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Enhancing Perceived Depth in Images Via Artistic Matting

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Abstract

We present a simple tutorial for the addition of artistic mattes to digital images for the purpose of enhancing the three-dimensional effect of the image. We show that artistic mattes add visual cues to an image enhancing the sense of depth in the image. We then demonstrate the construction of artistic mattes in a software system. We also report the results from two perception studies on matte color preferences and depth estimates in matted versus non-matted images.

Keywords: Image Processing, Non-photorealistic rendering, artistic, matte, frame, border, graphics

Enhancing Perceived Depth In Images Via Artistic Matting

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Figure 1: *The features of the left image are generally perceived to lie in the image plane. The features of the artistically matted image on the right are generally perceived to be non-coplanar and located behind the image plane.*

Abstract

We present a simple tutorial for the addition of artistic mattes to digital images for the purpose of enhancing the three-dimensional effect of the image. We show that artistic mattes add visual cues to an image enhancing the sense of depth in the image. We then demonstrate the construction of artistic mattes in a software system. We also report the results from two perception studies on matte color preferences and depth estimates in matted versus non-matted images.

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1 Introduction

Images of three-dimensional scenes rarely convey the rich sense of depth and geometric complexity apparent when observing the real world. One reason for this is that under almost all viewing conditions, the location of the surface on which the image is rendered is apparent [Rogers 1995]. The sense of a flat picture plane conflicts with the three-dimensional information contained in the image itself. Matting is a method of separating the perceived depth of features in the image from the image surface itself. Our research into artistic matting explores only those effects which enhance the three dimensional effectiveness of the matted image. An example of an image with and without a matte is shown in Figure 1.

2 Artistic Tradition

The matting of artistic images has evolved over time, with a wide variety of methods and purposes, relating to both practical and aesthetic functions. Mattes provide a method for hanging and protecting an artwork. Simultaneously, mattes are designed to either separate or harmonize the imagery from its surroundings. The borders created by mattes can contain and control the composition of the image within its boundaries. According to artistic principles the purpose of the artistic matte is to call attention to the image, not the other way around. Creating mattes calls for restraint and it is better to err on the side of simplicity [Keefe and Inch 1990].

Mattes can even be considered an illusion destroyer, but in a positive sense. "It says the work before you is not a work of Nature, but a creation of an artist; its only demand is to be looked at and enjoyed... The artwork wants to make you party to a deception, but do not allow it to go too far. No matter how real it seems, you must always remember that it is only an illusion, in other words you must consciously allow yourself to be deceived" [Mendgen 1995].

3 Image Perception

It has long been known that the three-dimensional effect of an image can be enhanced if the image is viewed through a reduction screen or a view-box (e.g., [Ames 1925; Schlosberg 1941]). This effect can be demonstrated by viewing an image through a rolled up sheet of paper held to one eye while closing the other eye ("peephole viewing"). A number of mechanical devices exist for this purpose and can sometimes produce powerful three-dimensional effects. The explanation for the effectiveness of these devices has been that the restricted view enhances the perception of pictorial-depth information with respect to distance and size by attempting to disassociate the three-dimensional information contained in the image with the conflicting flatness information inherent in the image.

Given this disassociation of the 2D image with the 3D world it represents, it is amazing that humans have no trouble perceiving sizes, shapes, and distances of depicted objects. The image is flat, moving our viewpoint (gaining information through binocular stereo and motion parallax cues) does not change the 2D image as it would if we were just looking out a real window. Mattes simulate peephole viewing, providing cues that enable the viewer to override the conflicting binocular stereo and motion parallax cues from the images surface. In removing these conflicting cues, the viewer is more apt to choose to perceive the illusion that the image represents a scene instead of a flat image.

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Figure 2: *An example of a double off center matte cut to emphasize slope and depth cues in the image.*

Perceptual psychologists [Palmer 1999] have codified a list of cues that allow the human visual system to perceive depth in two-dimensional static imagery.

The visual cues of perception of pictorial space:

1. Perspective projection
2. Convergence of Parallel lines
3. Edge Interpretation (includes occlusion)
4. Position relative to horizon of a surface (eye position)
5. Relative size
6. Familiar size
7. Texture Gradients
8. Shading Information
9. Aerial Perspective

Of these pictorial cues, image matting aids in the perception of depth through cues such as perspective projection, convergence of parallel lines, and edge interpretation. Properly used, artistic mattes enhance the apparent depth in an image by generating the appearance of an occluding frame around the image. Occlusion is an ordinal depth cue, signaling that surfaces apparent in the image are farther away than the viewing device itself. Occlusion provides another, less understood spatial cue as well. Not only is the occluded surface seen as more distant than the occluding surface, but it is also seen to continue beyond the occluding surface. Viewing an image through an occluder thus can serve to make the image surface look farther away and the image to look larger. Mattes also perceptually increase the dimensions of the image, a fact we are often reminded of when a frame or matte of an image is removed, the image appears to "shrink".

Photographs and other artwork are often framed using mattes with a three-dimensional appearance. The matte board is bevel cut, and there is often an inner, narrow matte as well. It is likely that the three-dimensional appearance of a matte increases its effectiveness as an occlusion cue. It may also be possible that the linear perspective cues associated with double matting simulate the effect of viewing an image through a tube or tunnel (Figure 2). Diagonals created by corners of a matte lead the eye into the picture (convergence of parallel lines). The layers created by mattes lead the eyes into the image, enhancing its perspective effect. The width of the border created by a matte fixes the scale of the frame relative to the picture's and determines the degree to which the imagery is isolated from its real surroundings [Mitchell and Roberts 1996].

Matte colors are typically chosen to match the hue of some region in the image. Several impressionist painters from the late 1800s, such as Mary Cassatt framed their works in colors complementary to the dominant tones of the paintings: "A red sunset was given a green frame, a violet canvas was surrounded by a dull yellow, a greenish spring scene was framed in pink; all this made everything more correct and harmonious" [Mitchell and Roberts 1996]. A well-chosen colored matte was also used to supplement the colors of the imagery or complete the tonal composition of the image. Figure 3 illustrates the effects different matte colors can have on an image.

In addition to the esthetic advantages of correctly chosen colors, there seems to be an effect on spatial vision as well. Different matte colors may alter the sense of depth seen in an image, as demonstrated in Figure 7. There appears to be nothing known about the perceptual psychology underlying this effect.

4 Computer Application

In order to build a computer application for artistic matting we begin by listing the parameters of a matte which can be manipulated to enhance the three-dimensional effect of the image. These parameters include the following.

1. Size – The size and proportion of matte relative to the image.
2. Texture – The material properties of the matte.
3. Bevel – The angel at which the inside edge of the matte is cut.
4. Number – The number of matte layers.
5. Color – The color of the matte.
6. Lighting – The color and position of the lights illuminating the matte.

The depth cue associated with peephole viewing works best if the size of the matte is maximized so that nothing but the matte and the image are visible in the environment. Because this maximization is not plausible both the size and proportion of the matte need to be taken into account. We use a simple heursitic of setting the distance the matte extends past the image to be of 25% of the maximum dimension of the image. However, we also provide user controls for altering the size of the matte. An optical illusion to be aware of is the fact that if all edges of the matte are the same size, the matte will appear to be too small along the bottom [Rodwell and Short 1988]. This illusion can be overcome by slightly increasing the size of the bottom edge of the matte. We found that a five to ten percent increase in the size of the bottom edge of the matte overcame this illusion.

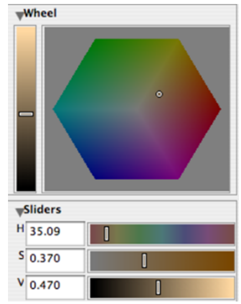
Making the matte visually separate from both the image and the viewing environment can intensify the occulusion depth cue. In our computer application we found that the occlusion cue can be enhanced using the texture and bevel parameters of the matte. We add a bump texture to the matte surface and then light the matte to create shadows and highlights. By using a bright spotlight and only a small amount of diffuse light we give the matte a hard highly detailed surface. The light is placed up and to the right, a convention often used by artists. The detailed bump texture on the matte underscores the fact that the matte is in front of the image.

(a) A mauve colored matte for this image does not add anything to the composition and brings attention to artifacts in the image.

(b) This complementary colored matte follows the rules set by Impressionist artists such as Mary Cassatt.

(c) Also eye pleasing is this more saturated and less bright colored frame which balances the bright purples.

Figure 3: *Image of a computer-generated painting framed with different automatically calculated mattes.*



(a) HSV Color Wheel

[0°, 25°)	=	Red
[25°, 45°)	=	Yellow
[45°, 160°)	=	Green
[160°, 250°)	=	Blue
[250°, 325°)	=	Purple
[325°, 360°]	=	Red
negative	=	Grey

(b) Color Bins

Figure 4: *HSV (Hue, Saturation, Value) Color wheel with 5 color bins used to categorize the dominant color in an image.*

In traditional matting the bevel is cut to avoid the matte casting a shadow onto the picture since this destroys the occlusion effect and reinforces the planar image cues. We found that the lighting information conveyed on the bevel served to further visually separate the image from the matte. The bevel of the matte has a default setting of a 45-degree angle with a fixed matte thickness in order to replicate real mattes. The bevel is lit using the same lighting information. The image is then composited onto the beveled matte image. By compositing we avoid introducing any lighting effects onto the image itself aiding in the illusion that the image is a separate world beyond the image plane.

An idea that we experimented with was attempting to magnify the convergence of parallel lines depth cue using multiple layers of mattes that have been cut and sized to match the perspective depth cue in the image. We did this by allowing the software user to annotate the image with a horizon line, a vanishing point, and two converging lines drawn toward the vanishing point. We then generated layered mattes with an off center opening for the image. An example of this type of off center matting can be seen in Figure 2.

Our application creates several default matte color choices based upon a cylindrical parameterization of HSV color space as shown in Figure 4(a). We divide the hue color plane into 5 regions: red, yellow, green, blue, and purple (Figure 4(b)). We chose only to use five bins because we found in pilot studies that more bins did not accurately capture the apparent dominant color (C_d) in the image. For example, if we were to divide the color space into: red, green, blue, cyan, magenta, yellow, we found that images which had a lot of cyan and blue but also had about the same yellow could be calculated to have a dominant color of yellow, although, viewers tended to say that the image was dominantly blue (because we would associate cyan and blue together).

Once we have calculated the dominant color bin, we average the HSV values for all of the pixels in that bin (channel by channel) to find the average dominant color. Next we provide more choices to the user by creating offsets for the color. First we provide the complementary color (C_c) of the dominant color (with the same saturation and value) by offsetting the hue by 180 degrees. In addition we modify the dominant and complementary color by adding and subtracting a percentage of the value (V) and saturation (S), as shown in Figure 5. Default percentages are set to 20%. We do not take into account grey tones in the image when calculating the dominant hue. Instead, we add to the palette of suggested mattes a grey color that matches the value of the dominant color in the image 6.

We additionally experimented with matte colors based upon observed color scaling in the image in an attempt to augment the three-dimensional effect of the images. Examples of color scaled mattes

(a) Dominant color: HSV = (35.09°, 0.37, 0.47)

(b) Dominant color, lower saturation: HSV = (35.09°, 0.17, 0.47)

(c) Dominant color, higher saturation: HSV = (35.09°, 0.57, 0.47)

(d) Dominant color, lower value: HSV = (35.09°, 0.37, 0.27)

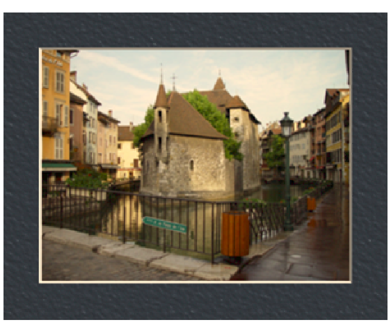
(e) Dominant color, higher value: HSV = (35.09°, 0.37, 0.67)

(f) Dominant color, higher saturation, lower value: HSV = (35.09°, 0.17, 0.67)

(g) Complementary color: HSV = (215.09°, 0.37, 0.47)

(h) Complementary color, lower saturation: HSV = (215.09°, 0.17, 0.47)

(i) Complementary color, higher saturation: HSV = (215.09°, 0.57, 0.47)

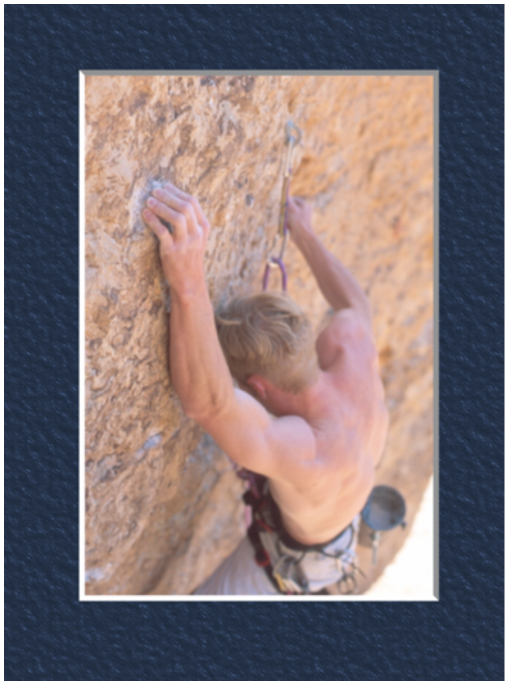


(j) Complementary color, lower value: HSV = (215.09°, 0.37, 0.27)

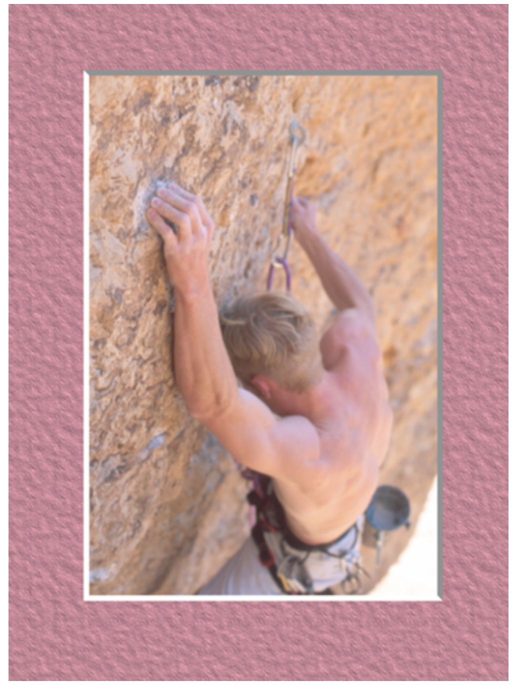
(k) Complementary color, higher value: HSV = (215.09°, 0.37, 0.67)

(l) Complementary color, higher saturation, lower value: HSV = (215.09°, 0.37, 0.47)

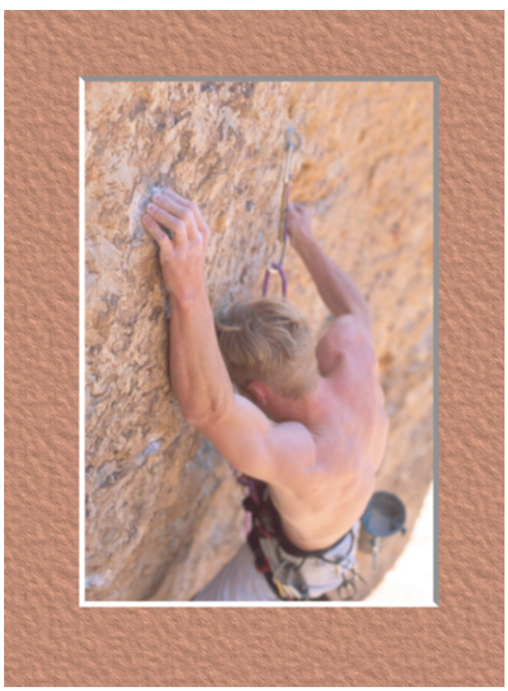
Figure 5: *Range of mattes automatically chosen by our software.*



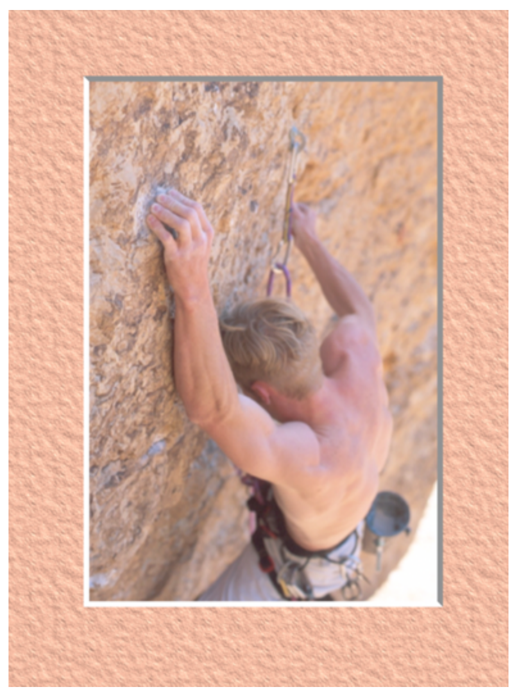
(a)



(b)



(c)



(d)

Figure 7: *This set of images demonstrates the affect of matte color on the perception of depth. The dark blue matte (a) seems to push the climber into the scene, away from the user, as if peering down a whole. The pink matte (b) on the top-right matches with the color of the climbers shoulders, giving the impression that the climbers arm projects beyond the image plane. The peach colors (c) and (d) on the bottom row more closely match the rock and some viewers see the matte as receding and the climber to be perceived as above the matte. Note that theses observations are somewhat subjective and the images may need to be viewed individually for the illusion to be apparent.*

(a) (b)

Figure 6: *Non-matted and grey matted image.*

are shown in Figure 7.

5 Perceptual Experiments

We report on two experiments which examine participants color matte preferences as well as whether these artistic mattes can be shown to increase perceived depth in an image.

5.1 Experiment 1: Aesthetic Preference

In order to evaluate the aesthetics of the automatic choices our software makes, we created a web-based experiment and asked participants to rank a series of different mattes on a single image in order of preference.

The participants were directed to a web page (http://buckrogers.cs.northwestern.edu/matting/) and requested to make their web browser fill the screen, which should enable them to see all of the images on one page, without having to scroll. For each trial, the participants were presented with 9 randomly arranged images, all the same source image matted in nine different ways. Although our algorithm outputs a minimum of 13 matting choices, in order to put all of them on the screen at the same time we choose to present:

1. Dominant Color (C_d)
2. Complement Color (C_c)
3. C_d with saturation (S) + 0.2
4. C_c with value (S) + 0.2
5. C_d with V - 0.2
6. C_c with V - 0.2
7. C_d with S + 0.2, V - 0.2
8. C_c with S + 0.2, V - 0.2
9. Grey matte (S = H = 0, use value of dominant color)

For our experiments we used 7 photographs and 7 computer generated images. For each trial, participants were asked to rank the images in order of aesthetic preference, with a rank of 1 representing the image they liked the most. We requested that they use their first impression so that they didn't think about the process or experiment, or what kind of data we are gathering. They were reminded to rank each page separately. When they finished with a trial, they clicked "Next" at the bottom of the page to go to the next trials. They were also reminded to treat each trial independently, not considering rankings made on previous trials.

Matte Color	N	Min	Max	Mean	Std. Dev
C_d	386	1	9	5.11	2.2
C_d, S + .2	385	1	9	5.28	2.58
C_d, V - .2	386	1	9	3.58	2.23
C_d, S + .2, V - .2	385	1	9	3.91	2.35
C_c	387	1	9	6.01	2.29
C_c, S + .2	386	1	9	6.45	2.53
C_c, V - .2	386	1	9	4.45	2.38
C_c, S + .2, V - .2	385	1	9	4.84	2.42
grey	387	1	9	5.21	2.64

Figure 8: *Experiment 1: Data comparing different mattes across all subjects and source images. Matte colors are either based upon the dominant color in the image (C_d) or its complement (C_c). A measure of 1 (indicated by the mean) would be the most favored matte, where as 9 would be the least preferred matte.*

5.1.1 Results of Experiment 1

We gathered data from 24 males and 7 females, ranging in age from 19 to 59 years old (28 scientists, 3 artists). We performed 9 paired sample T-tests based on matte color. In all 9 cases the difference in image type, photographs or computer-generated images, was not significant (p=0.00). In addition subject sex was not a significant factor. Over all of the images, the results of our analysis indicate that there may be a preference for the mattes that used the darkened dominant color and less preference for the complementary color and saturated complementary color (see Table 5.1.1). However the results are not significantly different due to the high variability.

The data we gathered might indicate that automating the choice of matte color does not lend itself to a simple algorithm. However, such color choices provide users with a set of colors that they can refine to suit their own aesthetic preferences.

Although our experiment methodology is only able to loosely control factors of monitor gamma, monitor resolution, and viewing distance, the participants are making relative judgments on a single screen. In the future we want to conduct more controlled versions of this experiment that would carefully control image display as well as explore user preferences for saturation and value levels.

5.2 Experiment 2: Depth Estimation

In our second experiment, we explored whether the matte actually affects verbal depth judgments in static images. In this experiment we used the same 14 source images from Experiment 2, either non-matted or matted in the saturated complementary color. For each source image, we selected 2 points in each of the source images (in the relative foreground and background of each image). In each presentation, the point in the image at which the participant is asked to judge the depth is marked by a small black and white cross which flashes for 3 seconds at the beginning of each trial. The flashing cross is used to draw the participant's attention as well to keep the cross from either becoming part of the scene or potentially flattening the image. Our stimulus is 14 source images x 2 judgment points x 2 matted/non-matted presentation. The images are presented in random order on a Mac PowerBookG4 at 1440x900 resolution. The images were presented in the middle of the screen with a neutral grey background and shown in a darkened room.

For each trial, participants were presented with a single image, asked to look at the scene in front of them, and judge the distance from them to the object under the flashing cross. There was not a time limit but the participants were asked to use their first impression of the scene. When they were ready to make their judgments, they were asked to speak them aloud and the experimenter recorded their judgments. Participants were also reminded to treat each trial independently and not consider judgments made in previous trials.

Image type	N	Min	Max	Mean	Std. Dev
CG	165	-2.75	2.5	0.033	0.6811
Photo	158	-2.33	2.34	-.0062	0.7335

Figure 9: *Experiment 2: Conditioned distance estimates in matted and non-matted images, grouped by the image source (CG or photograph).*

Participants continued to the next trial at their own pace by pressing a key on the keyboard.

5.2.1 Results of Experiment 2

Our experiment consisted of 12 participants (4 females, 8 males), ages 14 to 45. We analyzed the data by comparing relative judgments made in each image pair (same point marked in a matted and non-matted image). We conditioned the distance judgment data by dividing the matted distance judgment by the non-matted distance judgment and subtracting one if the matted distance was greater than the non-matted distance. Otherwise, we subtracted the ratio of non-matted to matted judgments from one. We eliminated any data points which were more than 3 standard deviations from the mean. The results are summarized in Figure 9. T-test show that neither of the image types are significantly different from zero.

The data from this experiment potentially contradicts the idea that artistic mattes enhance the three dimensional effectiveness of the matted image. The experiment indicates that there may be a slight increase perceived depth in matted CG images, however more experiments would be needed to understand this potential phenomenon. We would like to generate more carefully calibrated computer-generated and photographic scenes with known station points (and other camera parameters). Ideally the participants would be positioned at the station point of each image, creating a match between viewing distance and field of view. We would also like to explore different kinds of judgments, such as action based instead of verbal reporting, including judgments made with peep-hole viewing, as well as relative judgments made across the images.

6 Conclusion

We have demonstrated some simple methods of enhancing computer graphics images by adding artistic mattes. These methods work for both computer generated images and photographs. Our experiments lead to some interesting results, but in order to truly understand the perceptual benefits or drawbacks of adding artistic mattes to images, further examination will be required.

7 Acknowlegments

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