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Enhancing Perceived Depth in Images Via Artistic Matting

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Abstract

We present an algorithm for the addition of artistic mattes to digital images for the purpose of enhancing the sense of depth in the image. We provide examples exploring color and double mattes as well as report the results from a perception study which may indicate an increase in perceived depth in matted imagery.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: 2D Graphics

1. Introduction

Images rarely convey the rich sense of depth and geometric complexity apparent when observing the real world. In almost all viewing conditions, the sense of a flat picture plane conflicts with the three-dimensional information contained in an image [Rog95]. Changing viewpoint to gain additional information through binocular stereo and motion parallax cues does not change the 2D image as it would if we were looking at a scene through a window. 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 objects in images.

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 [Ame25, Sch41]. 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.

Artistic matting is a method of separating the perceived depth of features in an image from the image surface itself. Our research into artistic matting explores those effects which enhance the three dimensional effectiveness of the matted image. 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. An example of an image with and without a matte is shown in Figure 1.

2. Image Perception

Perceptual psychologists [Pal99] 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 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. Occlusion provides another, less understood spatial cue as well. Not only is the occluded surface seen as more distant

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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 located behind the image plane. Original photograph courtesy of William B. Thompson. Used by permission.

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 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. The linear perspective cues associated with double matting may 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 [MR96].

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" [MR96]. 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.

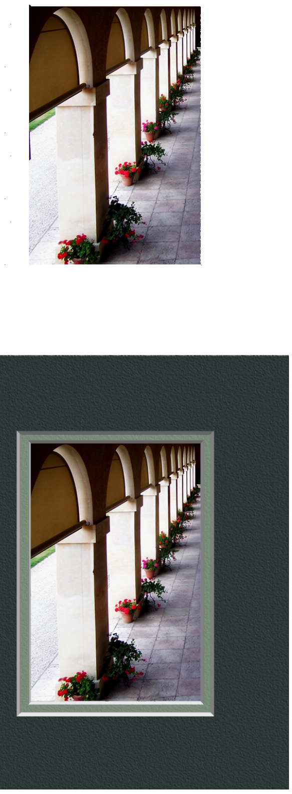


Figure 2: An example of a double off center matte cut to emphasize perspective in the image; more of the inner matte is visible on the left than the right. Image from `www.flickr.com/photos/hobo_pd/`; used under creative commons license.

In addition to the aesthetic advantages of correctly chosen colors, there may be an effect on spatial vision as well. Different matte colors may alter the sense of depth seen in an image (Figure 4). There appears to be nothing known about the perceptual psychology underlying this effect.

3. Algorithm

In order to build computer-generated artistic mattes, we begin by listing the parameters of a matte that 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 angle 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.

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. Although this is not plausible, both the size and proportion of the matte need to be carefully considered. We use a simple heuristic of setting the distance the matte extends past the image to 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 [RS88]. 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 strengthen the occlusion depth cue. With our algorithm, 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 to 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.

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,

(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.

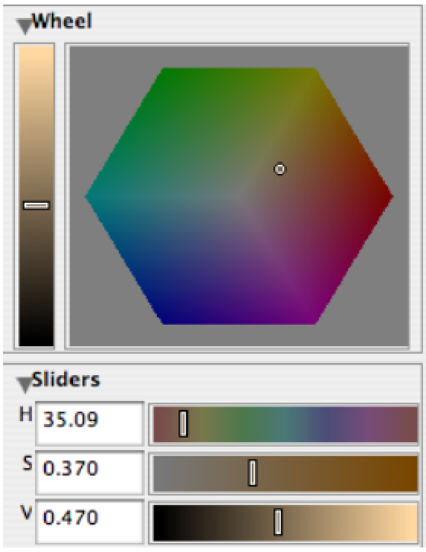
(c) Also eye pleasing is this more saturated and less bright colored frame which balances the bright purples.

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

(a) (b)

(c) (d)

Figure 4: This set of images demonstrates the effect 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 hole. 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 these observations are somewhat subjective and the images may need to be viewed individually for the illusion to be apparent. Original photograph courtesy of John McCorquodale. Used by permission.



(a) HSV Color Wheel

[0°,	25°)	=	Red
[25°,	65°)	=	Yellow
[65°,	160°)	=	Green
[160°,	250°)	=	Blue
[250°,	325°)	=	Purple
[325°,	360°]	=	Red
	< 0	=	Grey

(b) Color Bins

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

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

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

Figure 6: Sample mattes automatically chosen by our software.

however it may be possible to use inconsistent lighting for the bevel and the matte without ill effect. The image is then composited onto the beveled matte image. By compositing after lighting the matte we avoid introducing any lighting effects onto the image 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.

Our algorithm creates several default matte color choices based upon a cylindrical parameterization of HSV color space as shown in Figure 5(a). We divide the hue color plane into 5 regions: red, yellow, green, blue, and purple (Figure 5(b)). We chose only to use five bins because we found in practice 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, orange, brown, pink, yellow, green, blue, purple, we found that images which had a lot of red and pink 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 red (because we would associate red and pink 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 (Figure 6a). 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 (Figure 6b). In addition we modify the dominant and complementary color by adding and subtracting a percentage of the value (V) and saturation (S). 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. 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 are shown in Figure 4.

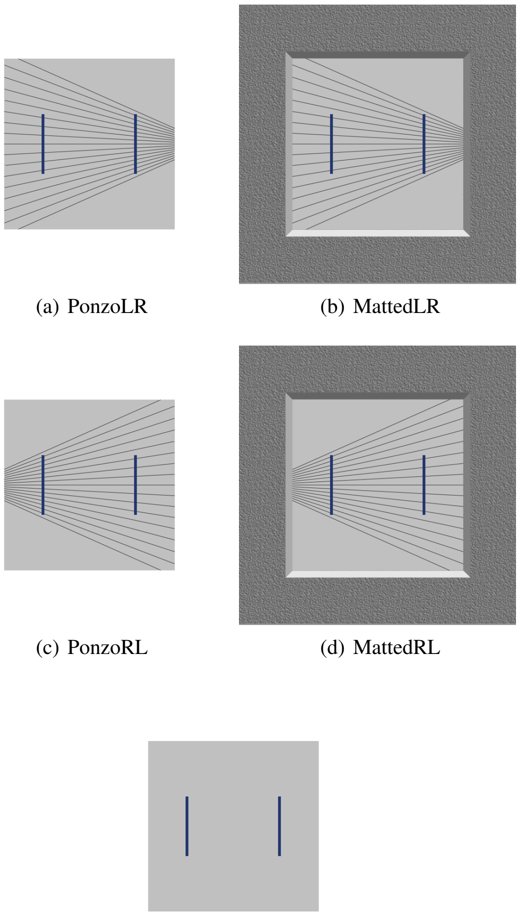
4. Perceptual Experiment

While many viewers agree that mattes may subjectively increase apparent depth in static images, we tried to quantify whether the addition of a matte affects perceived depth in static imagery. We initially piloted several experiments with full color images and various colored mattes, and asked subjects to make verbal distance reports to particular places in a matted and non-matted image. Additionally we piloted several timed experiments in which subjects were given a force-choice of two spots in an image and asked to select which one was closer. Neither of these experiments revealed a significant difference between matted and non-matted imagery.

We report here a study with much simpler stimuli, based upon the Ponzo Illusion discovered by Mario Ponzo in 1913. The Ponzo illusion, shown in Figure 7(a), illustrates that size perception depends upon interpretation of depth cues, i.e. although both vertical blue lines are the same length, the illusion leads us to believe that the right blue line is shorter than the left blue line. We hypothesized that adding a matte, as shown in Figure 7(b), may increase the overestimation if adding a matte increases the apparent depth in an image.

Our stimuli consisted of five cases: vertical lines only (Figure 7(e)), Ponzo illusion with horizontal lines converging right to left (Figure 7(c)) or left to right (Figure 7(a)), and matted Ponzo illusion with lines converging right to left (Figure 7(d)) or left to right (Figure 7(b)). The mattes were 50% gray with a texture and a lit bevel. In all five cases, the user was asked to modify the right (measurement) line until it appeared to be the same length as the left (reference) line in screen space. Each participant completed 5 cases x 8 line-sets, for a total of 40 counter-balanced trials, which took about 15 minutes. The program was seeded with 8 line-sets which consisted of a random reference line length and random position for the top and bottom of the measurement line, allowing correlations across the five cases.

The study consisted of 4 female and 6 male volunteers, who gave their informed consent to participate. Participants were given written instructions, which were also reviewed by the experimenter with a demonstration of how to use the mouse to adjust the measurement line. Participants were asked to give their first impression, go as fast as they can, and not spend a lot of time adjusting the measurement line. Participants were seated 26" from Macintosh PowerBook G4 with a 1440x900 display. The program was displayed on a uniform gray background, and the main stimulus subtended a visual angle of 9°.



(a) PonzoLR (b) MattedLR

(c) PonzoRL (d) MattedRL

(e) Lines

Figure 7: Five stimuli used for depth test experiments: Ponzo (a and c) and Matted Ponzo Illusion (b and d), converging left to right and right to left; Lines only (e).

4.1. Results

For each subject, for each trial, we calculated measurement line - reference line for all five cases. Then for each subject we calculated the mean for each of the five cases. The left-right Ponzo and Matted Ponzo illusion resulted in underestimation, and the right-left Ponzo and Matted Ponzo illusion resulted in overestimation, as reported in Table 1.

We were able to confirm the effects of the Ponzo illusion, with paired Student's T-test revealing $p = 0.00$ for Ponzo vs Lines and $p = 0.00$ for Matted vs Lines, where "Ponzo vs Lines" refers to a paired T-test comparing unmatted Ponzo illusion condition to the unmatted lines condition; "Matted" refers to the matted Ponzo illusion conditions. More importantly there is a significant difference between

Subject	PonzoLR	MattedLR	PonzoRL	MattedRL	Lines
E6	-4.63	-15.38	27.88	26.88	4.88
E9	-20.50	-18.88	26.63	29.13	0.00
E4	-8.88	-11.13	17.00	20.00	3.00
E3	-11.25	-11.75	14.75	13.75	1.50
E5	-12.75	-14.25	15.50	16.13	-1.38
E8	-16.38	-15.38	15.50	16.25	-0.88
E7	-22.13	-24.88	19.88	23.13	-0.75
E11	-7.75	-13.00	17.38	22.50	0.63
E12	-13.38	-12.00	16.13	13.88	0.88
E13	-10.13	-8.13	19.13	20.50	1.13
Avg	-13.66	-14.54	18.86	20.17	0.84

Table 1: *Subject data comparing measurement line - reference line for each of the five cases shown in Figure 7.*

the over/underestimation of the measured lines in the comparison of the Ponzo case to the Matted case ($p = 0.041$). Student's T-test compares the actual difference between two means in relation to the variation in the data, expressed as the standard deviation of the difference between the means. A p value of 0.041 means that there is a 4.1% chance that the effects we are seeing are due to random events. According to the statistical convention for behavioral studies, $p < .05$ indicates that the data is statistically significant.

5. Conclusion

A matte 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* [Men95].

We have demonstrated some simple methods of enhancing computer graphics images by adding artistic mattes for both computer-generated images and photographs. Additionally, our perception study indicates that artistic mattes may enhance perceived depth in static images. Future studies could establish the relative contributions of the bevel, size, color, and texture of artistic mattes, as well as matte-image contrast and matte shape. Additionally, we believe it may be of interest to examine the relative effects of mattes for computer-generated, artistic, and natural photographs.

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References

[Ame25] AMES JR. A.: The illusion of depth from single pictures. *Journal of the Opticial Society of America 10* (1925), 137–148.

[Men95] MENDGEN E. (Ed.): *In Perfect Harmony: Picture + Frame 1850 - 1920.* Van Gogh Museum/Kunstforum Wien. Waanders uitgevers, Zwolle, 1995.

[MR96] MITCHELL P., ROBERTS L.: *Frameworks: Form, Function & Ornament in European Portrait Frames*. Merrell Holberton Publishers, London, 1996.

[Pal99] PALMER S. E. (Ed.): *Vision Science: Photons to Phenomenology*. MIT Press, Cambridge Massachusetts, 1999.

[Rog95] ROGERS S.: Perceiving pictorial space. In *Perception of Space and Motion*, Epstein W., Rogers S., (Eds.). Academic Press, 1995.

[RS88] RODWELL J., SHORT G.: *Make Your Own Picture Frames*. Northlight, 1988.

[Sch41] SCHLOSBERG H.: Stereoscopic depth from single pictures. *American Journal of Psychology 14* (1941), 601–605.