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3D Medical Illustration Approach using real Patient Dataset

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Abstract Traditionally, there are three primary 3D rendering techniques applied to medical data which are surface rendering, volume rendering and maximum intensity projection (MIP). However, current medical society looks into non-photorealistic rendering (NPR), which offers a more interesting way to represent 3D medical data. The NPR techniques can adapt hand drawn medical illustration style such as water colour and pen and ink illustration. Another advantage of medical illustration in NPR is the capability to effectively present information and provide a familiar environment to medical practitioner had been trained with similar images for years. However, most of the NPR methods purpose such pen and ink, hatching and stippling and cartooning are based on standard medical data set. This paper investigation to see the impact of NPR techniques representing a real patient's CT scan dataset. New medical illustration shading is introduced, which adds an opacity variable to the traditional Phong shading. These illustration styles are implemented using the GL shading language, where each of the illustration algorithms is transformed to programmable vertex and fragment shader. Based on the questionnaire conducted, the medical illustration styles is preferred compared the traditional shading style. The overall rendering performances for all the medical illustration styles are above 37 fps which fulfill the real time rendering requirement.

Keywords: **Non-photorealistic rendering, Patient dataset, medical illustration rendering**

1. Introduction State Many sophisticated medical visualization for 3D medical images can help medical practitioners to understand more the human anatomy. The approach of medical visualization can be divided into volume and surface rendering, both with their own advantages and disadvantages. Even though direct volume rendering able to display 3D medical images without the segmentation process, gaining the multi dimensional transfer function for each organ on real patient dataset were a daunting task. Plus, volume rendering is usually much slower to render when compared to surface rendering. However most of previous works are on volume rendering based on standard medical dataset or dataset that accompanied with predefined transfer function. Fewer attempts are made to study the effect of NPR styles on real patient dataset.

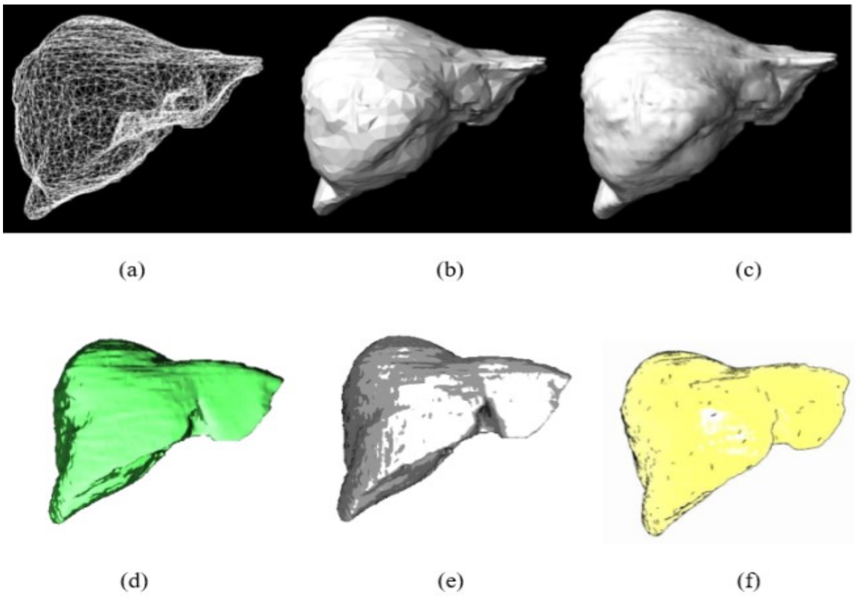

Figure 1. Variation of liver visualization using various shading methods.

NPR visualization option is not commonly found in current 3D applications. The standard rendering option for 3D medical application are wireframe, flat shading and smooth shading either adapting the Gouraud and Phong shading algorithm. However other option such as cartooning by Decaudin and technical illustration by Gooch shading has found their way in some 3D applications. Rendering the 3D liver and tumours models using the above shading option gave the following result as shown in figure 1 (a-c) for the traditional rendering option and figure 1 (d-f) for the NPR option. The wireframe (a) is unlikely the preferred rendering option for medical practitioner, since it provides massive amount of lines that can confused the depth information. Even though the flat shading (b) could represent the depth information, the output seems unpleasing and unrealistic caused by the jagged edges. The smooth shading gives a better representative of a 3D liver model, but still look 'plastic' in appearance. The cartoon shading (d) and (e) give alternative to smooth shading but still cannot deliver the notion of medical to it. The Gooch rendering (f) is suitable for technical illustration but lack in medical impression. Thus, to fully fulfill the medical illustration needs, a 3D representation of anatomy textbook material must provided to the medicals practitioner, a scene where they has been familiar of, by introducing an alternative medical illustration algorithm.

Non-photorealistic rendering (NPR) is an area of computer graphics that focuses on enabling a wide variety of expressive styles for digital art. In contrast to traditional computer graphics, which has focused on photorealism, NPR is inspired by artistic styles such as painting, drawing, technical illustration, and animated cartoons. An amazing amount of work has been carried out in the field of NPR since its emergence around 1990 introduced by Haeberli. Although not trying to exactly imitate the work of human artist, most researchers in photorealism have modeled their expressive effect on a well known image style such as pen and pencil, oil painting, water colour, and so on.

Starting in 1990, the medical community has started to take interest in NPR approach. The pioneering work by Saito and Takashi, has open the flood gate for 3D medical illustration. Later, Saito has introduced 3D scalar fields for a real time viewing of volumetric data. Csébfalvi and Gröller have introduced an interactive volume rendering technique called 'bubble model', where the iso-surfaces are rendered as thin semitransparent membranes similarly to blown soap bubbles. The bubble model can be combines with Phong shading surface to develop a better representation of the skull.

Stipple drawing is a pen and ink illustration that uses dots to present a surface by the point distribution and contrasting colour. Lu et al has presented stippling technique for volume rendering that can generate appropriate point lists at all resolution during an automatic pre-processing. Another stippling technique for the medical dataset can be found in paper by Baer et al. This technique does not require a pre-processing for placing points on surfaces. The surfaces are automatically parameterized to apply stippling textures guided by a decomposition of the space in cubes.

Hadwiger, Berger and Hauser have introduced a two-level volume rendering. Several objects are assigned with individual transfer function and then are rendered separately through several passes using the available rendering techniques such as the surface rendering, direct volume rendering and NPR. Tietjen, Isenberg and Preim have introduced a medical illustration that combined silhouette, surface and volume rendering for surgery education and planning. They have employed object-based edge detection for the silhouette rendering and have used direct volume rendering with shaded surface rendering. Another stunning illustrative visualization on volumetric data is done by Stefan Bruckner, where he had introduced low and high level abstraction techniques. The purpose is to have quality output as compared to real time rendering.

Most of the NPR visualization on the medical dataset are using the volume rendering method. The medical dataset used are the standard test data from Stanford University and University of North Carolina, Chapel Hill which consist of a CT head, MRI brain, terra-cotta bunny, 3D knee and so on. The transfer function for these data can be easily generated because these data are already cleaned and faultless. Some researcher input dataset has been professionally segmented and given separate multidimensional transfer function. On the contrary for a real patient dataset, the multidimensional transfer functions are hard to obtain because there is a huge parameter space which dependable on the complexity and condition of the volumetric dataset itself.

2. Methodology The methodology starts by introducing a new medical illustration shading model based on common features recognized to the hand drawn illustration. Then, three medical illustration styles are introduced in the sub-section which including the outline illustration, the stippling illustration and the shaded illustration which based on the new medical illustration lighting model, named as z-ray illustration.

Based on the medical illustration in several books and site, it can be concluded that medical illustrator used an algorithmic principles. Even though there are a wide variety of style and techniques, there are also some common characteristic when involving the shade of the examined organs. Figure 2 illustrates liver in hand drawn medical images.

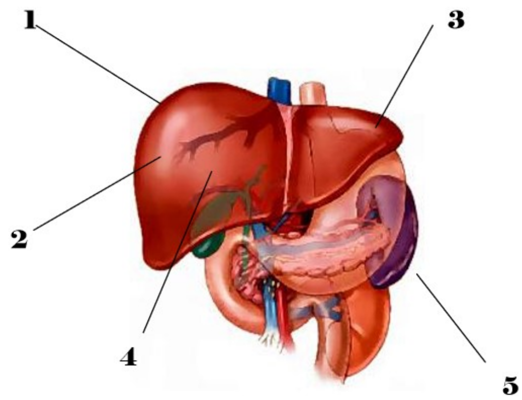

Figure 2 : An example of liver illustration showing the five characteristics taken from website of Hepatitis Foundation of NZ

Thus, after observing these medical illustration images, the following characteristics are recognized:

1. Edge lines are drawn with dark or black outline
2. Darker colour from the edge and continuing to lighten towards the inner of the organ
3. A highlight in the upper left of the organ, with a lighter or white colour
4. A transparent area in the middle of the organ showing the inner stuff if applicable
5. Shadow of the organ is not rendered should be clear and concise.

To develop a shading method that compliments the above features, an equation is needed to develop in representing the interaction between the light source and organ's material. In normal rendering, this interaction built up the shading equation or shading algorithm. In the next sub-section, a brief introduction on the traditional Phong shading equation is given, which then enhanced by building the medical illustration shading equation to suit the above characteristic of medical shading requirements.

A. The Phong Shading

The Phong Shading model may also be refers to as the Phong reflection model, Phong illumination or Phong lighting is one of the most used shading equation in producing a near real world representation of the light and material interaction. It is consisted of three elements as shown in figure 3 below, which are the ambient, diffuse and specular variable. The correct combinations of these elements give an object the individuality appearance.

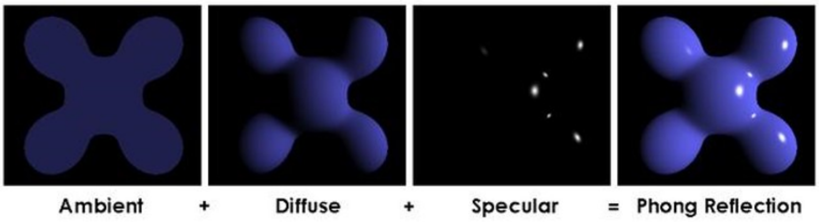

Figure 3: Phong reflection shading variables taken from Wikipedia.

The original Phong shading equation may be explains by the following equation,

$$i_p = i_{ambient} + i_{diffuse} + i_{specular} \quad (1)$$

where the RGB colour of a point i_p is the combination of $i_{ambient}$, $i_{diffuse}$ and $i_{specular}$. The ambient variable give the overall colour of an object, the diffuse variable give the intensity to the colour which creates dark and light shade on the object and finally the specular variable contributes the glossiness of an object. These basic variables in Phong shading are able to accomplish the second and third characteristic of the hand drawn medical illustrations, which are the dark shading edges and the upper left highlight. However the forth characteristic which is the transparency area showing the inner structure is still needed. Therefore in the following section, a new medical illustration shading model is introduced by fixing the diffuse and ambient variable, as well as adding the transparency characteristic.

B. The Medical Illustration Shading

The proposed medical illustration model consists of four elements which are the ambient, diffuse, specular and opacity variables in order to fulfil the above medical illustration characteristics. The ambient variable of i_a should remains as a constant, which will hold the RGB colour of an organ. Three new variables are introduced which are i_{dm} , i_{sm} and i_{om} to represent the diffuse, specular and opacity variable respectively in the shading model. The figure 4 illustrates the combination of these variables in producing the final medical illustration output.

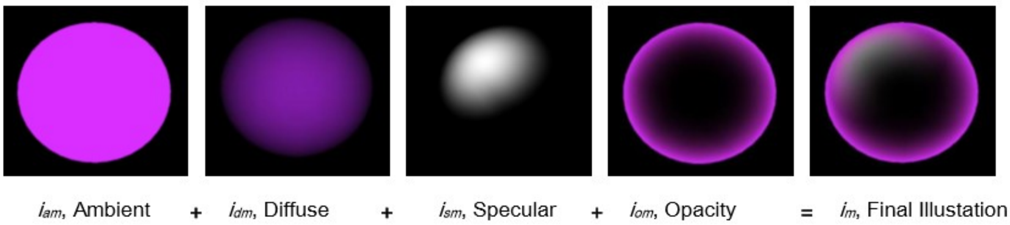

Figure 4: Medical illustration shading variable

C.The Medical Diffuse Variable

Looking back on the characteristic of shading in hand-drawn medical illustration, the intensity of the colour fades from the edge toward the centre of the organ. Darker colour can be seen on the edge and continuing to lighten towards the inner of the organ, where the lightest colour will be proportional to the viewing angle. The Lambert cosine law states that the brightness of a dissfusely radiating surface is proportional to the cosine of the angle form the line of sight and the normal to the surface. Figure 10 illustrates the diffuse reflection interaction between viewing point and the normal surface at the points A, B and C. Point B has the highest intensity value because the angle between the viewing vector, V and the normal vector, N is close to 0. Point A has a darker intensity because the angle is almost 90 degree. Finally point C should not be rendered because the angle is more than 90 degree, which indicates that the surface is facing backward from the viewing point.

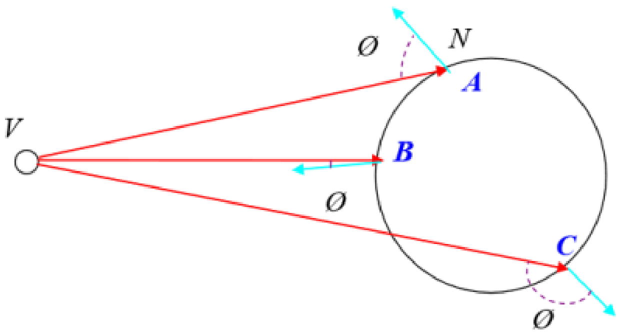

Figure 5 : The viewing vector, V and normal vector, N interaction

Thus for the medical diffuse variable, the light source is assumed to be in the same position as the viewing point, therefore the dot product of the viewing point vector and normal surface vector can be used to get cosine. The equation for medical diffuse variable at the point i_{dm} is given in the equation (2), where the viewing position remains at the eye position of (0,0,0) and h_d represents the diffuse reflection constant.

$$i_{dm} = h_d (V \cdot N) \tag{2}$$

D.The Medical Specular Variable

The specular variable is used to give the highlight appearance on the upper left reminiscent of the hand-drawn illustration. The Phong model states that the specular component is proportional to the cosine between the light reflection vector, R and the viewing vector, V, where R is the light vector, L mirror reflected on the surface.

If the viewing vector coincides with the reflection vector then the maximum specular intensity is achieved. As the viewing vector diverges from the reflection vector, the specular intensity starts to decay. The rate of decay is controlled by a shininess factor. The higher the shininess factors the faster the decay. This means that with a high shininess the bright spot caused by the specular component is smaller than with a low shininess value.

For the medical specular variable, the light position must be on the upper left of the viewing point. The specular term is large only when viewing vector, V aligned with reflection vector, R. Their alignment is measured by the α power of the cosine angle between them as shown in figure 6. The cosine of the angle between the normalized vectors R and V is equal to their dot product. When α is large, in the case of a nearly mirror-like reflection, the specular highlight will be small, because any

viewpoint not aligned with the reflection will has a cosine less than one which rapidly approaches zero when raised to a high power. The medical specular variable,
i_{sm} is given as follow,

$$i_{sm} = h_s(R \cdot V)^{\alpha} \tag{3}$$

where the L position must be setting on the upper left corner of the viewing component and hs represents the specular reflection constant.

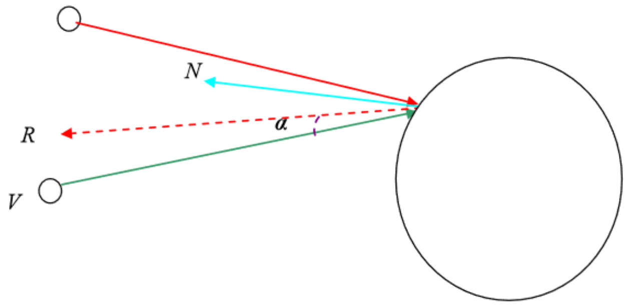

Figure 6 : The viewing vector, V and reflection vector, R

E. The Medical Opacity Variable

The opacity variable is needed to achieve the hand–drawn illustration inspiration that enabled the inside view of an organ. This variable is needed to fill the characteristic the medical illustration, where the highest transparency must be parallel to the viewing point. Therefore the same equation for the medical diffuse variable may be applied to opacity variable, which can be represents in equation

$$i_{om} = (V \cdot N) \tag{4}$$

To wrap up the medical illustration shading, the above four variables are combined together to get a new shading algorithm as given by equation (5). The value of ambient and diffuse variable is multiplied by the opacity variable, to get the basic shaded and transparent organ representation. Then the specular variable is added to give the highlight appearance on the organ. Figure 7 demonstrates the output of using the medical illustration shading model compares to the Phong shading model. In the

medical illustration shading model, the teeth and the skull is more clear and dominant compares to the Phong model.

$$I_m = (I_a + I_{dm})I_{om} + I_{sm} \tag{5}$$

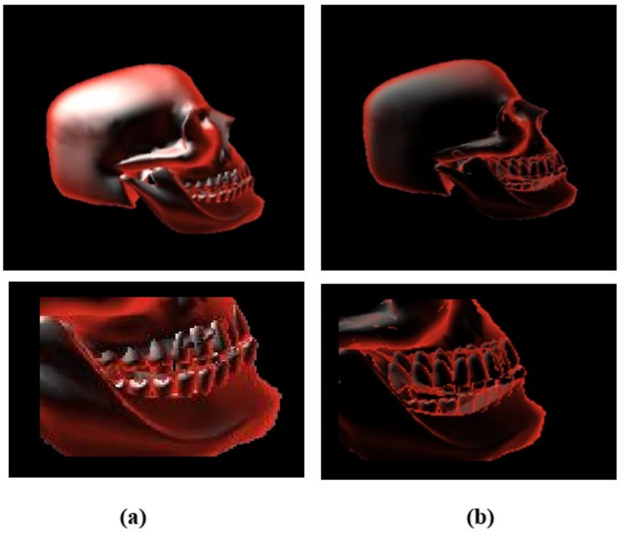

Figure 7: Comparison between (a) the Phong shading and (b) the new medical illustration shading

F. Medical Illustration Algorithm

A two-pass rendering method introduced by Raskar and Cohen is chosen because of its efficiency and reliability to give a clean and smooth silhouette line. This method renders an outline, slightly larger than the object itself. Back-face culling is inverted and the back-facing triangles are drawn in black. To dilate the silhouette, these back-faces may be drawn in wire frame multiple times with slight changed in translation. Alternately, back-faces may be rendered solid-filled, with their vertices translated along their vertex normal. After drawing the outline, back face culling is set back to normal in order to draw the shading or optional textures of the object. Finally, the image is composited via Z-buffering, as the back-faces always lie deeper in the scene than the front-faces.

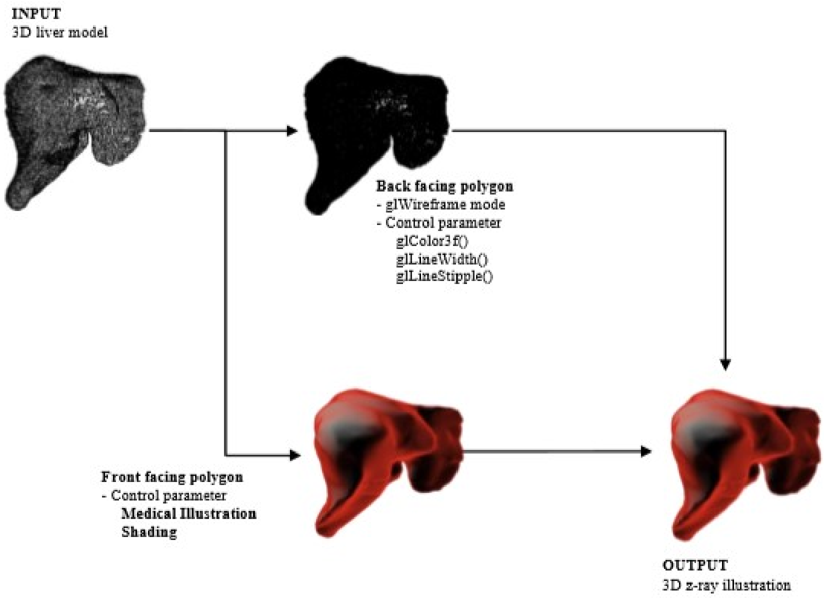

Figure 8 : Z-ray illustration algorithm

The z-ray illustration algorithm is given in the figure 8 above. The input for the algorithm is a 3D liver model. This model is rendered two times; first the back facing polygons is rendered using the glWireframe mode. The glColor, glLineWidth and glLineStipple functions can be use to create a variation for the silhouette line representations. The glColor function takes the RGB values to give different colour line. Meanwhile the glLineWidth function controls the thickness of the silhouette lines and finally glLineStipple function represents dash pattern lines. The second rendering pass is done using the medical illustration shading described in earlier. The control parameters for the second pass are the value of ambient, diffuse, specular and opacity variable.

Figure 9 shows an example of a liver and tumour rendered in z-ray illustration style with a black background, a dark red for the liver and green for the tumours. The figure illustrates different angle of the liver and tumours.

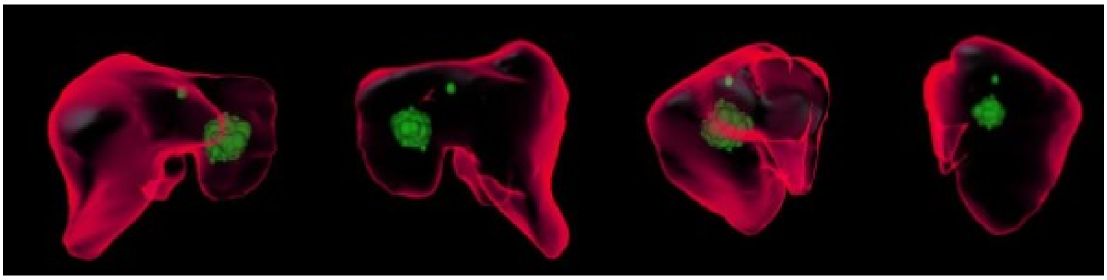

Figure 9 : Different angle of medical illustration of the liver and tumours.

3. Results and Discussion There is no bench marking when validating NPR visualization. Normally the researcher will compare their output to the styles that they wanted to achieve. There is also researcher that conducted a survey to check on the user preference by doing a questionnaire. The validation are conducted into two parts. The first validation check whether the characteristic of hand-drawn medical illustration has successfully achieved by the medical illustration algorithm and shader. Meanwhile, the second validation check upon the user acceptance on the medical NPR rendering method.

A. Survey setup

A survey has been done with the purpose of to see the preference of the respondent on CT dataset visualization and to introduce a new method for visualizing the liver and tumours anatomy in 3D environment. The survey has set-up for medical student in the Faculty of Medicine and Health Sciences, Universiti Putra Malaysia with the number of respondents of 108 students. Before the respondents answered the given questionnaire, a brief power point presentation is given explaining the purpose of this survey. In the presentation, justification for characteristic of hand-drawn illustration, example images of hand-drawn and computer generated medical illustration are also given. The overall respondents are between the age of 18 and 21, and constitute of 44 percent male and 56 percent female respondents. When asked on their preference between a textbook and digital model, 17 percent preferred the text book and 83 percent perforce the 3D model application which can helped

better in mentally visualized an organ. Next, they are asked on how well does a 2D CT scan images and 3D visualization represented the spatial location of a tumour relative to the liver.

B. Medical Illustration Similarity Validation

The medical illustration styles validation are designed to check whether the output from the illustration styles algorithm and shader proposed has fully achieved the common characteristic of the hand-drawn illustration. The table 1 shows the summary characterized comparison between the hand-drawn illustration and computer generated illustration using the medical illustration styles algorithms and shaders. The computer generated medical illustration has successfully accomplished the hand drawn illustration characteristics, thus indicating the successfulness of the developed medical illustration style algorithms and shaders.

TABLE I. TABLE TYPE STYLES

Hand-drawn Characteristic/Feature	*Computer Generated*
Edge lines are drawn with dark or black outline	√
Darker colour from the edge and continuing to lighten towards the inner of the organ	√
A highlight in the upper left of the organ, with a lighter or white colour	√
A transparent area in the middle of the organ showing the inner stuff if applicable	√
Shadowing is not shown (similarly to technical illustration)	√

Further comparison on the hand-drawn illustration and computer generated illustration using the medical illustration styles algorithms is done by the previously conducted survey. Complimenting the questionnaire is figure 10 illustrating a one to one evaluation between the hand-drawn illustrations with NPR medical illustration that had been generated. The subject are asked on their opinions on the similarity between these images, where 1 represents as not agree and 5 represents as totally agreed.

Figure 10 : Comparison between hand-drawn illustrations with computer generated illustration

4. Conclusions The problem in producing this alternative rendering is finding the best way to represent the 3D model that appealing to the medical practitioner. Therefore a series of NPR selection

for alternative medical illustration rendering algorithm has been developed which included the outline illustration, stippling illustration and z-ray illustration. The z-ray illustration is based on a new shading method named medical illustration shading, which adds an opacity variable to the traditional Phong shading. These illustration styles are implemented using the GL shading language, where each of the illustration algorithms is transformed to programmable vertex and fragment shader. Based on the questionnaire conducted, the medical illustration styles is preferred compared the traditional shading style. The overall rendering performances for all the medical illustration styles are above 37 fps which fulfil the real time rendering requirement.

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