Optical Illusions in Computer Graphics

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Abstract
In general terms, all techniques of computer graphics are fundamentally optical illusions. Optical illusions that result from errors in perception are currently unused in the field of computer graphics, remaining merely as novelties in expressionistic art and children's books. Through the use of illusions that result in the viewer failing to properly perceive parallel lines, it is possible to convey extra information beyond the basic geometry of the scene. Specifically, we demonstrate how such illusions may be utilized to convey Z-axis information on two dimensional displays. This is compared to techniques with similar code complexity and techniques with similar information complexity. Minimum required processing power is extremely low, indicating immediate applications in hand-held and embedded devices.

1. INTRODUCTION

At the most fundamental level, all computer graphics (CG) are an illusion. From the underlying motivation of the CG field, to the computational techniques used to present imagery to viewers, subtle use of illusion and trickery are the primary tools of a graphicist. We show that less subtle use of optical illusion, specifically static illusions that result from errors in perception, can result in complex graphical effects at very cheap cost. We measure cost in terms of rendering time. In the context of handheld and embedded devices, cost also relates to total power consumption.

The underlying motivation of computer generated imagery is to fool the viewer into believing they are seeing a scene that does not exist in reality. Point-like units of color comprise the component elements of a greater picture. These picture elements (pixels) converge to give the impression of an image that does not truly exist in the physical world. Because of this disconnect between reality and imagery, the CG developer has little motivation to use strictly accurate modeling. This becomes apparent when evaluating the various algorithms used for lighting and shading in a typical three dimensional scene.

Through the application of lighting and shading algorithms, rendered geometry will appear much more detailed than its modeled representation. With the use of Gouraud Shading [Gouraud 1971], cubes may be rendered to appear round. With the use of Phong Lighting and Shading [Phong 1975], a two dimensional disk can be mistaken for a perfectly round sphere. Bump Mapping [Blinn 1978] defines complex surface geometry that is never rendered, only being used to calculate shadows for painting on relatively simple structures.

With an appropriate application of optical illusions, it may be possible to create effects that are either impossible given the medium or where the price of accurate modeling is not justifiable. For example, the current convention for displaying motion in a static image is the use of arrow icons pointing in the direction of motion. This does not actually give a sense of motion and also creates clutter. Conceivably, an illusion could be used to give the actually perception of motion [Freeman, Adelson, Heeger 1991].

1.1. Types of illusions

There are many different types of illusions, some more subtle than others.

1.1.1. Illusions in Perceived Geometry

Through the use of lighting and shading algorithms [Gouraud 1971][Phong 1975][Blinn 1978], objects may appear to have a different shape than what is actually rendered (Figure 1).

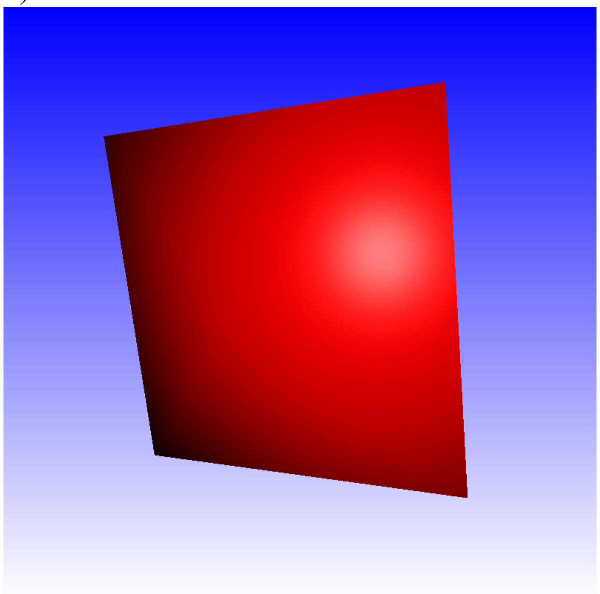


*Figure 1: **Phong Shading.** The Phong lighting and shading algorithm applied to a flat quadrilateral gives the impression of a rounded surface. [Sadie, 2002]*

1.1.2. Illusions in Perceived Motion

Certain types of illusions will create the perception of motion [Freeman, Adelson, Heeger 1991][Kitaoka, Ashida 2003][Fermeuller, Pless, Aloimonos 1996]. The remainder of this project will focus mainly on this area of illusion. With derivations of such illusions as the Primrose Field (Figure 2) or the Bulge [Kitaoka 2002], it may be possible to give the illusion of waving water where no motion actually exists, or hills on checkerboard grids.

1.1.3. Illusions in Perceived Orientation

Certain types of illusions will fool the viewer into misinterpreting the true location of objects [Yu, Choe 2004] (Figure 3).

1.1.4. Illusions in Perceived Size

Certain types of illusions will fool the view into misinterpreting the true size of an object[Christie

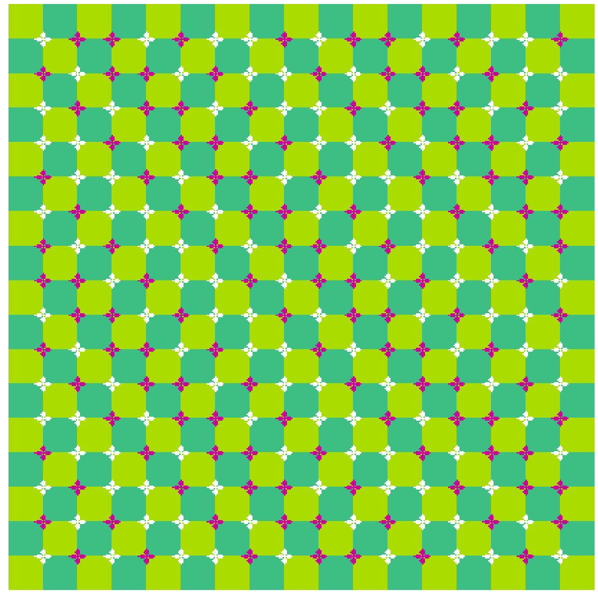


*Figure 2: **The Primrose Field.** The Primrose Field appears to churn as the viewer moves the image. [Kitaoka 2002]*

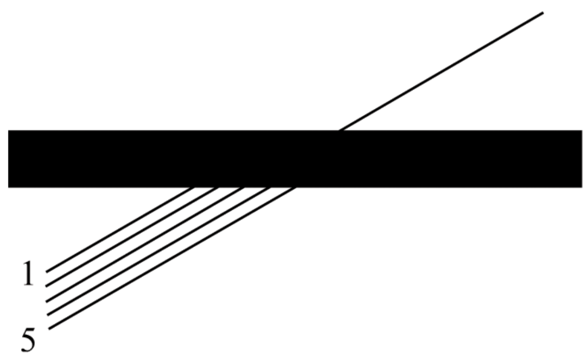


*Figure 3: **The Poggendorff Illusion.** "The five lines below the horizontal bar are labeled 1 to 5 from top to bottom. Line 3 is physically collinear with the line on top. In this example, line 4 is perceived to be collinear."*
[Yu, Choe 2004]

1975]. This has been used to great effect in film, with movies such as "Attack of the 50 Foot Woman" and "Honey I Shrunk the Kids". More recently, it has been used in video games like "Thief: the Dark Project" [Eidos 1995], in which the player is given a choice of halls to traverse. One hall is real and ends in a door of normal height, while the other uses forced perspective to trick the player into seeing a hall that ends in a 1 foot tall door as a normal hall.

1.1.5. Illusions in Perceived Color

The computer display itself is representative of an illusion in color perception. Each pixel is a combination of three phosphorescent elements that, when struck by electrons, individually emit light of red, green, or blue wavelengths. When the viewer maintains adequate distance from the display, the colors converge and create a nearly continuous spectrum of color. (Figure 4)

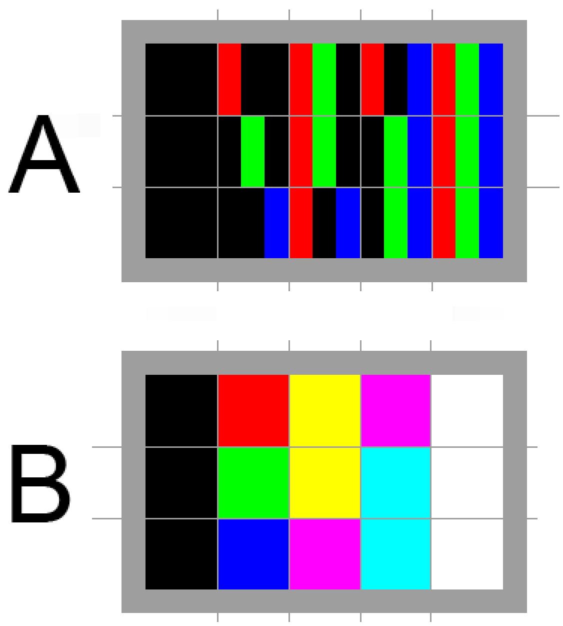


Figure 4: ***Pixels on a typical monitor.*** *A) Pixels as they physically exist, and B) pixels as they normally appear.*

1.1.6. Illusions in Perceived Passage of Time

Animation is also a fundamental illusion. Each frame of a computer generated animation represents a discrete, point-like moment in time. This is impossible to achieve using physical medium in the real world, such a moment in time is infinitely small and therefore impossible to capture. By displaying images at a rapid rate, these discrete moments in time converge and are perceived as a continuous flow of time.

2. EXPERIMENT

After studying the Primrose Field and Bulge illusions [Kitaoka], we hypothesize that use of optical illusion may enable one to convey extra information, information that may remain hidden when using similar graphical techniques that do not utilize optical illusion. In order to test this hypothesis, we designed an experiment to determine the usability of a system that utilizes optical illusions as a means of conveying extra data.

2.1. Data

The experiment is centered around a three dimensional, geographic map. The map is partitioned along longitudinal and latitudinal lines, creating individual tiles. These tiles are referenced by Cartesian coordinate locations on the map. Each tile stores a value that represents the average altitude of the land contained in that tile. The "extra data" that the experiment will test is therefore the height of the individual tiles.

2.2. Renderers

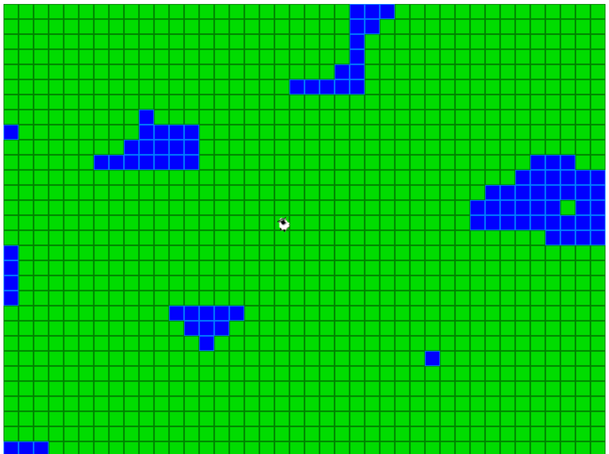
The tile map data is rendered in three different manners.

2.2.1. Flat Map

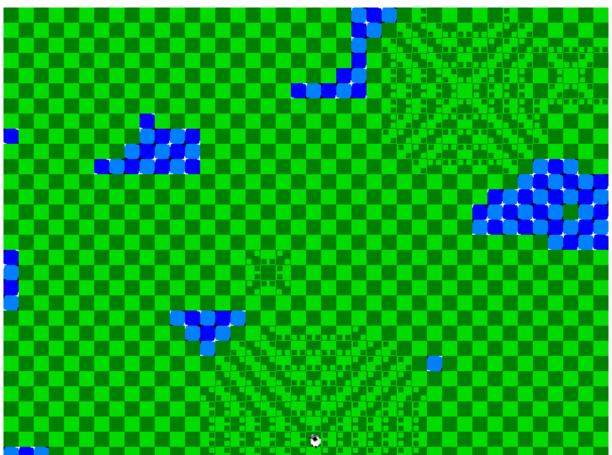
An orthographic projection of the map, utilizing a two-value color coding scheme to indicate areas of "land" and "water," is used as a control against providing no height information. In this environment, users must select points at random. (Figure 5.A)

2.2.2. Illusion Map

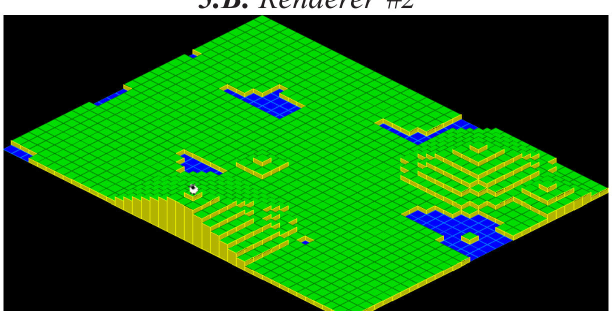
An orthographic projection of the map, utilizing the two-color coding scheme as well as optical illusions to indicate the areas of increasing slope of "land," is the experimental rendering technique. In this environment, users may or



5.A. *Renderer #1*



5.B. *Renderer #2*



5.C. *Renderer #3*

Figure 5. ***Rendererings From Survey.*** *A) Renderer #1 is the control for random user selections. B) Renderer #2 is the experimental renderer. C) renderer #3 is the control for effective use of height information.*

may not be able to determine the height of the hills. (Figure 5.B)

2.2.3. Isometric Map

An isometric projection, utilizing the two-value color coding scheme as well as perspective to indicate the height of individual tiles, is used as a control against providing explicit height information. In this environment, users can determine the height of hills quite easily. (Figure 5.C)

2.3. Survey

One of the three rendering techniques is chosen at random for a testing session. A test subject is sequentially presented with a total of five randomly generated maps, each rendered using the rendering technique for the test session. The user is given a task – they must select the tallest hill on the map. The user is not instructed on how the hills are represented. This task is reinforced with an animation of a small sheep running to the location that the user selected. After the task is complete for the five maps, the session's rendering technique and the user's success rate is recorded.[McBeth, 2005]

3. RESULTS

The survey was administered through "the leading online community for game developers of all levels," GameDev.net [GameDev, 2005, About] through the interactive forum system [GameDev, 2005, Survey]. The survey was advertised by pinning the associated thread to the top of the most active section of the web site, the General Discussion Forum.

A total of 110 test sessions were ran, with a total of 550 tasks completed. The success and failure rates for each rendering method were tabulated and summarized. (Table 1)

Key:
#: Rendering Type Number
TR: Total Runs
TS: Total Success
TF: Total Failure
%S: Percent Success
%F: Percent Failure

#	TR	TS	TF	%S	%F
1	140	7	133	5.000%	95.000%
2	220	172	48	78.182%	21.818%
3	190	186	4	97.895%	2.105%

*Table 1. **Initial Survey Results.** Results before discovery of rendering bug.*

Early in the survey process, a rendering bug was discovered that made selection of the tallest hills nearly impossible when using the experimental map renderer, essentially making it equivalent to the first control renderer. The bug was corrected and the survey continued. Because of this bug, test sessions that resulted in zero or one successes when using the experimental renderer were removed from the data set as corrupted data, and the results were re-tabulated. (Table 2, Figure 6)

#	TR	TS	TF	%S	%F
1	140	7	133	5.000%	95.000%
2	195	170	25	87.179%	12.821%
3	190	186	4	97.895%	2.105%

*Table 2. **Adjusted Survey Results.** Results after discovery of rendering bug.*

Each of the map renderers were profiled for performance data. A random set of maps of increasing size were rendered a thousand times for each rendering method, and the number of milliseconds that elapsed during the one thousand renderings was recorded along with the size of the map that was rendered. (Table 3, Figure 7)

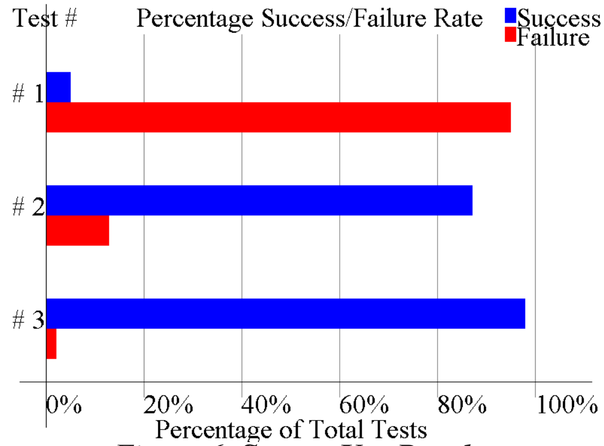


*Figure 6. **Survey Use Results.***

Map Size	Renderer 1	Renderer 2	Renderer 3
3 x 4	266	187	672
6 x 8	297	297	1734
9 x 12	453	468	2437
12 x 16	735	734	4359
15 x 20	1094	1140	6078
18 x 24	1609	1593	9343
21 x 28	2172	2204	13125
24 x 32	2890	2906	16390
27 x 36	3547	3532	21250
30 x 40	4078	4250	22266
Total	17141	17311	97654

*Table 3. **Rendering Benchmarks.***

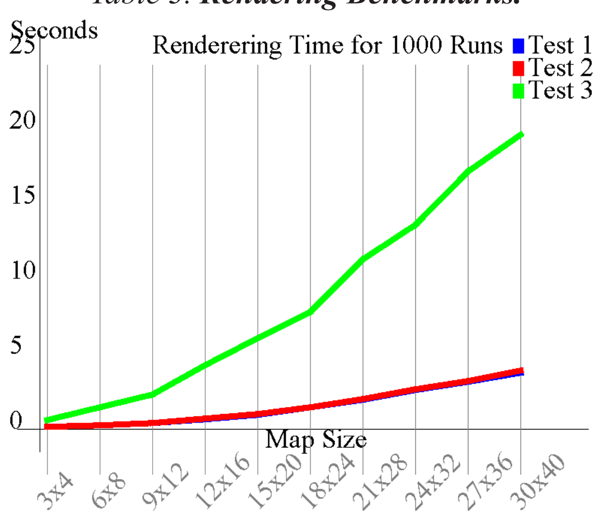


*Figure 7. **Rendering Benchmarks.** Test #1 is mostly obscured by Test #2.*

4. CONCLUSION

The survey results indicate that the test subjects were able to utilize the presented information, without coaching on how to use this information. The benchmarks show that difference in rendering time between the experimental rendering technique and the less content-rich rendering technique is negligible. This is to be expected, as the experimental rendering technique is merely a trivial application of the flat rendering technique. While the flat map indicates only length and width information, the map with illusions also indicates height information, a 50% increase in the total amount of information being presented in the scene. For a system that is capable of rendering only simple graphics, the experiment indicates that the use of illusion can be a useful technique for presenting the user with additional information.

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