Perception of Lighting and Shading for Animated Virtual Characters

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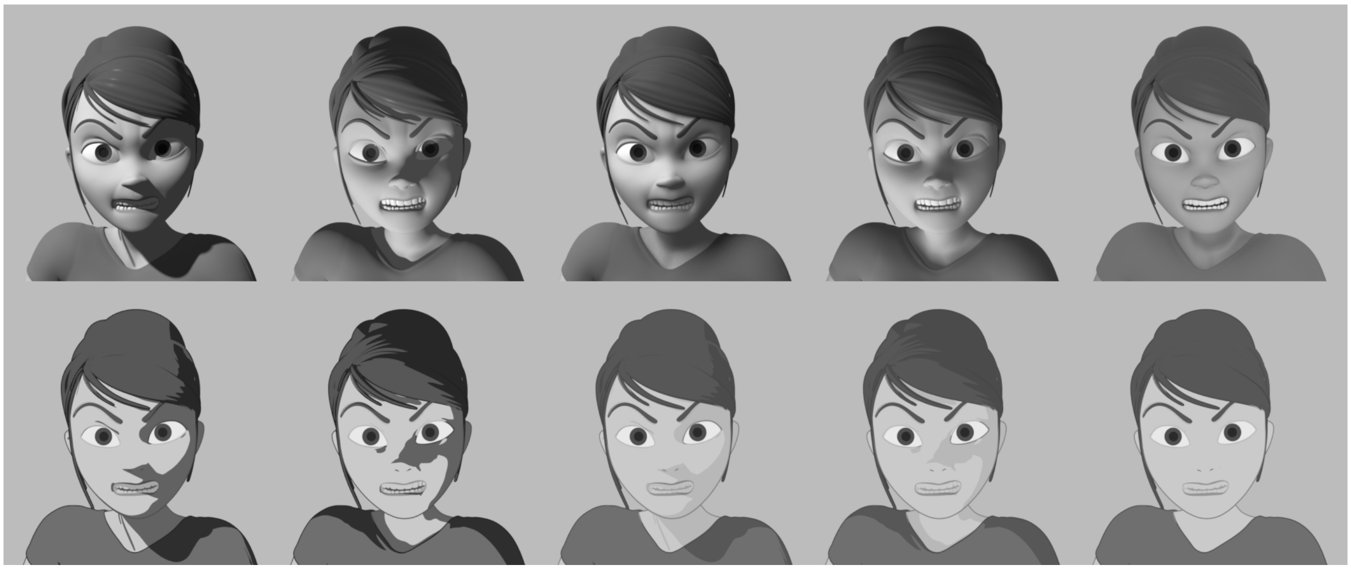

Figure 1: *Frame from angry animation rendered using CG-shading (top) and toon-shading (bottom), under the 5 lighting conditions tested. From left to right: High contrast/light from above, High contrast/light from below, Low contrast/light from above, Low contrast/light from below, No directional Light*

Abstract

The design of lighting in Computer Graphics is directly derived from cinematography, and many digital artists follow the conventional wisdom on how lighting is set up to convey drama, appeal, or emotion. In this paper, we are interested in investigating the most commonly used lighting techniques to more formally determine their effect on our perception of animated virtual characters. Firstly, we commissioned a professional animator to create a sequence of dramatic emotional sentences for a typical CG cartoon character. Then, we rendered that character using a range of lighting directions, intensities, and shading techniques. Participants of our experiment rated the emotion, the intensity of the performance, and the appeal of the character. Our results provide new insights into how animated virtual characters are perceived, when viewed under different lighting conditions.

Keywords: computer graphics, animation, virtual character, rendering, lighting, perception

Concepts: •**Computing methodologies** → **Perception;**

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1 Introduction

In visual arts, from the paintings of the Renaissance and Baroque, to the present day theater, photography and cinematography, lighting has been known to be an effective means of creating moods. Throughout art history, there have been many theories and terminologies connecting lighting to emotions. Computer Graphics took many of these principles and practices from the traditional crafts of theater and film with the objective of creating similar emotional impacts on the audience with light. One school of thought amongst CG artists closely follows the language of cinematography and has led to the development of rendering techniques that mimic lighting in film. This is considered the mainstream and most CG animated films fall into this category. There is another school that takes inspiration from 2D storytelling arts such as comics and manga, and focuses on stylization to achieve results closer to hand-drawn animation, with the aim of enhancing emotional expression [McCloud 1994]. Toon-shading is a common technique among artists in the latter group and it is still popular especially in the Japanese game industry. Despite the difference in render styles, both groups have a strong belief in the connection between lighting design and audiences' emotional response. This study is designed to validate the assumption that cinematic lighting would produce the emotional impact according to the conventional wisdom for both CG rendering styles. We are particularly interested in the influence of different lighting conditions on the performance of a CG cartoon in terms of emotion and appeal, as the result could provide insights for future work in virtual character research.

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2 Background

Lighting in Arts has been developed as early as in the Renaissance. *Sfumato*, meaning to soften or to shade, was one of the canonical painting modes prominently used by Leonardo da Vinci and his followers [Hall 1992]. This technique muddles the bright area and lightens the dark area, similarly to the concept of "**low contrast**" in photography and Computer Graphics. On the other hand, *Tenebrism*, meaning dark or gloomy, credited to have been invented by Michelangelo Merisi da Caravaggio, was a popular painting style in the Baroque utilizing the stark difference between light and dark, "**high contrast**", to add dramatic effects [Moffitt 2004].

The two lighting approaches are believed to evoke different emotions from the viewers, and lighting in general has been widely used in fields of visual arts such as photography, theater, film, and computer animation to create moods. However the association between lighting styles and emotional responses, particularly in film [Grodal 2005], are mostly conventional practices based on observations. Many filmmakers experimented with different types of lighting and concluded their own assumptions. To test the pragmatism of film theory, a recent empirical study by Poland [2015] found "low-key" (high contrast) stimuli produced reports of lightheartedness contrary to the beliefs of many theorists and cinematographers. However, the study used short films with storylines as stimuli and the results were concluded to be partially influenced by the narrative. De Melo et al. [2007] and Seif El-Nasr et al. [2006] studied effects of lighting in creating emotion in virtual characters and video-games respectively, but both studies focused mainly on the implementation and did not conduct any perceptual experiments.

In the field of non-photorealistic rendering, Mould et al. [2012] studied emotional response to images stylised using a number of well-known non-photorealistic rendering algorithms. Their study found that although stylisation affected participants' reported valence and arousal, emotional responses were muted. However, the stimuli in these studies were limited to static 2D images. Schumann et al. [1996] assessed the effect of 3D shaded and non-photorealistically rendered CAD objects on communicative goals during design, with results indicating that stylistic depictions were popular in the design process and were rated significantly higher on affective and motivational criteria.

There have been a number of studies directly investigating the effect of different render styles on the perception of virtual characters. McDonnell et al. [2012], tested the effect of render style on the perception of trustworthiness of a virtual human, but found that the audio and animation contributed to the interpretation of the characters' intention rather than the render style. Volonte et al. [2016] studied the emotional response of participants to realistic and stylized patients in a medical simulation, and found the different render styles evoked different emotional responses. More related to our work, Wallraven et al. [2007] studied the emotion recognition and intensity of a range of stylizations of faces using 2D filters to provide brush-stroke, cartoon, and illustration styles. They found differences in both the recognition and the intensity of emotion for different stylization techniques, with the brush-stroke method being rated as much less intense than the others. Our experiment differs in that we are interested in specific aspects of lighting and their effect on emotion recognition and intensity. Also, we focus on a more stylized cartoon character appearance and motion.

3 Stimuli Creation

In performing arts, properties of light are usually categorized into distribution, intensity, color, and movement [Wolf and Block 2014]. Since computer animation inherits many lighting principles from theater and film [Birn 2013; Calahan 2000], we will also adopt these lighting properties in our study. However, in order to minimize the length of the experiment (and fatigue of participants), we decided to reduce the number of variables and mainly focus on the distribution property which includes quality and direction (of the key-light). These lighting conditions will be applied to both **CG shaded** (smooth shaded) and **toon shaded** stimuli.

In terms of quality, there are a diverse range of lighting styles across different disciplines [Alton 1995; Millerson 1991; Wolf and Block 2014] but we decided to broadly generalize them into two groups: low contrast and high contrast lighting. **Low contrast** represents "soft light"–a large area light that produces subtle transitions from light to dark on the illuminated area and soft edge shadow [Lowell 1992; Millerson 1991], and also includes the middle ground between "gradated tonality" and "high-key" lighting [Malkiewicz and Mullen 2005]. **High contrast** lighting represents "hard light"–a small but intense light source that produces hard-edge shadows, and also covers a subset of "low-key" lighting. To achieve the low and high contrast in CG shaded stimuli, we used an area light and a point light. However, to avoid the bias of overall brightness–considered one of the controlled variables, we could not go too extreme on either end–for example, we cannot produce true high-key or low-key lighting (we used the blurred version of the renders to compare and balance the overall brightness across the stimuli). For the toon shaded stimuli, we used the standard technique from Lake et al. [2000] in which the area light would have no effect (this was also a reason why we did not generalize the light quality into soft and hard light). Instead, a point light was used in both low and high contrast scenarios. The low and high contrast conditions were achieved by using different darkness levels for the shadowed area.

For the directions, we will only consider a light source coming from above and below. Light coming from above or "motivated light" is a natural direction motivated by real world sources such as the sun or a ceiling lamp, hence the word "motivated" [Wolf and Block 2014]. Lighting coming from below or "unmotivated light" is commonly used to add dramatic effects, particularly in stage lighting, as the light comes from an unnatural source such as fire light [Wolf and Block 2014; Gurney 2010]. To create the light direction, a key-light is placed in front of the character, 45 degree to the right, and 45 degree above (or below) the eye level [Calahan 2000; Gurney 2010]. Please note that there are countless possible light directions but we only use this setup, as it is a common key-light position, such as in the well-known three-point lighting or three-quarter lighting methods [Gurney 2010]. A key-light is often coupled with a fill-light to slightly brighten up the shadow and can be artistically placed anywhere. In the CG shaded stimuli, we decided to use a low intensity dome light [Hery and Villemin 2013] instead of a fill-light to avoid the bias of fill direction in our key-light direction comparison. In the toon shaded stimuli, the effect of the fill-light could be added by simply controlling the darkness of the shadow and the dome light was not needed.

In this study we also considered a special case of no visible directional light (**No light**), a popular setup in pre-schooler television cartoon series, as it is quick to setup and easy to reuse in multiple episodes. We created this with the combination of a dome light and ambient occlusion to evenly light the character in the CG shaded stimuli, and completely removed shadows in the toon shaded stimuli.

As a character model, we chose Mery[Alvarez and Lora 2016], a female character with a typical cartoon appearance commonly seen in animated movies (figure 1). This character has a highly controllable facial rig, with the ability to squash and stretch each part, allowing animators to create highly expressive cartoon animations. We chose to use a greyscale rendering to control for potential color bias, as previous work [Seifi et al. 2012] showed that certain perceived emotions were enhanced when the color matched the expression in painterly rendered images of human faces. Greyscale was also easier to control in terms of matching the overall appearance of different stylizations to each other.

We acquired a set of animations from a professional animator which convey the six basic emotions: Anger, Happiness, Sadness, Fear, Surprise and Disgust, according to Ekman's classification [Ekman 1992]. For the dialogue, we provided the animator with audio replicating a previously validated list of affective sentences for spoken emotion identification [Martin et al. 2006]. Each sentence lasted approximately 3 or 4 seconds. In the experiment, we chose not to play the audio, in order that participants could focus specifically on the appearance of the character when making their judgements and to ensure emotion recognition was not too easy due to the content of the audio track. The character performing each of the emotional sentences was rendered in 2 shading styles (toon-shaded, and CG-shaded), under 5 different conditions: Lo/Ab, Lo/Be, Hi/Ab, Hi/Be, and No. Lo corresponded to the low contrast condition, and Hi to the high contrast. Ab and Be referred to the direction of the light coming from above or below the character's head. Finally, the No condition showed no directional lighting information. The animations were rendered using the Houdini 15 software package, at a resolution of 1280 x 720.

4 Experiment

A within-subjects design was used for this experiment where all participants saw each condition. We used 5-point Likert rating scales in order to collect the subjective opinions of participants towards the different render styles. We were particularly interested in whether the lighting and shading changed their ability to recognise the emotion, and how intense that emotion came across. We were also interested in which styles they found most appealing.

There were 100 trials in total in the experiment: 5 emotions (angry, fear, happy, sad, disgust) x 2 shading styles (toon-shaded, CG-shaded) x 5 lighting conditions (Lo/Ab, Lo/Be, Hi/Ab, Hi/Be, No) x 2 repetitions. In order to avoid fatigue we omitted the surprise emotion as the animation appeared happy to participants in a pilot study, and we included only 2 repetitions in order to account for participant variation. Participants viewed each video clip in a random order, and after each clip they were asked to answer three questions:

Which emotion did the character portray?: Participants were asked to indicate their choice by pressing corresponding keys on the keyboard, marked with the words Angry, Sad, Disgust, Fear and Happy.

How expressive was the indicated emotion portrayed by the character?: Participants were asked to rate expressiveness on a scale of 1-5 by mouse clicking a slider on the screen, with 1 representing a rating of "Not expressive at all" and 5 representing "Extremely expressive". They were instructed to base their decision on how strong an impression of the indicated emotion they saw in the motions of the character.

How appealing was the character overall?: Participants were asked to rate appeal on a scale of 1-5 by mouse clicking a slider on the screen, with 1 representing a rating of "Not appealing at all" and 5 representing "Extremely appealing". They were instructed to base their decision on how much they were captivated by the character appearance.

University ethical approval was granted for the experiment. 23 volunteers (11 male, 12 female) aged between 17-50 took part in this experiment. Participants were recruited mainly via university student and staff mailing lists with different disciplinary backgrounds. They had normal or corrected to normal vision and were naïve to the purpose of the experiment. As a reward for participation, they were given a 5 euro book voucher. The experiment lasted approximately 20 minutes.

5 Results

Recognition Accuracy: We first analysed the results for emotion recognition accuracy. Responses were converted to correct or incorrect and averaged over repetitions. A 3-way Analysis of Variance (ANOVA), was conducted on the data with within-subjects factors *emotion* (5), *shading style* (2), and *lighting condition* (5). A main effect of emotion was found ($F(4, 88) = 5.4, p < 0.0007$). Posthoc analysis was conducted using Newman Keuls comparison of means, for this and all subsequent tests. Results indicated that sad and disgust were the least recognised, with angry, fear and happy being equally recognised. All were recognised above 80% accuracy, indicating the participants were very good at the task of recognising emotion. No other main effects or interactions were found, indicating that the shading style or the lighting condition did not affect accuracy.

Intensity: Results for emotion intensity were then analysed, using a 3-way ANOVA, with the same conditions as before. A main effect of emotion was found ($F(4, 88) = 25.07, p \approx 0$). Post hoc analysis indicated that the sad emotion was rated as the least intense ($p < 0.002$ in all cases), fear and disgust next ($p < 0.0004$ in all cases), and angry and happy were rated as the most intense ($p < 0.0004$ in all cases). Intensity ratings were high in general, ranging from 3.11 for fear to 4.15 for angry. A main effect of shading style also occurred ($F(1, 22) = 23.2, p \approx 0$), with posthoc showing that animations rendered in CG-shading were rated as significantly more intense than those that were toon-shaded ($p < 0.0003$) (figure 2(a)).

A main effect of lighting condition was also found ($F(4, 88) = 3.94, p < 0.006$), where posthoc tests showed that all conditions were rated equally intense except for No light which was rated as significantly less intense than all others ($p < 0.02$ in all cases) (figure 2(b)). An interaction between shading style and lighting condition ($F(4, 88) = 3.94, p < 0.006$) gave us further insight, as posthoc tests showed that for CG-shading, there was no difference in ratings of intensity for any of the lighting conditions, whereas in toon-shading there was a difference, with the No light condition, rated significantly less intense than all others ($p < 0.002$ in all cases) (figure 2(c)).

No other interactions were found. In particular, we did not find an interaction between emotion and lighting condition, which was unexpected since we had hypothesised that different lighting conditions would have different effects across emotion (e.g., the angry emotion with a high contrast light below would be considered most intense). However, this was not the case and it seems that, for our examples, intensity of emotion perception is consistent across lighting conditions for different emotions.

Appeal: Finally, we conducted a 3-way ANOVA on the ratings for Appeal. We found a main effect of emotion ($F(4, 88) = 4.55, p < 0.003$), where posthoc analysis showed that the happy emotion was rated as more appealing than all others except for fear ($p < 0.02$ in all cases). Ratings of appeal ranged from 3.0 for sad to 3.42 for the happy emotion. A main effect was also found for shading style ($F(1, 22) = 16.8, p < 0.0005$), with CG-shaded being rated as significantly more appealing than toon-shaded (figure 2(d)).

A main effect of lighting condition was also found ($F(4, 88) = 5.69, p < 0.0004$), where posthoc analysis showed no difference between the light direction conditions (Hi/Ab vs. Hi/Be, or Lo/Ab vs. Lo/Be). However, both low contrast conditions (Lo/Ab and Lo/Be) were rated as significantly more appealing than both high contrast conditions (Hi/Ab and Hi/Be), with $p < 0.02$ in all cases (figure 2(e)). Finally, the No light condition was considered significantly less appealing than Lo/Ab.

One interaction was found between emotion and shading style

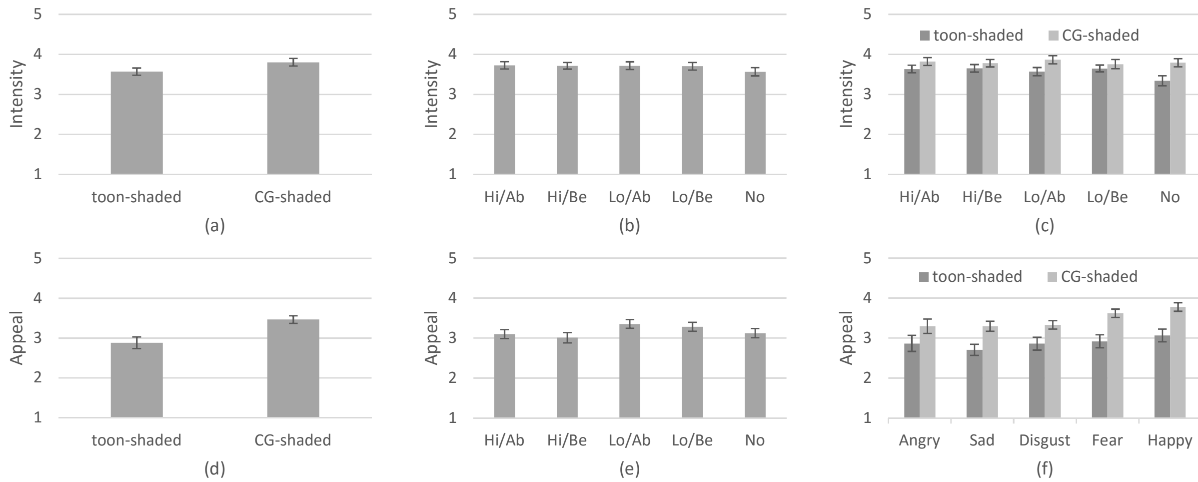

Figure 2: *Averaged ratings of some of the main effects and interactions for intensity (top) and appeal ratings (bottom). Hi:hi contrast, Lo:low contrast, Ab:above light, Be:below light, No:no directional light.*

($F(4, 88) = 2.68, p < 0.04$). Posthoc analysis showed that animations rendered in CG-shading were rated as significantly more appealing than toon-shaded renders for all emotions ($p < 0.0002$ in all cases). As can be seen in figure 2(f), in CG-shading style, all were rated as equally appealing except for fear and happy which were equally appealing, and more appealing than all others ($p < 0.0007$ in all cases). In toon-shading style, the appeal ratings were more even across emotions, with only happy being rated as significantly more appealing than angry and sad ($p < 0.04$ in all cases), and fear more appealing than sad ($p < 0.05$).

6 Discussion

Our results provide new insights into the perception of CG and toon render styles, under different shadow intensities and directions. Our main finding is that the shading style used (CG vs. toon) does not change the recognition of emotion, but does change the perception of intensity of that emotion, with toon-shaded renders being rated as displaying emotions as less intense than CG-shaded across the board. This implies that the smooth shading information in CG is important for the portrayal of intense emotions. Furthermore, we found that for CG-shading, there was no effect of shadow or lighting direction on emotion intensity. We believe this was due to the fact that shading information was present throughout all CG-shading conditions and was enough to convey high emotion intensity. For toon-shading, there was a big drop in intensity when there were no shadows or shading present (No light). These results indicate the importance of shading and lighting on the perception of emotion intensity. We also found that CG-shading was rated as more appealing than toon-shading and that low contrast lighting was preferred to high contrast lighting. Interestingly, we found no difference in appeal for the above and below lighting directions.

It is possible that our toon-shaded animations had lower intensity values than our CG-shaded animations due to the lack of visual information. In particular, the abstraction of the shaded surface could obscure facial shape and features crucial to emotion perception. We believe this could be compensated by more expressive animation and exaggerated contour lines in the toon-shading in order to achieve higher ratings of intensity. Also, we used a standard toon-shading approach which produces realistic shadows which may have contributed to the lower ratings of appeal. More complex toon-shading (e.g., [Todo et al. 2007]) would likely increase appeal ratings.

Our character model had a stylized appearance, optimized to portray emotions, and was animated with strong emotions, which may have made it robust to some lighting variations. It would be interesting to determine if lighting has a greater effect on a more realistic character model and using more neutral expressions. Furthermore, it is typical for artists to combine multiple cinematographic techniques with different psychological effects to increase the uneasiness of a scene. Future work will investigate different combinations and more extreme shadow examples, such as those used in film noir or tenebrism.

Finally, it would also be important to determine the effect of audio on the perception of emotion intensity. Hyde et al. [2014] found a large effect of auditory emotion level on perceived emotional intensity for their stimuli. In our case, it would be interesting to investigate if the intensity of speech would overwrite the intensity differences due to render style. In our study, we reduced the number of variables to explore by using only one character model and animator style and investigated only greyscale images. The importance of these factors will be investigated in future work.

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