Color, Texture, and Geometry

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Abstract

What distinguishes computer-generated art from other art genres? The ease of changing color palettes allows for experimentation not possible with conventional pigments. Randomness of color and size of thousands of individual geometrical objects produces textures which would be difficult to produce otherwise. Finally, the use of vector graphics allows for explorations with scale and size not possible with a physical canvas. Careful integration of color, texture, and geometry results in images clearly belonging to the realm of computer-generated art.

Introduction

I have been experimenting with geometrical art since college, when I began creating pieces involving mathematical envelopes using graph paper, ruler, and pencil. Recently, I took an art class at the school where I teach mathematics, and found myself wondering what I might have created back then if I had access to the technology of today. My experiments involved randomness in a significant way, and produced unexpectedly pleasing results. The use of randomness in computer-generated art is not new (for examples, see the article by Schönlieb and Schubert [6], or the work of Tarbell [7]); this paper will discuss some particular experiments with randomness and briefly discuss a few aspects of the creative process.

Color Spaces

Computer-generated colors are usually described by using either red-green-blue (RGB) values, or cyan-magenta-yellow-black (CMYK) values. We will use CMYK values in this paper.

Various techniques may be used to avoid broad expanses of the same color. In Figure 1, the color in the upper left has CMYK values $(0.4, 0.7, 0, 0.1)$. In the first large square, a random number between 0 and 0.1 is added to each of the CMYK values in each of the 100 smaller squares. In the next square, the random number is in the interval $[0, 0.25]$, while in the third square, the interval is $[0, 0.4]$ (a value larger than 1 may be obtained in this case, but is treated as 1).
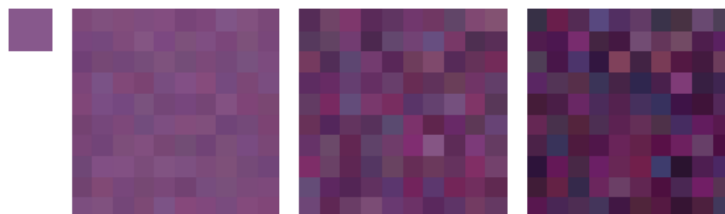

Figure 1 : *Random assignment of colors to squares.*

Important here is that since randomness is consistently "added" to the same base CMYK values, the various colors produced are fairly coherent. This coherence will be evident later in our discussion of textures.

Color

Experiments with color are easily undertaken with a computer. A *purposeful* use of color should guide the would-be artist; arbitrarily assigning color values because they are appealing does not always mean that the resulting palette is coherent.

In *Yin Yang IV* (see Figure 2), the use of color was influenced by the color studies of Josef Albers [1]. Each unit consists of "p" and "d" figures, as well as two small squares. The small squares are all the same color. In each unit, when the CMYK values for the "p" and "d" are numerically averaged, the common color of the small squares is obtained. Use of a random number generator determines how far the colors of the "p" and "d" are from that of the small squares.
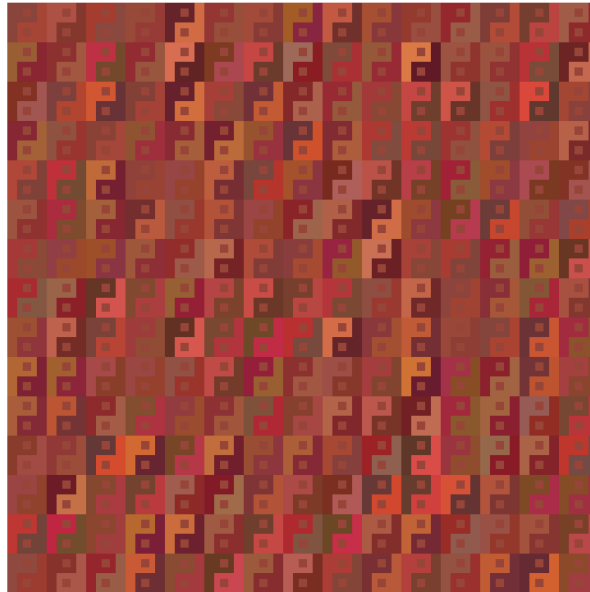

Figure 2 : *Yin Yang IV, 8" × 8".*

For example, suppose the small squares have CMYK color vector $c = (0.4, 0.5, 0.6, 0.2)$. A vector whose components are random numbers between 0 and 0.2 is generated, say $r = (0.03, 0.15, 0.1, 0.08)$. Then in one of the units, the "p" figure may be colored with $c - r$, while the "d" figure may be colored with $c + r$.

Artistic choices involve answers to the following questions:

1. How many units should be included for an image of a desired size?

2. What size should the small squares be?

3. What should the color of the small squares be?

4. How "random" should the CMYK values be; that is, what is the maximum value for the terms in r?

Moreover, the algorithm used here simply uses $c - r$ and $c + r$. Squaring the terms in r, for example, would make more of the units closer in color to the small squares. The seed of the random number generator is significant—different seeds sometimes produce surprisingly different results, so that dozens or perhaps hundreds of pieces need to be generated in order to find one which is well-balanced and sufficiently interesting. It is up to the individual artist to decide—among this almost infinity of possible choices—which options produce an aesthetically appealing result.

Texture and Geometry

There are various ways to create texture. Ray-tracing programs (such as POV-Ray) use very sophisticated methods to recreate metal, stone, wood, or glass textures. Randomness may be used to create interesting textures which suggest "real" surfaces, but without the intent to duplicate them. Variations in geometry may be used to create textures, as shown in Figure 3. It is not simple (nor necessary) to separate "texture" from "geometry" here.
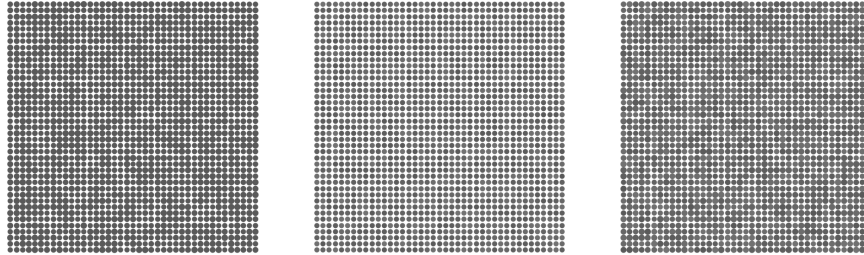

Figure 3 : *Three textures: random radius, random gray, and both radius and gray random.*

In the first square in Figure 3, the circles are all the same color, although their radii are randomly generated. The second square involves circles with constant radius, each a random gray. The third square involves both random grays and random radii. The effects are slightly different, and certainly other textures are possible by including other measures of randomness.

These ideas are used to create texture in "Four to One," shown in Figure 4. Large regions are visible which show circles with radii and color differening only slightly from their neighbors.
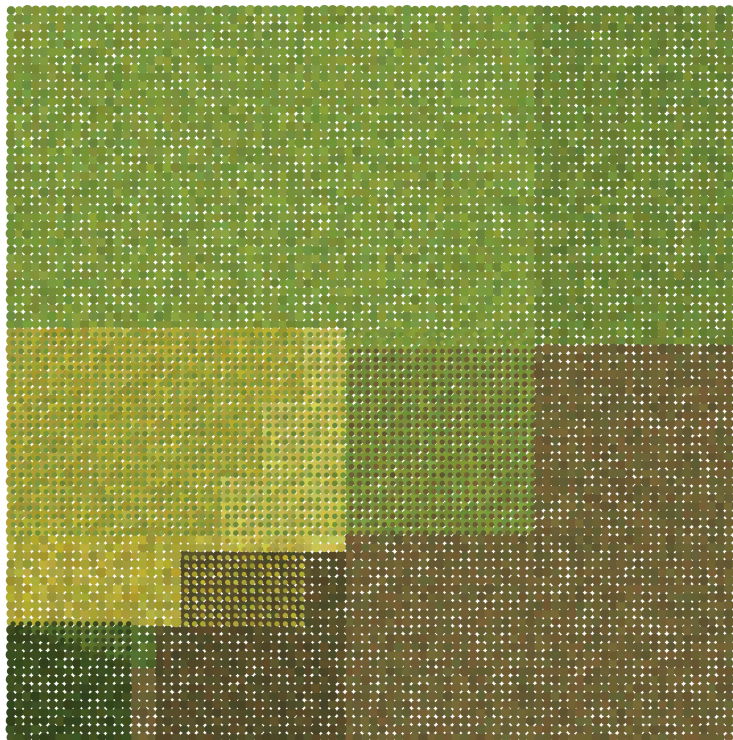

Figure 4 : *Four to One, 10" × 10".*

The image is based on a dissection of four squares to one, inspired by the dissections of Greg Frederickson [3]. As shown in Figure 5, squares of sizes 15, 36, 48, and 64 may be dissected into pieces and arranged to form a square of size 89, illustrating that

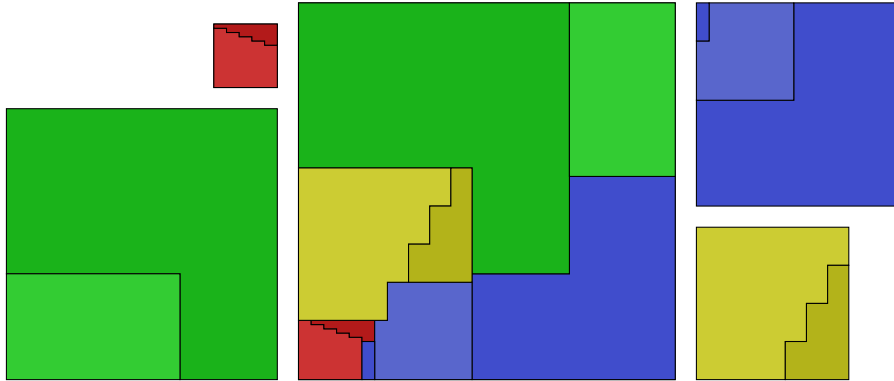$$15^2 + 36^2 + 48^2 + 64^2 = 89^2.$$

Figure 5 : *The geometry of Four to One.*

Rather than creating five different squares, suggestions of the four component squares are created by overlaying smaller circles (again, with random radii and colors) on top of the larger circles. For example, the large green square (of size 64) is suggested by both the larger green circles which create the piece of the dissection, along with the smaller green circles overlaid on the yellow pieces of the dissection. As a result, the original dissection on which the image is based can be found within the square of size 89.

The choice of colors came from a November drive through Princeton. The abstract austerity of the algebraic relationship contrasts with the organic color palette. Shades of tree trunks, pine trees, and dead leaves are evident.
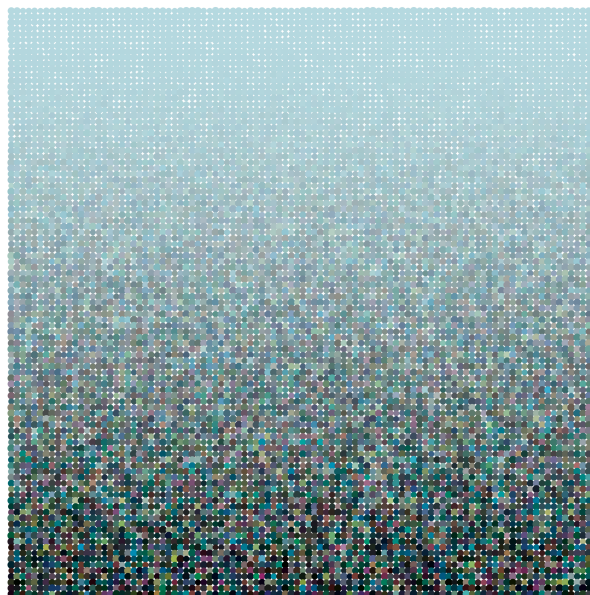

Figure 6 : *Evaporation, 16" × 16".*

Other effects may be created by varying the color gradient, as suggested in the comments following Figure 2. In Figure 6, the randomness of the colors varies as the square of the distance from the top of the image. This "quadratic" gradient creates a region near the top which is fairly monochromatic. Changing the exponent from 2 to 3 or any other real number will produce color gradients with different effects.

Additional textural effects may be created by randomly varying the opacity of various colors. In Figure 7, the positions of the circles, the radii, the colors, and opacities of the various circles are randomized.
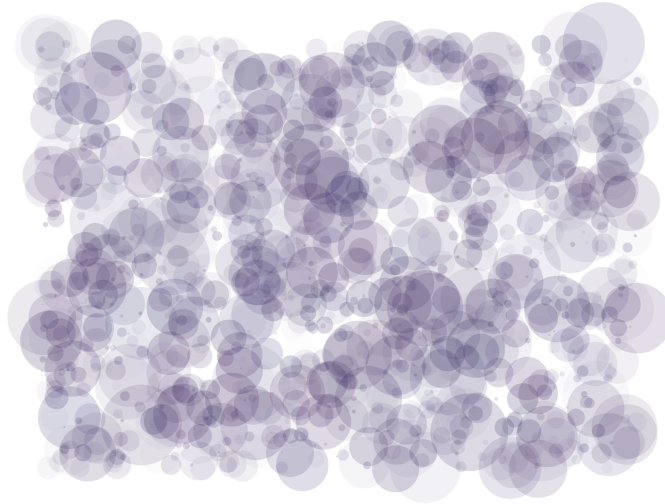

Figure 7 : *Circle Dimunition.*

In this example, the seed of the random number generator produced rather different images. Many images were examined for a balance of circle colors and sizes, as well for a "rectangular" feel; some attempts had rounded corners which seemed imbalanced.

The raindrops in Figure 8 are all oriented at the same angle, but the sizes and opacities are randomized. Here, the position of the raindrops is random, but based on a gradient so that the drops cluster at the top of the image.
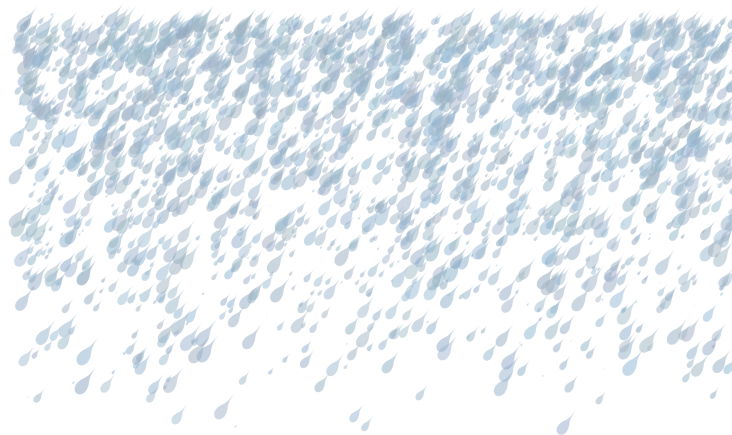

Figure 8 : *Raindrops.*

Conclusion

The images illustrated in this paper all involve randomness in some structured way. They involve a limited number of geometrical forms, as well as fairly restricted color palettes. There is still much to do in developing these ideas into larger, more complex works.

As a mathematician interested in art, I am excited to be a participant in the technology explosion which has allowed for the creation of new artistic genres. I have particularly enjoyed creating the images in this paper, which in my mind involve little more than a few simple geometrical motifs along with a controlled measure of randomness. I often amaze myself when I look at what pops up on my computer screen, and marvel at the fact that just these simple ideas can produce images which have such a profound effect upon me.

To the seasoned computer artist, these comments might seem commonplace. But for those relative newcomers (like myself), I would like to share a few ideas which helped me along the way. Because I am fascinated by color, I am frequently tempted to use a broad palette filled with vibrant color combinations. This often leads to a lack of coherence in the final image, so that a deliberate use of color is key. I also tried to keep in mind the medium—the computer—in that I strove to create effects which could not be created using more conventional media. In other words, I wanted to contribute specifically to the genre of *compter-generated* art. In these experiments, randomness was a key factor. Finally, I cannot overemphasize the significance of the many lively conversations with my art teachers, Alkan Nallbani [5] and Geoffrey Miller [4], and Alkan's colleague Bryan Christie [2]. As artists, they were able to share perspectives on my images—especially with regard to color—that I would otherwise not have encountered. Their encouragement and advice were instrumental in making my participation in Bridges possible.

Image Generation

All images except Figure 5 were produced using *Mathematica,* while Figure 5 was created using the Ti*k*Z package in LATEX.

References

[1] Albers, Josef, *Interaction of Color,* Yale University Press, 2009.

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