Department of Computer Science & Engineering

WUCSE-2006-11

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March 13, 2006

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EUROGRAPHICS 2006 / E. Gröller and L. Szirmay-Kalos
(Guest Editors)

Volume 25 (2006), Number 3

Perceptually Meaningful Image Editing: Depth

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Abstract

We introduce the concept of perceptually meaningful image editing and present two techniques for manipulating the apparent depth of objects in an image. The user loads an image, selects an object and specifies whether the object should appear closer or further away. The system automatically determines target values for the object and/or background that achieve the desired depth change. These depth editing operations, based on techniques used by traditional artists, manipulate either the luminance or color temperature of different regions of the image. By performing blending in the gradient domain and reconstruction with a Poisson solver, the appearance of false edges is minimized. The results of a preliminary user study, designed to evaluate the effectiveness of these techniques, are also presented.

Categories and Subject Descriptors (according to ACM CCS): I.3.4 [Computer Graphics]: Graphics Editors

1. Introduction

Researchers have been studying the human visual system for centuries. The amount of research literature on the human visual system, and the rate at which new findings are published, is extraordinary. Modern research from the fields of Biology, Physics, Psychology, Physiology, and Neuroscience has given us better insight into the functioning of the human visual system. Although the visual system is far from being fully understood, the knowledge we have gained, especially about the early stages of the visual pathway, is quite substantial. In fact, many of the visual effects created by traditional artists can now be explained in terms of the features of the human visual system. By tapping into this wealth of knowledge, a new class of image editing techniques which are *perceptually meaningful* can be developed.

We define a perceptually meaningful editing technique as one designed to explicitly trigger certain visual cues. In this paper we present two such techniques for manipulating the apparent depth of objects in an image (see Figure 1). Our depth editing operations are based on techniques used by traditional artists. In general, artists manipulate the apparent depth of objects in a scene either by changing the color temperature (warmth/coolness) or the luminance values in particular regions of the scene.

Colors that appear closer to the red end of the visible spectrum are said to be warm while the colors that appear closer to the blue end are said to be cool. Our visual system exhibits a slight bias toward warmer colors because our photoreceptors respond more intensely to colors that are closer to red than to blue (see Figure 2). Hence, warm regions appear to advance toward the viewer while cooler regions appear to recede. An example of the use of warm-cool colors to create a sense of depth is shown in Figure 3(a). The warm orange and red colors of the hat, hair and cheeks of the girl against the cooler light blue causes her face to appear more advanced than the rest of the painting. This enhances the depth that we perceive. Compare this to her left elbow which appears flat because there is very little warm-cool color contrast in that area.

Artists also create apparent depth in their paintings by manipulating the luminance range. They do this by abruptly changing the luminance values across the boundary between two objects in specific regions of the painting as illustrated in Figure 3(b). The wide range of luminance between the woman's back and the background increases the apparent depth in the scene. This effect can be explained in terms of the center-surround organization of the cells in our vi-

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Figure 1: *Enhancing apparent depth using luminance technique (bottom left) and color temperature technique (bottom right). Input image (top).*

sual system. Center-surround cells respond more intensely to the local discontinuities than to gradual changes in a scene. Hence, a sharp luminance change across the boundary between an object and the background causes the object to appear more advanced.

Techniques for manipulating luminance values and the warmth (or coolness) of colors are well established in existing editing systems. However, their use for adjusting apparent depth in an image is typically not a defined operation. Users are still left with the time consuming task of manually selecting and manipulating groups of pixels. Additionally, users have to ensure that any edits they make are seamless.

The techniques presented in this paper eliminate these drawbacks. The user simply selects an object and specifies whether it should appear closer or further away. The system automatically determines target values for the object and/or background that achieve the desired depth change. The Poisson Image Editing [PGB03] framework is used to ensure that the appearance of false edges is minimized.

Previous work is discussed in section 2. In section 3, we describe our techniques in more detail. The results of a user-study to test the effectiveness of our techniques is presented in section 4. We conclude in section 5 and discuss future directions for our research.

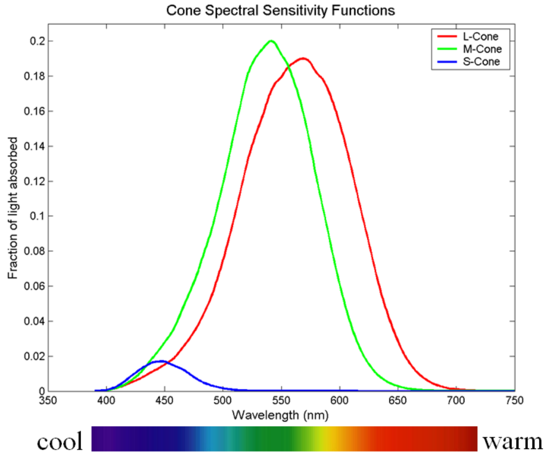

Figure 2: *Response of the long, medium, and short wavelength (L, M, and S) sensitive cones to different wavelengths of light. Data based on experiments conducted on human observers [Stockman et al. 1999] [Stockman and Sharp 2000].*

(a) Warm / cool colors. Renoir, Fille au chapeau de paille (1884).

(b) Luminance range. Seurat, Le Noeud Noir (1882).

Figure 3: *Apparent depth in traditional art.*

2. Previous Work

Various sources of information in a scene contribute to our perception of depth. These are referred to as depth cues and are typically grouped into three categories: pictorial, occulomotor and stereo cues [Gil95]. The pictorial depth cues are ones that we obtain from 2D images. These include information such as relative size, distance to horizon, focus, occlusion, shadows, shading, color temperature, relative brightness, and atmospheric effects [Pfa00]. Perspective cues such as relative size, occlusion, and distance to the horizon are generally more effective at conveying depth than shading, luminance, and color temperature [WFG92] [HD93] [SDK*94].

Traditional CG approaches for manipulating depth are typically scene-based (relying on 3D representations where depth information is readily available). These include the introduction of atmospheric effects like haze or fog [Rog00] [Ope02], perspective changes such as the shape, size, or position of objects (or camera) [FvDFH96], and level of detail (LOD) changes [HG94].

Very little work has been done in the area of image-based depth manipulation. The most commonly used approach is to simulate the depth-of-field effect from traditional photography. This effect can be achieved in commercially available image editing packages by applying a a sharpening filter to the foreground and a blurring filter to the background. This has the effect of bringing different areas of an image in or out of focus. There has also been some recent work by Gooch and Gooch which suggests that the perceived depth in an image can be enhanced by adding an artistic matting [GG04].

In this paper, we show how subtle apparent depth changes can be introduced in an image by manipulating luminance and color temperature values of the object and/or background. Object selection is done using an interactive min-cut max-flow segmentation algorithm proposed by Boykov and Jolly [BJ01]. The appearance of false edges along the boundary of the edited regions is minimized using the Poisson image editing technique [PGB03].

3. Depth Manipulation

This section describes how target values are automatically generated for the luminance and color temperature manipulation techniques. Target values are assigned to the pixels that lie on the object boundary (i.e. object pixels that lie closest to the edge) and to pixels that lie on the background boundary (i.e. background pixels that lie closest to the edge). These values are then propagated to every pixel in the image.

3.1. Notation

Let **B** be the set of background pixels, **O** be the set of object pixels, **I** = **O** ∪ **B** be the set of all image pixels, **L** be the set of luminance target values, and **C** be the set of color temperature target values. Let $p_o \in \mathbf{O}$ be an object boundary pixel and $p_b \in \mathbf{B}$ be the closest corresponding background boundary pixel. Let n be some user specified neighborhood size ($n = 9$ for the images in this paper) and let N_{p_o} and N_{p_b} be the n x n neighborhoods about p_o and p_b respectively.

3.2. Luminance Target Values

Let

$$Avg_o = 1/num(p_i) \sum_{p_i \in N_{p_o} \cap O} p_i$$

and

$$Avg_b = 1/num(p_i) \sum_{p_i \in N_{p_b} \cap B} p_i)$$

be the average neighborhood pixel values of p_o and p_b respectively. Furthermore let $AvgLum_o = luminance(Avg_o)$ and $AvgLum_b = luminance(Avg_b)$ be the average neighborhood luminance values of p_o and p_b respectively. Target luminance values **L** are assigned to p_o and p_b using the following rules:

- Case 1 - Reducing apparent depth by manipulating both object and background:
  - $\mathbf{L}(p_o) = \mathbf{L}(p_b) = \frac{1}{2}(AvgLum_o + AvgLum_b)$
- Case 2 - Reducing apparent depth by manipulating the object only:
  - $\mathbf{L}(p_o) = AvgLum_b$
- Case 3 - Reducing apparent depth by manipulating the background only:
  - $\mathbf{L}(p_b) = AvgLum_o$
- Case 4 - Enhancing apparent depth by manipulating either the object and/or background:
  - if $AvgLum_b \leq AvgLum_o$
    - $\mathbf{L}(p_o) = 1.0$ (white)
    - $\mathbf{L}(p_b) = 0.0$ (black)
  - if $AvgLum_o < AvgLum_b$
    - $\mathbf{L}(p_o) = 0.0$ (black)
    - $\mathbf{L}(p_b) = 1.0$ (white)

Once boundary target values have been assigned, they can be propagated to all pixels in the image using any flood-fill algorithm. We use a fast breadth-first approach. A Gaussian blur filter is applied to the resulting target image. This gives smoothly varying target values and hence a more natural looking result once the depth editing operation is complete. Target values for all cases can be precomputed and stored as images. This reduces lag time when performing depth manipulation, especially on large images.

When assigning target values for reducing apparent depth, it should also be noted that we can substitute the average neighborhood pixel values (Avg_o and Avg_b) for the average neighborhood luminance values ($AvgLum_o$ and $AvgLum_b$ respectively). This has the same effect of reducing luminance contrast between the object and the background, however it does not limit us to grayscale target values. We found that this generally gives more aesthetically pleasing results and is the approach used for the images in this paper.

The left column of Figure 4 shows the target luminance values generated for a hypothetical image.

3.3. Color Temperature Target Values

In order to assign target values for the color temperature technique, we simply modify the target luminance values **L**. The user specifies a warm color w and a cool color c (by clicking on an image of a color spectrum). Target color temperature values $\mathbf{C}$ are assigned to p_o and p_b using the following rules:

- Case 1 - Reducing apparent depth by manipulating both object and background:
  - $\mathbf{C}(p_o) = \frac{1}{2}(\mathbf{L}(p_o) + c)$
- Case 2 - Reducing apparent depth by manipulating the object only:
  - $\mathbf{C}(p_o) = \frac{1}{2}(\mathbf{L}(p_o) + c)$
- Case 3 - Reducing apparent depth by manipulating the background only:
  - $\mathbf{C}(p_o) = \frac{1}{2}(\mathbf{L}(p_o) + w)$
- Case 4 - Enhancing apparent depth by manipulating either the object and/or background:
  - if $AvgLum_b \leq AvgLum_o$
    - $\mathbf{C}(p_o) = \frac{1}{2}(\mathbf{L}(p_o) + w)$
    - $\mathbf{T}(p_b) = \frac{1}{2}(\mathbf{L}(p_o) + c)$
  - if $AvgLum_o < AvgLum_b$
    - $\mathbf{T}(p_o) = \frac{1}{2}(\mathbf{L}(p_o) + c)$
    - $\mathbf{T}(p_b) = \frac{1}{2}(\mathbf{L}(p_o) + w)$

We experimented with several other approaches for assigning target color temperature values including estimating the color temperature (position along the spectrum) of values in the image then traversing to the right or left to make the target values warmer or cooler. Such approaches are generally computationally expensive and do not offer any significant advantages over the approach presented here.

The right column of Figure 4 shows the target color temperature values generated for a hypothetical image.

3.4. Results

The actual value V_p assigned to a pixel during depth manipulation is a weighted combination of the target pixel value $\mathbf{L}$(p) (or $\mathbf{C}$(p)) and the original pixel value $\mathbf{I}$(p) at that point:

$$V_p = (1 - f(d))\mathbf{I}(p) + f(d)\mathbf{T}(p)$$

where the parameter d, is a user specified (slider) depth value. f is some user specified falloff function of distance from every pixel to the edge between the object and background. We experimented with Gaussian, quadratic, and linear functions - all with pleasing results. Additionally, the user is allowed to select the distance over which the blending occurs or have the system generate variable distances based on distance to the object skeleton.

Figure 5 and Figure 6 show some typical results obtained using our techniques. Additionally, interesting effects can be created by combining our luminance based depth manipulation technique with a user provided gradient as in Figure 7.

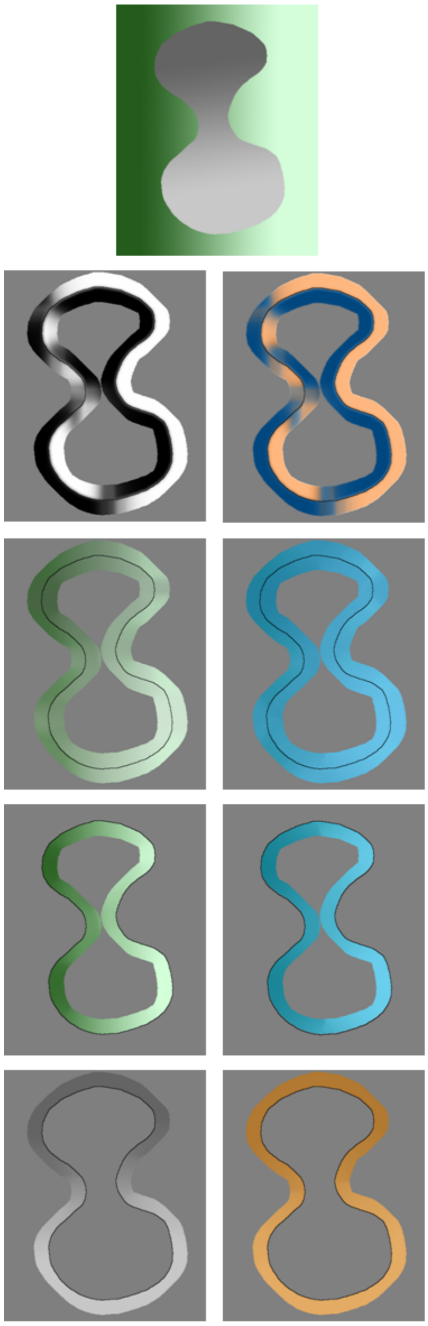

Figure 4: *Target luminance values (left column). Target color temperature values (right column). Input image (top). Case 1, 2, 3, and 4 (top to bottom). The original edge is shown by a black line. Only a 60 pixel wide area of the target values are shown to better illustrate the relationship with the original image.*

Figure 5: *Apparent depth manipulation using luminance technique (top row) and color temperature technique (bottom row). Input image (left).*

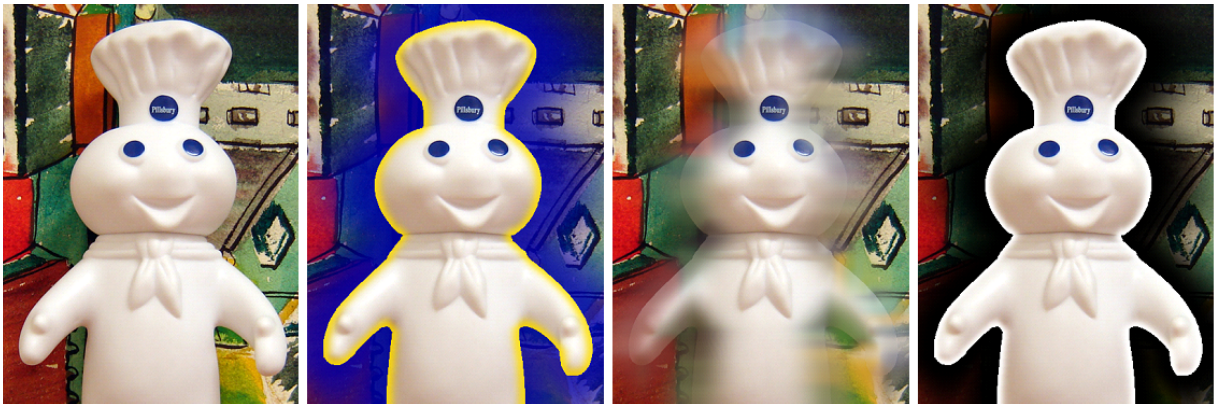

Figure 6: *Wide range of effects possible that are possible. Input image (left).*

Figure 7: *Applying depth manipulation across some user provided gradient to generate an effect similar to Figure 3(b)*

4. User Study

We conducted a preliminary user study to get an idea of how effective our techniques were at manipulating apparent depth. For a given image, we create 4 additional depth adjusted images by varying the depth parameter d (keeping all other options (editing object only, editing background only, or editing both object and background) constant). These 5 images comprise a test set. We conduct a simple *paired comparison test* where all possible pairs of images from the set are compared. Such studies are more effective than ranking or rating studies, which require a large number of trials and often suffer from distorted results [SC88]. Participants were shown all possible pairs of images in a randomized order and were asked to click on the image where the object in question appeared closest.

Feedback from participants (grad students in our lab) suggest that our techniques are somewhat effective at manipulating apparent depth. In particular, in most cases the participants arrived at the correct depth order ranking when evaluating the luminance technique.

The results for the color temperature technique, however, are not as conclusive. The overall color contrast in the image seems to limit the effectiveness of color temperature cues.

5. Conclusion

We introduced the concept of *perceptually meaningful image editing* as a collection of techniques designed to explicitly trigger certain visual cues. Two such techniques for manipulating the apparent depth of objects in an image were discussed. The preliminary results of the user study suggest that the luminance technique is more effective than the color temperature technique. As part of our future research, we will be conducting a comprehensive user study in a controlled environment to further evaluate our techniques. Additionally we be will be investigating the effectiveness of other perceptually meaningful editing operations.

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