the aesthetic role of postproduction: what kind of "look" is better adapted to the fantastic spirit of the story. That was the beginning of our NPR real-time software testing. We wanted to develop a tool that was useful for matching the story and its aesthetics: to merge the expressive (NPR) and the narrative (3D) dimensions of the film. We knew that the natural environment of

3D cinema is photorealism, but the surreal context of the story gave us the aesthetic justification for a non-photorealistic treatment. The next step was testing the NPR filters in a 3D film conceived with cinematographic principles based on visual comfort [7].

3 Test Framework of NPR Effects for Cinema

From a technical point of view, NPR methods can be classified into object space and image space (or screen space) methods. Although in our case study the 3D model of the scene was available, in general, only film shots were available and so we chose image space methods for stylization. These approaches work with 2D image streams and therefore can use only color and texture data. However, we may assume that limited geometric information is available in the form of depth images, which may be extracted from the stereo images or directly captured using an additional depth sensor during film shooting. Thus, in addition to standard image processing methods we also considered depth-based effects that are also calculated in image space, but pixel data may correspond to depth.

Among image space NPR methods, we looked for ones that allow interactive performance. This may seem contradictory, as rendering methods used by cinematography are traditionally performed offline. On the other hand, we intended to include this stylization framework into the fast previz stage of film production where many different styles are tested rapidly, possibly during shooting, and thus performance is favored over high quality. Based on the preliminary results shown by the previz stage, high quality offline (possibly manual or semi-automatic) methods may be developed or selected in latter production stages.

Our previz tool is implemented as post-processing effects, using the Unity game engine [15]. We implemented a stand-alone video editor software in the same platform that supports various parameterized NPR effects. These effects execute basic image processing algorithms on the GPU and are capable of real-time performance. Thus, users can see the original shot and the immediately computed stylized results both at once. The selected effects are based on two principles: artists enhance relevant details and at the same time simplify the image by mitigating irrelevant details.

Relevant details are emphasized by drawing lines (i.e. applying edge detectors). We used the flow-based, extended difference-of-Gaussians (DoG) filters proposed by Winnemöller, as these were shown to produce aesthetically pleasing results [19] and can simulate various effects such as black and white or colored pastel. It is also related to edge detection by approximating the Laplacian of Gaussian (LoG) filter, which is equivalent to blurring the input with a Gaussian filter and then applying a Laplacian, i.e. second order edge detection. The result of the DoG filter is thresholded: smooth thresholding is used by applying the *tanh* function in order to produce aesthetic results [19]. To avoid noisy responses, smoothing along the flow field is used. First, we compute the smoothed structure tensor (i.e. the standard structure tensor for color images, blurred with a Gaussian filter), from which the gradient and tangent directions are extracted,

similarly to [5]. Then, in a second pass, line integral convolution that follows the edge tangent flow is applied. Line parameters such as color, width and smoothness are user-controlled parameters in our system; the parameters correspond to the reparameterization of the DoG filtered as proposed by Winnemöller in [19]. Black and white contour enhancement using the flow-based extended DoG filter is referred to later on as "Added contours". We also defined an effect that takes the original pixel color and use it as edge color, referred to as "Colored line drawing". Additionally, with proper threshold parameters, the DoG filter can produce pastel-like effects [19], which we consequently named "Pastel" and "Colored Pastel".

Image simplification methods consist of lowering image complexity in terms of texture details and color details. To reduce texture complexity, we used an extension of the flow-based implementation [5] of the bilateral filter [17,20], which is an edge-preserving smoothing filter. In our case, the bilateral filter is a product of two Gaussian filters; one is applied in the spatial domain, and the other is computed in the intensity domain. The intensity-dependent filter component ensures that neighboring pixels that are placed on the same side of a step-like signal as the center pixel have greater weight, while pixels from the other side of the edge contribute less to the filter output, better preserving the edge. The amount of blur is controlled by the variance parameter of the spatial domain Gaussian filter, while the amount of details kept is determined by the intensity domain variance parameter. In order to avoid color-bleeding artifacts, the bilateral filter is applied in the CIE-Lab color space [17]. Originally, the bilateral filter is non-separable, and thus expensive to compute. In real-time applications, usually the flow-based approximation [5] is used instead, which applies a one-dimensional bilateral filter along the gradient flow, and then another one-dimensional bilateral filtering on the tangent flow. Similarly to the flow-based DoG filtering, the gradient and the tangent flow directions are extracted from the smoothed structure tensor. The bilateral filter is usually performed iteratively several (2–5) times to produce visually appealing results.

Color complexity is lowered using luminance quantization, similarly to [20]. We refer to the output of the application of the bilateral filter and luminance quantization as a "Simplified" image. Another way of lowering color complexity is to reduce image saturation ("desaturation") in HSV on HSL color spaces.

The combination of these effects together can simulate different artistic styles. Additionally, the level of abstraction is parameterized in each of the effects: i.e. the line thickness and density in edge detection, the strength of details that are kept in texture simplification and the amount of desaturation. This allows us to guide the viewer's gaze [8,11], as well as to create the illusion of depth. The parameters corresponding to the level of abstraction may depend, in the first place, on camera depth, as a way to show objects in full detail in the foreground and as an abstraction in the background. Another typical use is to define the level of abstraction based on the radial distance from a particular point on the image, which guides the viewer's gaze to this particular point.

Effects are applied on the two stereo images independently — without modifying the stereoscopic parameters. This is known to break 3D perception [4]. However, in our case this is less noticeable for several reasons. First, contours are generated on each-eye basis, which was shown to be capable of avoiding binocular rivalry [4]. In most styles (except for line drawings), there is interior information between lines, mitigating binocular rivalry caused by line segments that are seen only by one eye. Additionally, lines are not textured, and thus line style is coherent. Finally, image simplification methods usually aim at removing less relevant details while preserving relevant ones. Thus, these approaches remove details instead of introducing new ones. This means that most of those details are present in the output image, which were also visible in the original, photorealistic shot; everything else is smoothed out.

Our preliminary user studies showed (results are not included in this paper) that the consistency of the two images can be high and thus disturbing artifacts may often not be present: 3D illusion is not affected by some of the NPR effects. We note that the effects are intended to be used for previz, and thus an offline stylization method that is used to render the film in its final form should be very carefully designed in order to achieve perfect 3D sensation.

4 NPR Rendering for 2D Cinema: Experimental Results

An experimental phase of the research was carried out in order to identify and analyze how cinematic perception in 2D is affected by NPR. Given the cultural centrality of our habit of 2D cinema, we considered a priority to compare three "extreme" or "polar" (clearly distinguishable) types of NPR filters. We worked with a young audience of university students, characterized by high audiovisual consumption. The experiment was conducted in October 2014 in Santiago, Chile, and it was conceived to identify the conditions in which visual abstraction of NPR processing can affect the narrative understanding of a 2D film. We applied three NPR filters, COLOR COMIC, PASTEL, PAINTING (Fig. 1), in a 7-min fragment of the feature film "Las Niñas Quispe" (Dir. Sebastián Sepúlveda, winner of best cinematography at Mostra de Venezia 2014). Then we organized a screening in a movie hall of these three NPR versions, divided into three groups of 10 students each, from a total of 30 college undergraduates of cinema

Fig. 1. Three samples of NPR filters: Native frame (left), COLOR COMIC (center-left), PASTEL (center-right), PAINTING (right).

and journalism, ages 19 to 22. After each screening, we combined a quantitative methodology (survey of 25 questions) and a qualitative questionnaire (three focus groups of 10 people each). The first part of the survey allowed us to validate the base line of a general high audiovisual consumption on that group of college students. The second part consisted of questions divided by themes: space-time perception, emotion identification, recognition of characters and backgrounds. The focus group results allowed us to build an analytical reading of the survey's results.

For the three groups of students, the qualitative consensus was that character recognition, more than backgrounds or objects, is the most important factor to evaluate the impact of NPR on film narrative. This result could suggest that the NPR do not affect depth perception because character recognition remains significant even in the "extreme" filters (Pastel and Painting), where the backgrounds and foregrounds seem to be combined in similar textures.

As we can see in the quantitative results (Fig. 2, left), the morphological perception of characters (facial features, sizes, textures) was clear in NPR1 (Color Comic); the vertical axis indicates the number of mentions. In NPR2 (Pastel) greater importance was given to voice as a differentiating criterion, due to the general darkness. However, in NPR3 (Painting), voice becomes the main element of recognition, leaving the morphology in the background. We concluded that one reason is the visual disturbance of the predominance of white, which seems to decrease visual perception and encourage auditory perception. Colors (blue component) was not mentioned as a recognition criterion, and a combination of factors, labeled as Others (violet component) was only mentioned in NPR1 and NPR3.

These results suggest that we do not need so much detail (as we found in photorealism) to understand a film narrative, because, in fact, much of the information comes from character identity, produced by the combination of body movement and voice. Therefore, when using NPR, subjects are able to abstract, relate and follow a story, even when we see more blots and stains than sharp facial expressions. NPR seems to bring a new atmosphere to the story, without affecting its dramatic understanding. The use of "extreme" filters, two of them clearly distant from the native realistic picture of the film, stimulates new interpretations of the characters emotions and intentions and the narrative importance of their environments. In short, understanding the story does not seem to be affected by NPR filters. The main conclusion to be drawn from this experiment of non-photorealistic 2D film lies in a dual dynamic generated by NPR: general narrative comprehension is unaffected but, by modulating the morphological aspects of characters and by increasing the perceptual importance of sound, new approaches to the film intentions are generated. The same story seems to produce new interpretative variants in its viewers. This seems to happen in 2D.

The second result, based on a panel of 12 professionals of film postproduction, is related to the use of NPR filters in cinematographic genres (Fig. 2, right). There was a genre in which professionals were more open to seeing NPR: Science Fiction. This suggests that post-producers imagine a possible use of NPR in

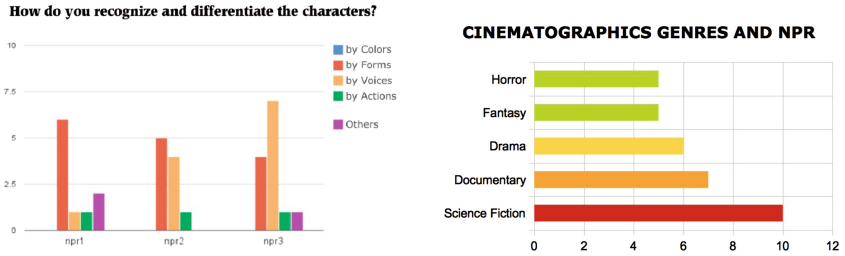

Fig. 2. Left: comparative factors for character recognition in NPR1, NPR2 and NPR3. Right: use of NPR in cinematographic genres. (Color figure online)

movies with non-realistic stories. But the surprise comes with the second genre (documentary), generally more associated with realistic characters or landscapes. If we confront the results of both groups (students and professionals), we find no contradiction: if NPR filters do not affect character recognition, the stories will be correctly understood. However, to explore passing NPR from 2D to 3D cinema we must remember the main perceptual difference between monocular and binocular vision: spatial understanding. In 2D, a singular visual scanning is enough to understand instantly the spatial nature of the scene, but in 3D, visual scanning is essentially comparative: an ocular backward and forward movement that could be called "depth scanning". Therefore, even if the characters remain the most important factor of NPR perception in 2D, it will be necessary to evaluate how this constant "depth scanning" of 3D perception could modify the impact of NPR.

5 Comparing Samples of 3D Frames Processed with NPR Filters

As we said before, "depth scanning" is an attribute of 3D perception. Buñuel's house, used for the shooting, was filled with objects in order to increase depth perception in the filmic space. We were also sure about the visual comfort of the photorealistic 3D content, that means, before the NPR processing. We also had the NPR software, so we needed to prepare the concept test of processing a scene with different NPR filters. And the final step — which we shall present as future work — should be the user-test of NPR 3D with viewers. So, we created a two-pattern method to compare the NPR 3D samples.

Instead of defining depth perception by optical principles, we first developed a comparative method of NPR effects with a specific validation criteria: the expressive and narrative needs of the film. We chose a scene with six different layers of depth, where the narrative intention was the sadness felt by the female character. The comparison of the resulting images after NPR processing, analyzed with anaglyph glasses, was described in terms of 3D quality (perceived layers) and related to the impact of NPR on stereoscopic illusion (whether it keeps the binocular depth or not). We know that the anaglyph is not the best

Table 1. Comparison of different NPR filters applied to a stereoscopic frame. In (B) and (G) pastel refers to the pastel-like effect from [19], in (C) and (D) (de)saturation means (lowering) increasing the saturation of colors based on the radial distance from the center of the image, in (E) the results of edge detection were added, (F) is an image abstraction method based on [5], while in (H) the result of an edge detector was taken and the original input was used as edge color.

	Native Shot	**Non-Photorealistic Shots**						
	(A) Photo-realistic	(B) Colored pastel	(C) De-saturated color	(D) Saturated color	(E) Added contours	(F) Simplified	(G) Pastel	(H) Colored line drawing
3D quality	clear layer separation	layers with ghosting	layers with ghosting	clear layer separation	clear layer separation	clear layer separation	no layer separation	no layer separation
Depth perception	binocular depth	monocular depth	weak binocular depth	intense binocular depth	realistic binocular depth	unrealistic binocular depth	monocular depth	monocular depth

way of visualizing 3D (polarized glasses are the cinema standard), but at the same time, all 3D contents available on the Internet are on anaglyph format. Currently, both kinds of glasses coexist, but in this exploratory phase, anaglyph visualization was sufficient. We must assume a general lack of "3D culture". Almost everyone has seen 2D films. But in adult ages, even among cinema students, the experience of watching 3D films is still rare. We should not forget these differences in cinema backgrounds for our future NPR 3D user tests. That is why we started with two intuitive criteria for the comparison: (a) 3D quality, and (b) depth perception. We had to conceive intuitive notions of 3D that could be easily expressed in a social context of users with no "3D culture".

We compared the "native" photo-realistic shot with seven non-photorealistic shots (Table 1), as a preliminary basis for a user test that will be presented as future work. From the point of view of perception, the choice of these seven non-photorealistic filters was oriented to produce a continuous scale of proximal types of depth, contrary to the 2D NPR experiment, in which we chose two "polar" filters and just one proximal filter to the "native" frame. Once the scene was processed with NPR filters, we could work on a questionnaire based on two patterns, that could be summarized in two kinds of questions: (a) about "3D quality": do you see "edge ghosts" when you compare the depth levels of the image? (b) about "depth perception": which samples seem to appear to you as normal 2D image?

A simple comparison of perceptions among the research team (we all have a different binocular vision) revealed a comparative panorama of which NPR filters produce different kinds of 3D illusion. For instance, NPR samples that reduce the stereoscopic illusion by producing a monocular depth perception (B, G and H in Table 1) are less suitable for stereoscopy. Something similar may be concluded for those samples that create a defective stereoscopic illusion (B and C

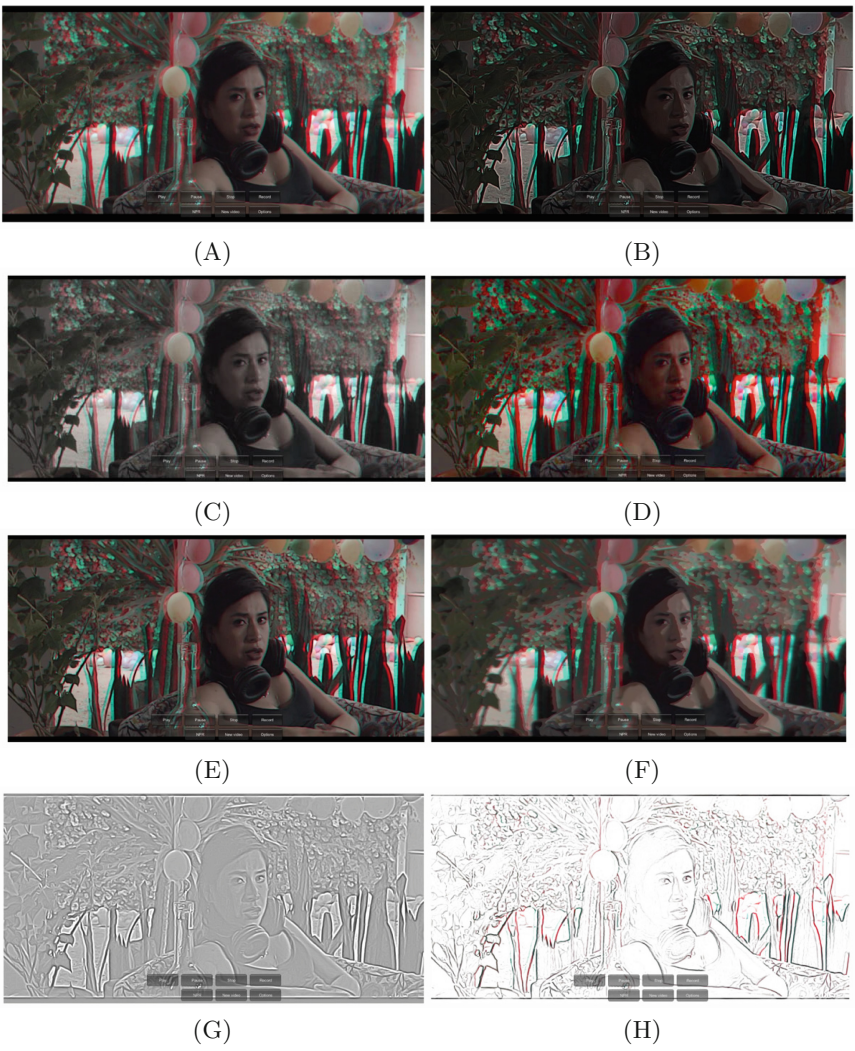

Fig. 3. Photorealistic shot (A) and non-photorealistic stylized shots (B–H).

in this case), by producing "ghosting" around the edges. Combining these two intuitive criteria we could select the most suitable NPR effects in terms of visual comfort (D, E, in F in Fig. 3).

Even if these preliminary results are just a first intuitive step in our methodological path towards a systematic experimental strategy, we can already identify some ideas to consider for our future work: (a) we could use optical solutions (as eye tracking devices) to corroborate the verbal identification of "ghosts" in the figure's edges; (b) for a qualitative approach, we should consider intuitive definitions of "3D quality" and "depth perception" if we want to consider the lack

of "3D culture"; and (c) also for a qualitative approach, we must define a set of descriptive attributes that would be useful to compare and establish differences between the expressive contribution of each NPR filter in the same 3D scene.

6 Concluding Remarks: Exploring the Limits of Photorealism in Cinema

The use of NPR in cinema means a challenge to the global tradition of photorealism. The common sense of our visual culture tells us that NPR and stereoscopy are destined to be separated. This paper suggests that this combination is not a perceptual contradiction. Our experimental results in 2D cinema indicate that narrative comprehension is not significantly affected by NPR. In 3D cinema we conducted a trial study that produced preliminary observations. These observations will be used in future research as the basis for a user study aimed at identifying NPR stylizations that may preserve the binocular depth of stereoscopy. Our current work indicates that a combination of the expressive quality of NPR with the immersive effect of stereoscopic cinema could produce a new form of augmented narrative.

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