Non-photorealistic Rendering Using an Adaptive Halftoning Technique

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Abstract

One of the common goals of Non-Photorealistic Rendering is to emphasize or highlight particular image attributes by using different rendering styles. In order to do this often other information such as depth, surface or lighting information is incorporated into the rendering process. Most halftoning techniques try to preserve particular image attributes such as grey-scale intensities or edges, while avoiding the introduction of artifacts into the resulting image. In *Importance Driven Halftoning* Streit and Buchanan [1] introduced a technique that allows the preservation of other attributes by controlling rendering through the specification of the importance function and the chosen type of drawing primitive. This paper illustrates how importance driven halftoning can be extended for the creation of non-photorealistic images with information outside the 2D grey-scale image such as a 3D scene or model. Our extensions to Importance Driven Halftoning will provide the user with control over drawing primitives for the creation of tone and texture which is needed to create non-photorealistic images.

Keywords: Halftoning, Importance function, Non-photorealistic rendering, Drawing primitive, Texture, Tone

1 Introduction

The display of images using non-photorealistic rendering (NPR) allows the image to be presented so that important aspects of the image are highlighted. Some important aspects can be extracted from the image such as edges, however there may be other information that the designer of the image may wish to use. This additional information may include the distance of the object from the camera, the location of the object in the camera plane, and the importance of the actual object. In this paper we use this additional information as an importance map to control the way in which the image is rendered. The display of the resulting image is then possible on a variety of devices. When the image is displayed on a binary device the enhanced image must be halftoned, possibly causing the destruction of the effects used to highlight the important aspects of the image. Thus, this paper will be limited to the discussion of rendering techniques that are comprised of two tones, in particular pen-and-ink illustration techniques.

Currently, there are two possible methods that allow for the incorporation of outside information or allow the user to emphasize certain image attributes. One class of techniques allows for the procedural generation of textures, common to many pen-and-ink illustration techniques. These techniques generally control the placement and type of texture allowing for the emphasis of information based on the amount and variation in texture. While they do allow for the introduction of many different textures including *traditional illustration* textures, they trade off this control of texture at the expense of accurate tone reproduction. The second class of techniques include adaptive halftoning methods. These techniques allow for control over texture while accurately reproducing tone without a tremendous amount of user interaction. Thus one technique in particular has been chosen from this class as the focus of this paper - Importance Driven Halftoning.

Importance Driven Halftoning [1] is a halftoning technique that allows the user to have control over the resulting image by having the user specify an importance function and the types of drawing primitives to be used. This enables the control of global distribution or density of drawing primitives as well as local control over texture or high frequency information. The technique not only controls the primitives and some of their properties, but ultimately allows the user to decide which image information should be rendered with which drawing primitives. This technique was previously presented using 2D information mainly for producing photorealistic effects.

In this paper, Importance Driven Halftoning is extended to use

*On leave at Electronic Arts, Vancouver, Canada scene information to produce non-photorealistic renderings of various types of image information. Some of the information used to create the various effects include lighting, surface and depth information from the model or scene. Results created using other texture information in conjunction with the original image's intensity map are also shown. Our extensions to Importance Driven Halftoning provides the user with control over drawing primitives for the directed creation of texture, necessary for non-photorealistic images.

An overview of the similarities of halftoning and non-photorealistic rendering are presented in this paper. After reviewing the background in these two areas, the basic technique of Importance Driven Halftoning will be outlined. The details of how this technique is extended and examples of it's additional functionality are provided. These include examples of using 3D scene information, external texture information, and regions of emphasis in the image or scene.

How Similar are Halftoning and NPR?

The main difference between halftoning an non-photorealistic rendering is the control of texture. Halftoning techniques typically focus on eliminating unwanted high frequency or texture information where pen-and-ink illustration techniques purposely introduce texture to enhance or alter the rendition of image attributes [2].

The second difference is the amount of user intervention. Halftoning is generally an automatic process for the display of continuous tone images on bi-level devices where pen and ink illustration techniques typically demand a large degree of user intervention. More recently however, halftoning techniques with user controlled texture parameters have been presented [1, 3]. Furthermore, less user intensive pen-and-ink techniques have been presented [4, 5, 6].

Non-photorealistic rendering techniques are often used for the creation of art works or illustrations such as medical illustrations or technical drawings. In non-photorealistic rendering the goal may be to render a scene or to re-render another image. In the case of halftoning the starting point has typically been a grey-scale image. In either case the initial data is represented as image information whether that be intensities, light information or viewpoint. To produce a non-photorealistic rendering the task then becomes how to display this information in an image using particular primitives, textures or styles. Ultimately, this requires the user to have some degree of control over the placement of drawing primitives.

Two-tone Rendering Techniques

Non-photorealistic rendering techniques typically strive to achieve three effects: tone, texture and outline [5, 2] Pen-and-ink renderings create these three effects in a variety of ways. Tone is typically created by defining different *stroke textures* for varying intensities [5] or by overlaying multiple strokes or textures until the desired tone is achieved [6, 7]. Tone and texture has also been achieved using multiple strokes or parametric curves [8, 9] and contour lines [10]. Texture is defined by the type, thickness, orientation, placement, and quantity of strokes. In this way, texture and tone may not be independent and thus, these techniques tend to trade control between tone and texture. Outline can be created using edge detection [11] and the strategic placement of skeletal strokes [12].

Many traditional halftoning techniques attempt to produce tones that are perceptually similar to the tones present in the original grey-scale image. Some attempt to approximate the tone on an individual pixel basis [13, 14] and others approximate tone over a small local region using what is typically known as a dither matrix [15, 14]. Most of these techniques inadvertently introduce unwanted texture into the rendered image. Some techniques have been developed to lessen the introduction of unwanted texture while preserving tone by optimizing the dither matrix [16, 17, 18, 19, 20, 21], adjusting the propagation of error [22, 23] or adjusting the path taken over the image [13, 24, 25, 26]. Other techniques attempt to preserve the texture in the original image [27, 28, 29]. Finally, there is a class of halftoning techniques which attempt to use texture to provide alternative effects [30, 31, 32, 3]. Most of these however, do not allow the user to create controlled effects.

Both pen-and-ink illustration and halftoning techniques can be generalized to place ink or drawing primitives both globally and locally. In pen-and-ink illustration the stroke textures and placement of strokes determine the global placement of ink, where the type of stroke and the size, width or curvature will determine the local placement of ink. Schlechtweg and Strothotte [33] alter the global placement of drawing primitives depending on which areas of the image are important and need more detail. The local placement of ink is altered by adjusting the shape or structure of the drawing primitive. However, this technique does not allow the user to control texture and thus, their results are comparable with line drawings [9, 10]. Importance Driven Halftoning has a similar notion of altering both the distribution and the structure of drawing primitives, however it allows the user to indirectly control texture through specific parameters.

2 Importance Driven Halftoning Alterations

Importance Driven Halftoning [1] allows the user to create various halftoned images by controlling three parameters: the importance function, the type of drawing primitives and the number of drawing primitives. The importance function is first evaluated over the original image to form an importance map of the image (See figure 2).

(a) (b) (c)

Figure 1: Original Images (a) Photograph of Lenna (b) Computer generated polygonal model of Beethoven's bust rendered using two light sources. (c) A Grey-scale image of the bones in the human foot.

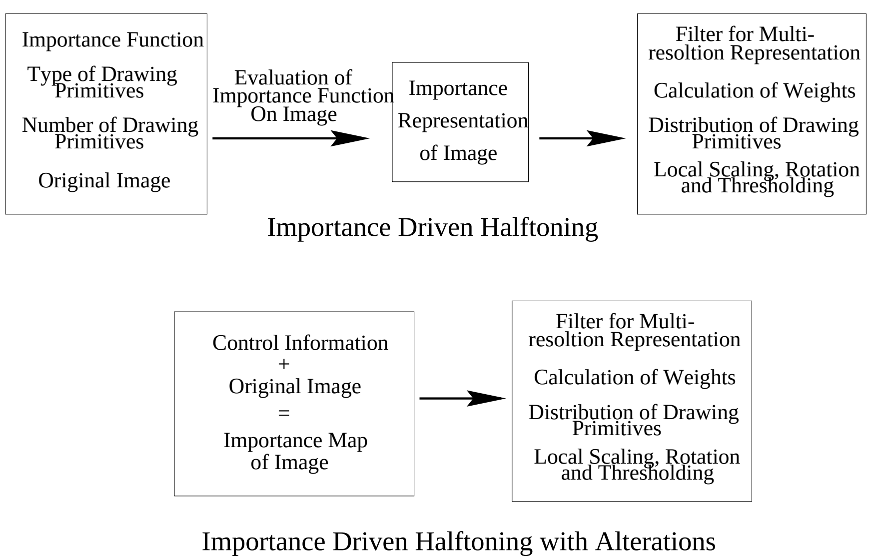


Figure 2: Alteration to Importance Driven Halftoning - The importance map is composed of the original image and control information in the form of another image. This control information enables the importance values to be based on information other than that contained in the original image, unlike the original technique shown above.

This representation of the image is filtered using a box filter to create a multi-resolution representation. Then weights are constructed by comparing neighboring values in this multi-level representation and finally the drawing primitives are distributed according to these weights. Control over the importance function provides the control over the global distribution of drawing primitives. At a local level, the drawing primitives can be arbitrarily rotated, scaled or thresholded to control placement of local texture or detail.

In this paper a segmentation of this process shown in figure 2 is proposed. Instead of the user providing a importance function that is automatically evaluated over the original image, the user defines an importance map. The importance map is composed of the original image and control information in the form of another image. This control information enables the importance values to be based on information other than that contained in the original image, unlike the original technique where the results were generated using variance, gradient and intensity. Since the user has control over the importance map they can use 3D scene information, textures unrelated to the original image, and interactively chosen regions in the image. This means that any 3D scene can be rendered non-photorealistically using the original image (projection of the model into the viewing plane) and whatever other control information from this 3D environment the user may choose to illustrate.

One of the possible uses of this importance map is to control texture. This technique allows for the preservation of relative tone in the original image while providing control over texture by locally *tuning* the drawing primitives according to the control information. The following sections show how this enhancement to Importance Driven Halftoning can be used to render 3D scenes, incorporate external textures or emphasize a region of the image chosen by the user.

3 Original Images used for Illustration

The original images used in this paper are shown in figure 1. Figure 1(a) is a grey-scale photograph of the infamous Lenna. Figure 1(b) is a lithograph of a shepherd done by Peter Hurd [34] and figure 1(b) is a computer generated polygonal model of Beethoven's bust. Finally, figure 1(c) is a computer generated grey-scale image of the bones of a human foot.

4 Using 3D Scene Information

Non-photorealistic rendered 3D scenes is becoming more common. Typically the user focuses on certain attributes in the 3D scene and tries to re-create them in the non-photorealistic image so as to perceptually preserve these attributes. In this section a polygonal model of Beethoven's bust is used to illustrate how external scene information can be used to control the structure of the drawing primitives, and consequently the resulting tone and texture. Figure 1(b) shows this model projected into the viewing plane. This scene also has two light sources, one positioned above the model and the other positioned above and in front of the model. Finally, global ambient light is also present in the scene.

The importance map is constructed using the original image shown in figure 1(b) and three different types of control information: light, surface and depth information. This control information is used to adjust the structure and distribution of drawing primitives in order to control local texturing. This section will explain how the control information is extracted from the 3D scene and collected. It will conclude by presenting some results obtained from using this control information.

4.1 Lighting Information

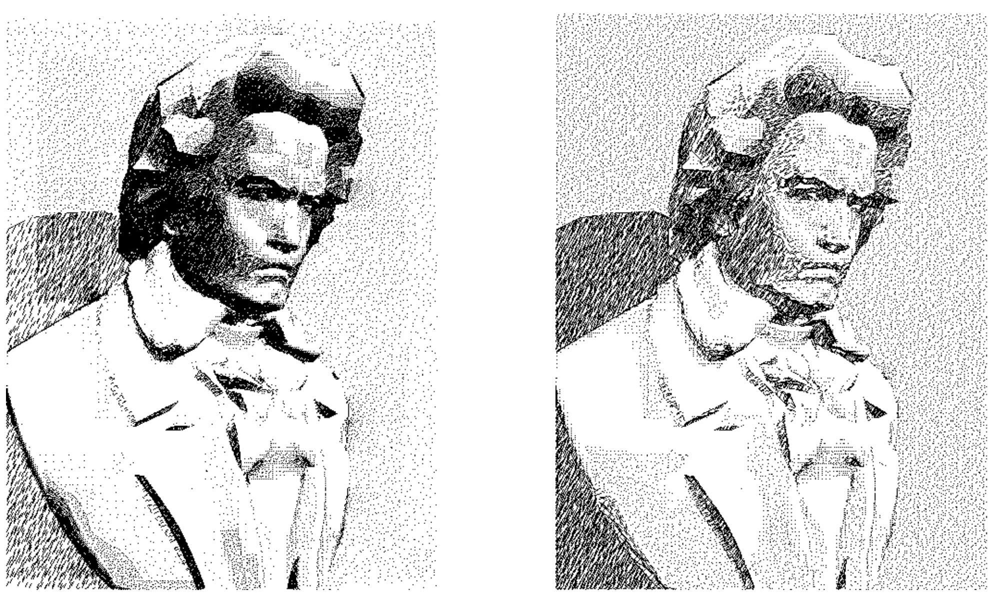
Lighting typically affects both perceived tone and texture. Often in NPR different textures are used in shadowed regions than in illuminated regions. Hence it is natural to adjust the structure of the drawing primitives according to lighting information. In our model the lighting information for each light source is extracted from the scene and then projected into the viewing plane. This information is then mapped to a grey-scale ramp. The image in figure 3(a) illustrates the lighting information extracted for the light source positioned directly above the model and the image in figure 3(b) illustrates the lighting information for the light source position above and in front the model. In these images a value of 255 (white) represents direct light, a value of 127 (mid grey) represents ambient light or self shadowing and a value of 0 (black) represents shadows on other objects. These images represent information that will be used to adjust the drawing primitives.

4.2 Surface Information

Another type of information used to control the structure of drawing primitives and hence texture is surface information. Similar to lighting, different textures are used to show changes in surface attributes or regions of discontinuity. The surface information from the model is extracted by mapping the surface vector to an intensity value. The vector is the angle between the light ray and the surface projected onto the viewing plane. Figure 3(c) shows the surface information for the light source positioned directly above the model. The intensity is 0 (black) where the angle is 0 degrees and is 255 (white) where this angle is π. This surface information will be used as control information for the adjustment of the drawing primitives.

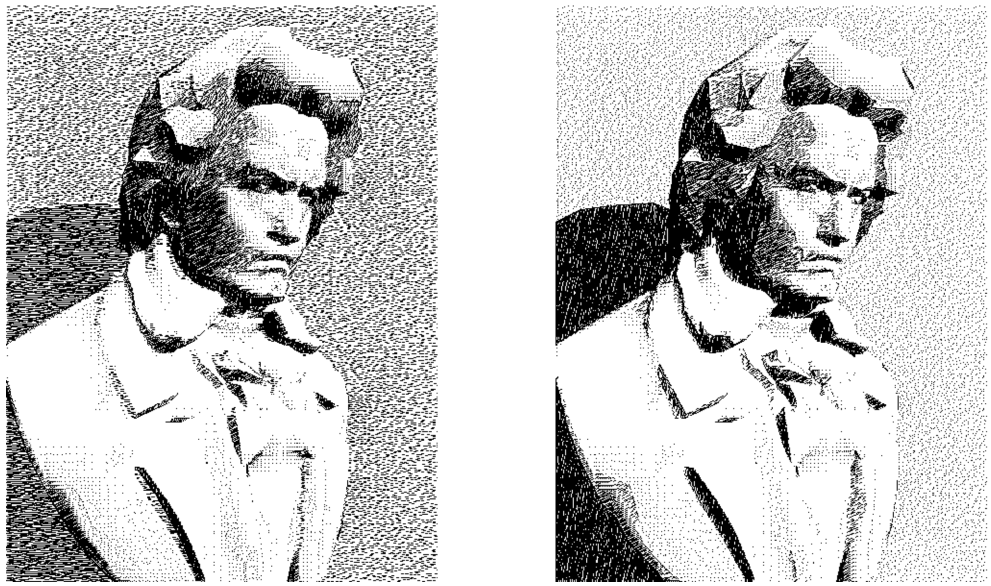
(a) (b) (c) (d)

Figure 3: Scene Information (a) lighting information for light positioned directly above the model (b) lighting information for light positioned above and in front of the model (c) surface information for first light (d) depth information



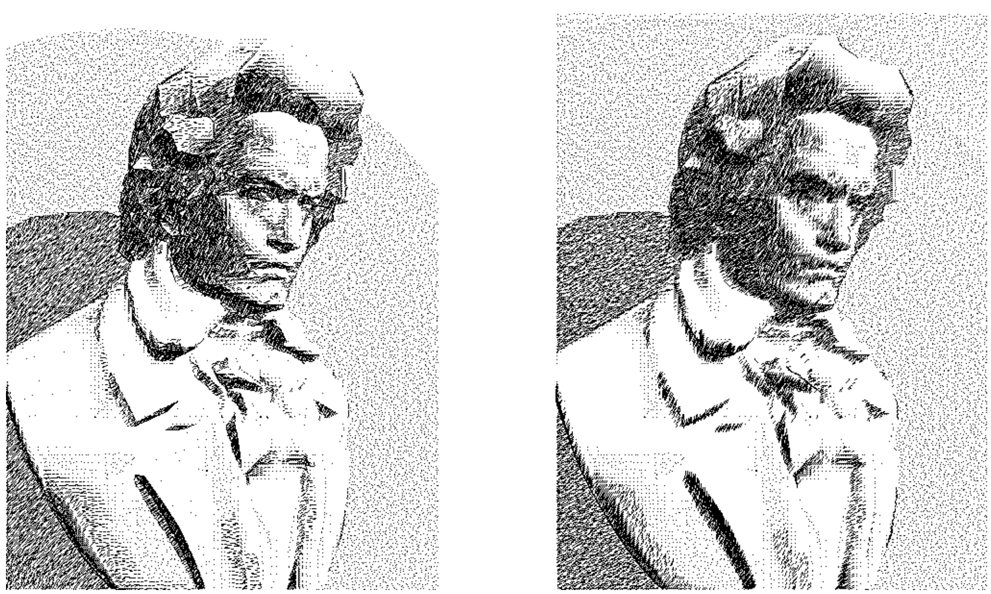
(a) (b)

Figure 4: Alteration of Distribution. Both images distribute 10 pixel lines according to an averaged intensity value. The line segment is scaled, thresholded and rotated according to the original image intensity values. (a) The distribution is made according to an average of the original image intensity values and the lighting information of the image in figure 3(a). (b) The distribution is made according to an average of the original image intensity values and the surface information of the image in figure 3(c).



(a) (b)

Figure 5: Rendering using light information. Both images use the same 10 pixel line as a drawing primitive and distribute the drawing primitives according to the original images intensity values 1(b). They also both scale the line segment to the original image intensity values. (a) the line segment is also thresholded to the original image intensity values and rotated according to the light information found in 3(a). (b) the line segment is thresholded and rotated according to the light information found in 3(b).



(a) (b)

Figure 6: Rendering using depth information. Both images distributed 10 pixel lines according to the original image intensity values 1(b). (a) The drawing primitives are also thresholded and rotated to the original image intensity values, but scaled to the depth information found in 3(d). (b) The drawing primitives are also scaled to the original image intensity values but thresholded and rotated according to the depth values found in 3(d).

4.3 Depth Information

The third type of information used to control the structure of drawing primitives is depth information. Often artists reduce detail in the regions of the image that are further away. To assist in the creation of this effect the drawing primitives can be adjusted according to z-buffer values. The z-buffer information is extracted from the model as the distance from the viewer to the object given the defined view-point in the original scene shown projected in figure 1(b). The closest objects are mapped to 0 (black) and the farthest objects are mapped to 255 (white) as shown in figure 3(d).

4.4 Explanation of Results

Using this lighting, surface and depth control information from figure 3 in conjunction with the original image in figure 1(b) the images in figures 4 to 6 were created. In all these images the drawing primitive is a 10 pixel line segment that is either distributed, or locally adjusted according to the importance map. In these images Importance Driven Halftoning uses the importance map to distribute the drawing primitives and the control information to structure the drawing primitives. The line segment is thresholded by laying a linear threshold matrix over the line as presented in [1]. The line segment is rotated by aligning the line segment in the direction of maximum gradient magnitude in regions where the gradient magnitude is high and by aligning the line segment as a function of intensity in regions of low gradient magnitude.

The images in figure 4 illustrate how the distribution of drawing primitives can be altered using different control information. In these images the structure of the drawing primitive is set according to the original image intensities in figure 1(b). The drawing primitives are distributed according to an averaged intensity value. In figure 4(a) the drawing primitives were distributed according to the average intensity between the original image 1(b) and the lighting information for the first light in figure 3(a). In figure 4(b) the drawing primitives are distributed according to the combined average intensity of the original image 1(b) and the surface information for the first light in figure 3(c). In both cases the drawing primitives are scaled, thresholded and rotated according to the intensities in the original image. Both images distribute the same number of drawing primitives and set approximately the same number of black pixels. In both images relative tone is preserved and yet texture is quite varied due to the alteration in distribution of drawing primitives.

Figure 5 illustrates how the structure of the drawing primitives are altered according to the specified control information. In both of these images the drawing primitives are distributed according to the original image's intensity values 1(b). Both images contain the same number of drawing primitives. In figure 5(a) the drawing primitives are thresholded and scaled to the original image intensity values, but rotated according to the intensity values from the control information from the first light (see figure 3(a)). In figure 5(b) the drawing primitives are scaled to the original image intensity values, but are thresholded and rotated according to the intensity values in the control information from the second light (see figure 3(b)).

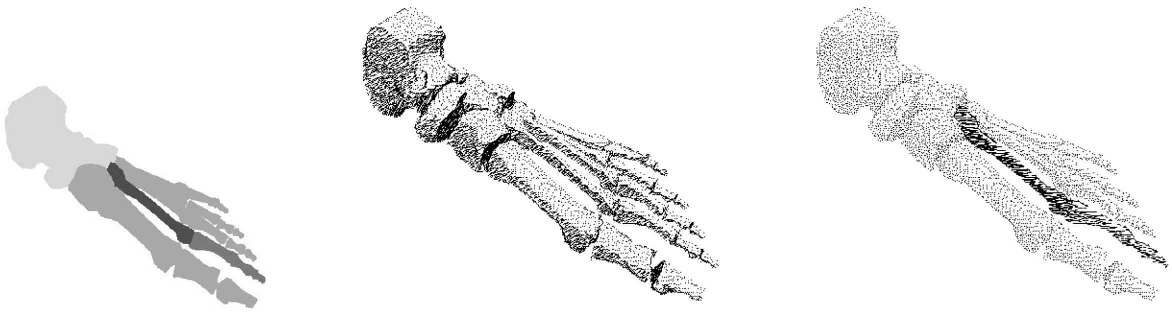
Figure 7: This image is created using the original intensities from the infamous photo of Lenna weighted with intensities from a darkening oval centered in photo. The drawing primitive is a ten pixel line scaled to the texture image's intensities and thresholded to the original image.

Finally, figure 6 illustrates the use of depth information for adjusting the structure of the drawing primitive. In both images the drawing primitives are distributed according to the original image intensity values. Approximately the same number of black pixels are set in each image. In figure 6(a) the drawing primitives are thresholded and rotated to the original image intensity values, but scaled to the z-buffer information (see figure 3(d)). In figure 6(b) the drawing primitives are scaled to the original images intensity values, but thresholded and rotated according to the z-buffer information. The last image creates a blurred type of effect, since the lines segments are aligned in the direction of view (direction of increasing z-buffer values).

The images in figures 5 and 6 show that while keeping the type, the number and the distribution of drawing primitives constant, altering the structure of the drawing primitive locally provides control over texture in the image.

5 Using External Textures or Detail

In addition to using this extended technique with 3D scene information it can also be used with external textures. The incorporation of texture information into the non-photorealistic image is done by us-



(a) (b) (c)

Figure 8: (a) This image was created by the user from figure 1(c). The user has chosen to emphasize certain regions of the image, namely more emphasis is placed on the toes of the model, with particular focus on the second toe, second segment. (b) This image was created by distributing the drawing primitives according to the original image (figure 1(c)) intensities. The drawing primitive used was a 10 pixel line segment scaled, thresholded and oriented using the original image (c)This image was also created by distributing the drawing primitives according to the original image (figure 1(c)) intensities. The drawing primitive was also a 10 pixel line, however, the local adjustments to the drawing primitive (scaling, thresholding and orientation were done using the importance map found in figure 8(a).

ing the texture as the control information of the importance map. In figure 7 the control information is an image of an oval increasing in intensity as a function of radial distance from the center of the image. This image in conjunction with the original image is used to construct the importance map. Using such a control image places emphasis on the center of the image and tends to form a portrait like effect. The drawing primitive is a ten pixel long line segment scaled to the control information or texture intensities and thresholded to the original image intensities. These drawing primitives are distributed according to a weighted combination of the control information intensities and the original image intensities.

6 Emphasizing Regions of an Image or Model

Finally in addition to incorporating 3D scene information and texture information this extended technique allows the user to emphasize particular regions or attributes in the image. to do this the user can construct the control information to be based on geometric relationships in the image. In figure 8(a) the user has chosen to place more emphasis on the toes of the model and additional focus on the second toe, second segment. Figures 8(b) and (b) show results of using importance driven halftoning with and without this extra information. Both images use a ten pixel long line segment as the drawing primitive and distribute the drawing primitives according to the intensities in the original image (see figure 1(c)). In figure 8(b) the drawing primitives are scaled, thresholded and rotated according to the original image's intensities. In figure 8(c) the drawing primitive has been scaled, thresholded and rotated according to the importance map in figure 8(a). In this manner the user can focus on particular regions of the image.

This emphasis on a particular region is difficult to achieve with other techniques. Halftoning the original image would yield results similar to figure 8(b). Tone is typically preserved throughout the image but there is no focus. If the image in figure 8(a) was halftoned there would be an obvious loss in tone approximation and hence a loss of detail as seen by comparing figures 1(c) and 8(a). Other non-photorealistic techniques such as pen-and-ink either rely totally on the user to approximate tone or automatically replicate tone at the expense of the user's control over the drawing primitives.

7 Conclusions

By segmenting the original Importance Driven Halftoning technique functionality has been extended. Leaving the user to specify the control information instead of automatically evaluating an importance function over the original image allows the user to have the control needed to explicitly render the image with particular tones and textures. Control over these two properties are essential to the non-photorealistic rendering process.

This paper showed how the user could specify the control information as 3D scene information to both adjust tone and texture by altering the structure and the distribution of drawing primitives, while keeping the type and number of drawing primitives fixed. Secondly, this paper showed how the user could chose to specify the control information as an external texture. By using a texture as the control information the incorporation of this texture into the original image is effortless, and yet the preservation of the texture is ensured through the printing process. Finally the user can chose to specify the control information as geometric precedence information. This allows the user to allocate resources to certain areas of the image. More importantly it allows the user to arbitrarily specify areas of focus as another image.

This extended technique provides a bridge between automatic two tone rendering techniques and user-controlled techniques for the creation of non-photorealistic images. It also provides a method that allows the user to control both tone and texture for the creation of non-photorealistic images.

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