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Interactive toon shading using mesh smoothing

Riyad Al-Rousan, Mohd Shahrizal Sunar*
and Hoshang Kolivand

MaGIC-X (Media and Games Innovation Centre of Excellence),
UTM-IRDA Digital Media Centre Universiti Teknologi Malaysia,
Skudai, Johor, 81310, Malaysia
Email: riyad@magicx.my
Email: shahrizal@utm.my
Email: hoshang@utm.my
*Corresponding author

Abstract: Toon shading mimics the style of few colour bands and hence offers an effective way to convey the cartoon-style rendering. Despite an increasing amount of research on toon shading, little research has been reported on generation of toon shading style with more simplicity. In this paper, we present a method to create a simplified form of toon shading using mesh smoothing from 3D objects. The proposed method exploits the Laplacian smoothing to emphasise the simplicity of 3D objects. Motivated by simplified form of Phong lighting model, we create non-photorealistic style capable of enhancing the cartoonish appearance. An enhanced toon shading algorithm is applied on the simple 3D objects in order to convey more simple visual cues of tone. The experimental result reveals the ability of proposed method to produce more cartoonish simplistic effects.

Keywords: non-photorealistic rendering; mesh smoothing; cartoon rendering; Phong.

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Biographical notes: Riyad Al-Rousan received his BS and MS in Computer Science from Jordan University of Science and Technology, Jordan, in 2005 and 2008 respectively. He is currently working toward his PhD in Computer Graphics at Universiti Teknologi Malaysia under the supervision of Dr. Mohd Shahrizal Sunar. His research focuses on non photorealistic rendering. He is specifically interested in stylised shading and interactive line drawings.

Mohd Shahrizal Sunar obtained his PhD from National University of Malaysia in 2008. His major field of study is real-time and interactive computer graphics and virtual environment. He served as academic member at Faculty of Computing, Universiti Teknologi Malaysia since 1999, where he has recently headed the Media and Game Innovation Center of Excellence (MaGIC-X). He has published numerous articles in international journals, conference proceedings and technical papers, including chapters in books. He is an active professional member of ACM SIGGRAPH and IEEE Computer Society.

Hoshang Kolivand received his MS in Applied Mathematics and Computer from Amir-Kabir University, Iran, in 1999, and his PhD from Media and Games Innovation Centre of Excellence (MaGIC-X) in Universiti Teknologi Malaysia. Previously he worked as a lecturer in Shahid Beheshti University, Iran. He has published numerous articles in international journals, conference proceedings and technical papers, including chapters in books. He is an active reviewer of many conference and international journals. He has also published many books in object-oriented programming and mathematics. His research interests include computer graphics and Augmented Reality.

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1 Introduction

The goal of producing realism has attracted a lot of researchers in the areas of film industry and computer games (Kolivand and Sunar, 2014). While the saturation point of realism was reached, a different area of research has been revealed within computer graphics that goes against this goal. Non-photorealistic rendering (NPR) is a branch of computer graphics which concentrate on the algorithms that generate images in a diversity of artistic and illustrative styles (de Juan and Bodenheimer, 2004; Raskar et al., 2006). In many cases, the photorealistic is not the optimal solution for rendering the scene. In contrast, non-photorealistic image is important for conveying the information and adding the simplicity of complex objects. NPR images distinguished over photographs in many practical advantages such as lack of dispersion (e.g., in scientific illustration), focusing and clarification of essential details (e.g., in maps, caricature and technical illustrations) (Liew Suet Fun et al., 2004; Mandryk et al., 2011).

Shading in computer graphics has an extraordinary ability to express illumination, surface shape and materials (Vanderhaeghe et al., 2011). Many successful shading techniques have been proposed to generate correct physically based shading, which are suitable to express the 3D models in realistic styles (Okabe et al., 2007; Tada et al., 2012). But with emergence of NPR research, shading has been used in stylised manner. However, despite the growing demand for stylised shading in case of NPR, both animators and users are often complain from the complexity and seamlessly nature of the existed stylised shading interfaces. The goal is to allow users to easily generate shading techniques which produce the impression of simplicity as accomplished by artists. The worth mentioning, non-photorealistic shading has become indispensable element in scientific illustrations, artistic illustrations and technical illustration (Gooch et al., 1999; Lux et al., 2013; Todo et al., 2013).

Toon shading is a type of NPR techniques developed in order to produce computer graphics output appear to be hand-drawn (Lake et al., 2000). It often used to convey the cartoon-style at movies, video games and comic books. The intuitive end result of toon shading is very simplistic and exaggerative 2D animation. The main feature of toon shading is the hard edge that separates between the shadowed and illuminated colours on the surface of 3D model. Though toon shading exploited little number of colours, it has an ability express a great amount of information. Figure 1 illustrates how the toon shading technique can depict the 3D models. It is obvious that the toon shading technique employed the shading to convey the light and dark orientations on the surface.

Our method takes advantage of the simplified Phong model in the generation of 2D toon shading from 3D models. Further processing of 3D models is necessary before they can be used as inputs to generate a simplified toon shading image. The proposed method exploited the smoothing operation to eliminate the extra details of the original 3D geometry, which emphasise the simplicity of the final shading effect.

Figure 1 Olaf rendered using cartoon shading (see online version for colours)

Source: Lake et al. (2000)

2 Related work

Gooch et al. (1998) was a pioneer in introducing a non-photorealistic lighting model for technical illustration based on adding two tone-colours (warm colour and cool colour) to convey the perception depth of the object. In Lee et al. (2006), a new shading technique based on modifying the light diction according to surface geometry features is proposed. It enhanced the comprehension of complicated model details. In same context, Rusinkiewicz et al. (2006) introduced a non-photorealistic shading model-based adjusting the light position according to the smoothed normals. It applied multi-scale of shading to convey details of the underlying model at all frequencies.

In context of cartoon rendering, Lake et al. (2000) proposed a very efficient real-time cartoon method to render cartoon style. It is based on the hard shading technique that relies on mapping one-dimensional texture. Barla et al. (2006) extended one-dimensional texture to two-dimensional textures in order to support view-dependent effects, such as depth perception and abstractions levels. Several techniques exploited this approach to convey more visual features such as visual saliency (Kang et al., 2009) and material depiction (Hao et al., 2010).

To provide users more ability to control the stylised shape appearance over 3D model, several techniques have been proposed that modify the shade effect. One of the works that attracted the attention in this context was (Anjyo and Hiramitsu, 2003). They proposed a method to manipulate the highlight shape in stylised appearance.

In Anjyo et al. (2006), a new method to modify stylised light and shade is proposed. It allows controlling some operations such as splitting, scaling, rotation and translation on shaded regions. Wang et al. (2013) introduced a cartoon rendering style based on Phong illumination model. The work in Todo et al. (2007) follow the same idea, presenting a controllable shading method to manipulate the shading and lighting distribution over the surface of 3D model in direct intuitive panting approach.

One of the biggest challenges faced the researchers in NPR is how to produce computer generated images like hand-drawn artist (Gooch et al., 2010). Decaudin (1996) described the first toon shading method to render the cartoon style. They started with generating the outline edges on 3D objects-based CPU implementation. For models with a huge number of polygons, this method is expensive and produce poor outline edges. Silhouette detection, rendering and stylising are very important for toon shading and for NPR in general. Important techniques are presented for the silhouette detection (Raskar et al., 2004; Northrup and Markosian, 2000; Lee et al., 2007).

3 Methods

We return to artistic drawing as a most significant direct motivation for identifying the visual perception principles of shaded images. Artists in real world are able to control the simplicity of shading surfaces according to their aesthetic sense. We use this property to enhance the shape depiction of 3D objects by proposing a toon shading technique to colour the surface of an object in cartoonish way. More precisely, the technique is based on Laplacian smoothing (Vollmer et al., 1999) in order to eliminate the extra surface details of the original 3D geometry. A simplified Phong model then is developed in order to generate a cartoonish image from a simplified 3D model. As a consequence, the simplicity of the final shading effect is emphasised and the cartoonish style is enhanced.

3.1 Mesh smoothing

For some models with high level of details like the bunny, there are too many noises of rough meshes. In context of NPR, these noises frustrate an ability to convey the visual features for 3D surface model. Therefore, it is necessary to eliminate some of the surface details in favour of a more simplified toon shading result. Mesh smoothing has come to control the density of shading and thus to improve their presence in the final shading result.

Figure 2 illustrates the bunny model as input to our proposed method. It could convey more visual features which are considered not necessary in many areas of computer graphics such as cartoon rendering. To remove these derails without affecting the topology of the mesh, Laplacian smoothing has been used. Vollmer et al. (1999) described the smoothing operation according to the idea of pushing the vertices to new positions which determined based on the average of the positions of adjacent vertices. The vertex v_i is computed in the smoothing operation as follows:

$$v_i = \frac{1}{N} \sum v_j \qquad (1)$$

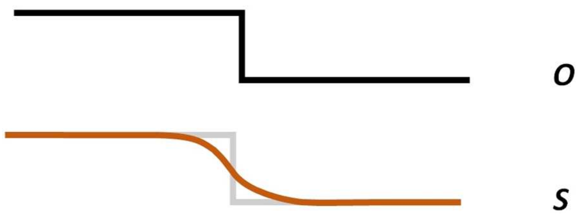
where *N* defines the number of adjacent vertices to the vertex and v_i and v_j represents the all set of theses vertices. Inspired by image processing, we apply the Laplacian smoothing filter in order to obtain the smoothed version *S* from the original 3D model *O* (see Figure 3). The geometry smoothed effect depends mainly on one parameter: the number of iteration of Laplacian smoothing filter to produce the smoothed version *S* from the original 3D model *O*. By modifying this parameter, we can obtain reasonably different visual results. By using a large number of smoothing steps, the level of geometry details decreases. For small number numbers, the opposite effect is obtained. Various choices for number of smoothing iteration are illustrated in Figure 4. It is obvious that the surface details are decreased while the number of smoothing iteration is increased.

3.2 Toon shading

Toon shading considered one of the most NPR techniques to express a great amount of information by using a limited number of colours, silhouettes and sharp features (Lake et al., 2000). Two of the most interesting visual styles are cartoon-style rendering and sharp features. This work presents a combination of these vital features in one non-photorealistic style in order to improve the shape perception and overall appearance.

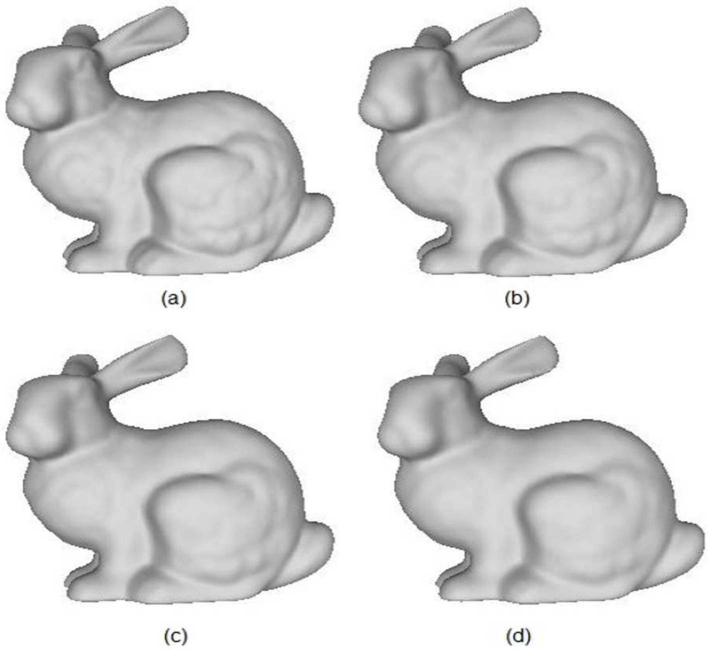
Figure 2 Stanford bunny model

Figure 3 The Laplacian smoothing filter to obtain the smooth signal *S* from the original signal *O* (see online version for colours)



Formulating the light equation that describes the interaction between light source and the properties of the object surface is the first step in creating the toon shader. The simplest way to describe the light reflection from surface is Phong lighting model (Phong, 1975) which combined three types of lighting: ambient, diffuse and specular to convey the final result of light reflection. Traditionally, this type of refection model can effectively convey the photorealistic style. This work exploits Phong lighting model to create non-photorealistic style capable of enhancing the cartoonish appearance.

Figure 4 Different levels of smoothing applied to the original bunny model: (a) the bunny model after three iterations; (b) the bunny model after five iterations; (c) the bunny model after seven iterations and (d) the bunny model after 10 iteration



Here we are going to explain how Phong model can be simplified to emphasise the boundaries between the reflection parts (diffuse and specular) to create a hard edge that separates between the surface colours and enhance the non-realistic style. The next formula can express the Phong lighting model

$$C_i = a_l \times a_m + \max(L \cdot n, 0) \times d_l \times d_m, \tag{2}$$

where C_i is the vertex colour, a_l is the ambient coefficient of light, d_l is the diffuse coefficient of light, a_m is the ambient coefficient of the object's material, d_m is diffuse coefficient of the object's material, L is the light unit vector and n is normal unit vector surface at the vertex. We can note that the specular part is omitted since to the realistic behaviour that give to 3D model. The main contribution of Phong lighting model is the smoothing while transition from ambient to diffuse colour. But as we mentioned before, the main attribute of the toon shaded image is the hard edge that divides the light area and the shaded area. This look of traditional cartoon can be achieved by using threshold for each two colours and applying the discrete numbers for colours. This can be achieved by replacing the max(L, n, 0) in (1) by a threshold function that defined as:

$$\text{thresh}(a,b) = \begin{cases} 0, & a < b \\ 1, & a \geq b \end{cases}. \tag{3}$$

Now we can reformulate equation (1) with new function thresh (a, b) to define new lighting equation as

$$C_i = a_l \times a_m + \text{thresh}(L \cdot n, t_h) \times d_l \times d_m \tag{4}$$

where t_h is the diffuse threshold ($-1 \leq t_h < 1$). This produces the desired effect of creating the hard edge between the illuminated area and shadowed area. The new threshold t_h parameter can effectively control the relative sizes of illuminated and shadowed areas. Small value of t_h creates small dark area and large illuminated area and vice versa for large values of t_h. The flat-shaded colour that consists of one colour can be achieved through setting t_h to 1 or -1.

Although the specular term is omitted from our Phong lighting model, most of the artists desire to add a third colour to the object which represents the highlight of the shape to symbolise the shiny surface (Anjyo and Hiramitsu, 2003; Anjyo et al., 2006). Therefore, it is necessary to render this type of lighting in non-photorealistic style for enhancing the cartoonish style. Specular term in Phong lighting model is expressed.

$$C_s = S_l S_m \left(L \cdot v\right)^n, \tag{5}$$

where S_l the specular is light, S_m is the material colour, L is the light unit vector, v is the view vector and n is the shininess coefficient of highlight. Now, the simplified Phong lighting model combined three different types of lighting separated by hard edge to enhance the cartoonish style. Formula (5) can express this

$$C_i = a_l \times a_m + \left(\text{thresh}\left(L \cdot n, t_h\right) \times d_l \times d_m\right) + (\text{thresh}(L \cdot v, t_s) \times S_l \times S_m), \tag{6}$$

where t_s is the diffuse threshold ($-1 \leq t_s < 1$).

The bunny model is rendered by our technique. Figure 5 illustrates the proposed toon illumination model to create a hard boundary that separates between colours without using mesh smoothing.

Figure 5 Original toon shading (see online version for colours)

4 Experimental results

The proposed technique is designed with focus on interactive applications such as video games and cartoon applications. Our main focus has been to incorporate the complex 3D models into the toon rendering style. In our experiments, we evaluate the proposed technique using a set of complex 3D models that often ignored in many cartoon applications. The end result is a simplified cartoon style that works with simple illumination models such as Phong shading.

Compared with other toon shading techniques (Kang et al., 2009; Wang et al., 2013), the proposed technique effectively enhance the cartoon style by smoothing the complex 3D models without impairing the ultimate appearance. Detail-adaptive toon shading (Kang et al., 2009) introduces abilities similar to the proposed technique in the context of incorporating the complex 3D model. However, the technique cannot exploit the underlying concepts of the Phong shading model in order to render both cartoon shading and minimal shading. Figure 6 illustrates the visual comparison between our shading technique and the detail-adaptive toon shading (Kang et al., 2009).

On the contrary, Wang et al. (2013) introduced a toon shading technique improved from Phong illumination model which allows the user to control the shading effect over 3D model surface. However, this technique cannot render the complex models without impairing the cartoon style. Figure 7 gives us the comparison of our toon shading technique and cartoonish results of Wang et al. (2013).

Figure 6 Comparison with toon shading technique proposed by Kang et al. (2009): (a) the Phong shading model; (b) Wang cartoon result (Kang et al., 2009); (c) the The toon-shaded style proposed by our technique ans (d) the The toon-shaded model after 5 iterations (see online version for colours)

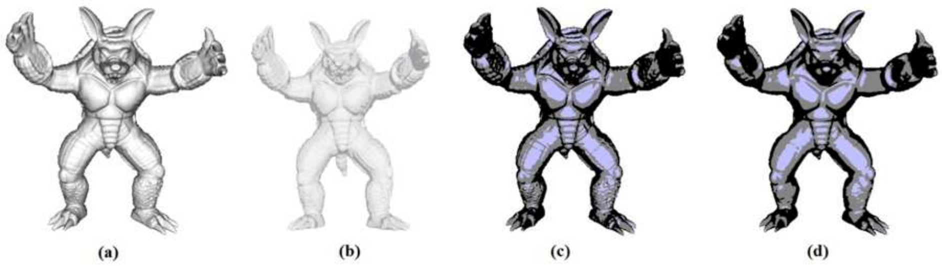
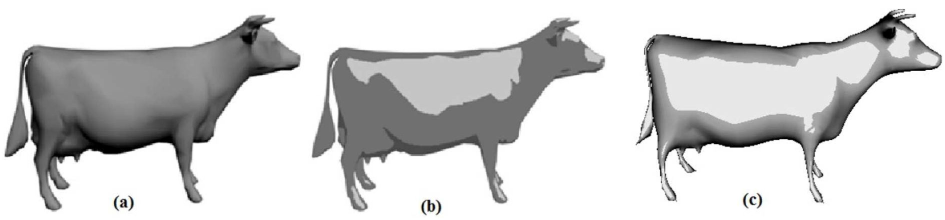


Figure 7 Comparison with toon shading technique proposed by Wang et al. (2013): (a) the Phong shading model; (b) Wang cartoon result (Wang et al., 2013) and (c) rendering with our proposed technique



The final results of this research show that our stylised shading technique can effectively produce simplified cartoonish appearance for 3D models. The proposed technique was tested with NVIDIA GeForce GT 525 M display card and Intel (R) Core (TM) i7-2630 QM CPU. Figure 8 illustrates the toon shading effect with different levels of smoothing. The final results illustrate that as the number of iterations increases, the simplicity of shading effect increased. More models rendered by the proposed shading method are shown in Figures 9 and 10, respectively. It is obvious the ability of our technique to render the complex 3D models such as Stanford dragon and elephant model in the context of cartoon style.

Figure 8 Different levels of smoothing applied to the original toon shading: (a) the bunny model after three iterations; (b) the bunny model after five iterations; (c) the bunny model after seven iterations and (d) the bunny model after 10 iterations (see online version for colours)

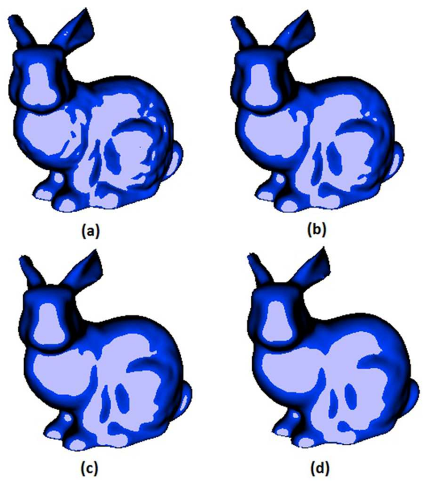


Figure 9 Toon shading through mesh smoothing: (a) starting from Stanford dragon model; (b) applying toon shading; (c) the dragon model after 10 iterations of smoothing and (d) the toon-shaded dragon model after 10 iterations of smoothing (see online version for colours)

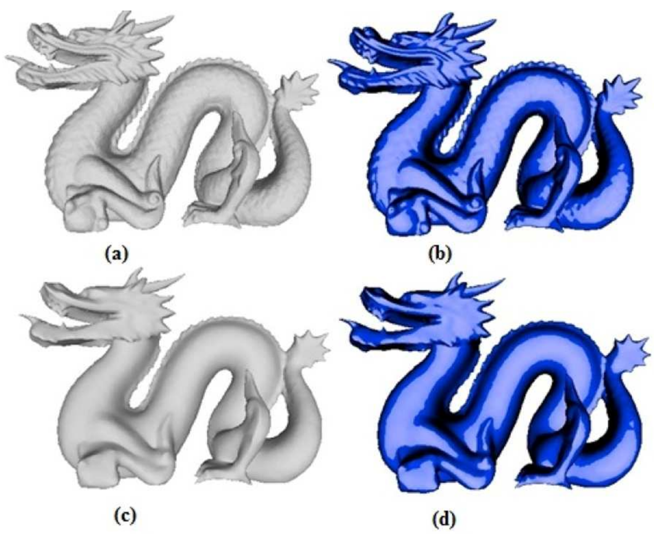
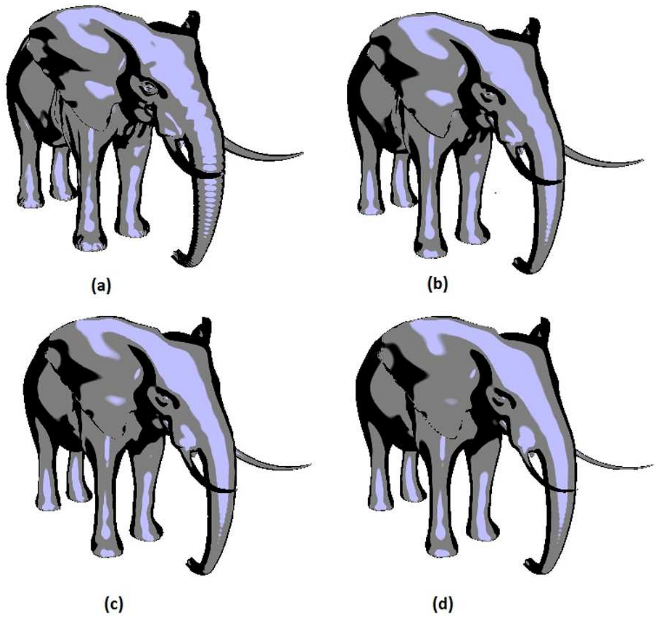


Figure 10 Toon shading through mesh smoothing: (a) applying toon shading to the elephant mode; (b) the toon-shaded model after 3 iterations; (c) the toon-shaded model after 5 iterations and (d) the toon-shaded model after 10 iterations (see online version for colours)



5 Conclusion

In this study, we were able to propose an interactive toon shading technique that decreases the extra surface details of the object and enhances the simplicity of final shading effect. The main contribution of this research is to depict the shape through shading in a way that based on mesh smoothing. This technique can be applied on a wide variety of 3D models with more ability of controlling the shading appearance over the surface of 3D model.

Currently, our work is limited to creating toon shading effects with feature simplicity available. In future, it will be interesting to see how other features such as line drawings can be combined in order to enhance the shape depiction.

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