

# **VIDEO DITHERING**

A Thesis

by

JIN NAH YU

Submitted to the Office of Graduate Studies of  
Texas A&M University  
in partial fulfillment of the requirements for the degree of

**MASTER OF SCIENCE**

May 2004

Major Subject: Visualization Sciences

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Major Subject: Visualization Sciences

## **ABSTRACT**

Video Dithering. (May 2004)

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In this work, we present mathematical and artistic techniques for the easy creation of artistic screening animations in video resolution by extending the artistic screening technique of adapting various patterns as screen dots for generating halftones.

For video dithering, three different animations are needed. One is for screen dots which is a simple black and white animation; another is for the goal (or perceived) animation on the screen; and the other animation is for controlling the color and the size of screen dots. By combining three different animations with video dithering techniques, two animations appear simultaneously on the result video screen and provide complex and unique animation.

Our techniques assure creating of aesthetic looking movies by providing frame to frame coherence and avoiding spatial and temporal aliasing that can be caused by low quality of video images.

We shows how this technique is a powerful and effective way to create artistic results, by demonstrating variety of video dithering.

To my family

## ACKNOWLEDGMENTS

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# CHAPTER I

## INTRODUCTION

### I.1. Layered Imagery

We often come across artwork showing hidden patterns and unexpected illusions of real objects or impossible figures by a unique combination of a variety of objects and different positions of viewer. These works of art intentionally express a layered two dimensional look. It is quite interesting and enjoyable to discover these hidden patterns and identify the illusions.

The earliest pioneer of such artworks is 16<sup>th</sup> century Italian painter, Giuseppe Arcimboldo who developed a unique composite portrait style. He made perfectly recognizable figures of human heads by combining a variety of objects, both natural and man-made. These objects included painted human figures, animals, flowers, fruits, and books [1, 2, 3]. His unique decorative and fantastic portrait reminds one of 20<sup>th</sup> century surrealist art.

M.C. Escher(1898-1972), one of the world's most famous graphic artists, created unique art works which were impossible structures, spatial illusions, and complicated repeating patterns by mathematical ideas beyond the limitation of space and time. In Escher's work *Day And Night* [4], repeating geometric patterns (tessellation), the black and white birds, nicely blend into the picture to create the whole expanse. And also the transition of pattern images represent time changing with halftoning artifacts through the whole image. *Metamorphosis* [5] is one of his fascinating tessellation art works. It was created using several different tessellation shapes. Similar shapes of patterns completely cover the plane without overlapping and blank space with transforming by using several different

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tessellation shapes.

Surrealism, one of the unique style artistic movements of the 20<sup>th</sup> century represents reality and the surreal together in fantastic visual imagery without the intention of making the artwork logically or physically comprehensible. Salvador Dali is probably one of the best-known Surrealist artists. With his unique visual sense he discovered a human face in a postcard of African tribesmen by rotating 90 degree clockwise [6]. He later used a likeness of this face in one of his paintings [7]. The *Metamorphosis of Narcissus*, one of Dali's masterpieces, [7] shows the double imagery of death and life with repeated images, contrast of color, and human figures of diverse look.

Computer graphics pioneer and also artists, Ken Knowlton, created mosaic portraits using various mediums such as seashells, the alphabet, geometric pieces, numbers, dominos, ceramic tiles, baseball cards, keyboards, equations and etc. [8]. His mosaic portraits sometimes combines the face with the important symbols or objects of the person in a portrait.

Artist Zeke Berman has created one of famous optical illusions, *Faces or Vases* using silhouettes of actual people. The faces or the vases can be recognized depending on what you perceive the black space or the white space is as the background [9].

## **I.2. Artistic Screening in Computer Graphics**

This unique artistic concept was successfully transplanted for generating digital halftone techniques by Ostromoukhov-Hersch [10]. These halftone techniques are called artistic screenings. With artistic screenings one can generate halftoning images by generating continuous geometric transformations of dots which can be freely adapted. Inspired by Escher's tiles [10] was generated by artistic screenings. This is a complex character-based artistic screen which is easily generated by one of artistic screening techniques [11].

Based on these historical artistic background, this research was motivated. Especially owing to artistic screening techniques, these unique artistic ideas can be extended to digital halftoning. The invention of computer-based artistic screening techniques brought flexibility and capability to process complex and repetitious tasks through digital media, making it possible to get a high quality aesthetic result.

### **I.3. Video Dithering**

The goal of this thesis is to develop techniques to combine more than two animations within one screen in such a way that two animations will be clearly visible. Our approach to combine animations is based on halftoning techniques which were inspired by artistic screening. Our technique, called as video dithering, can create two layered animations within one video simultaneously. One animation is represented as animated patterns and the other is shown as a video itself.

Motion in images has been attempted by various film and 2D graphic artists. Our work will aim at providing tools film and 2D graphic artists to allow to create unique and aesthetic works of art. Based on our techniques, a user interface will be developed for allowing users to combine two animations easily.

## CHAPTER II

### HALFTONING: A HISTORICAL BACKGROUND

#### II.1. Photographic Halftoning

This section briefly presents a historical perspective on halftoning (or, in other words, screening) techniques.

Photographic (or traditional) halftone techniques were developed for printing a photograph with various gray tone. The common printing process can print images or letters by only solid ink with blank paper and therefore cannot reproduce the continuous tone pictures. Photographic (or traditional) halftone techniques make possible to print variable intensity levels of a photograph using a limited number of inks and became commercialized in the 1890's [12].

The term “screening“ came from the etched glass screens used to create traditional halftone images. Figure 1 shows how traditional halftone images were created by using an etched glass screen with finely ruled grids to divide the image into many small dots. The etched glass screen is placed close to high contrast film and exposed to the light. The light source shining through the screen remains dots of varying sizes on the high contrast film. The sizes of dots under the glass screen are proportional to the amount of light passing through the screen grids. With this processing, the original photograph is converted to dots of varying size on the high contrast film, and these small dots represent different intensity areas of a photograph.

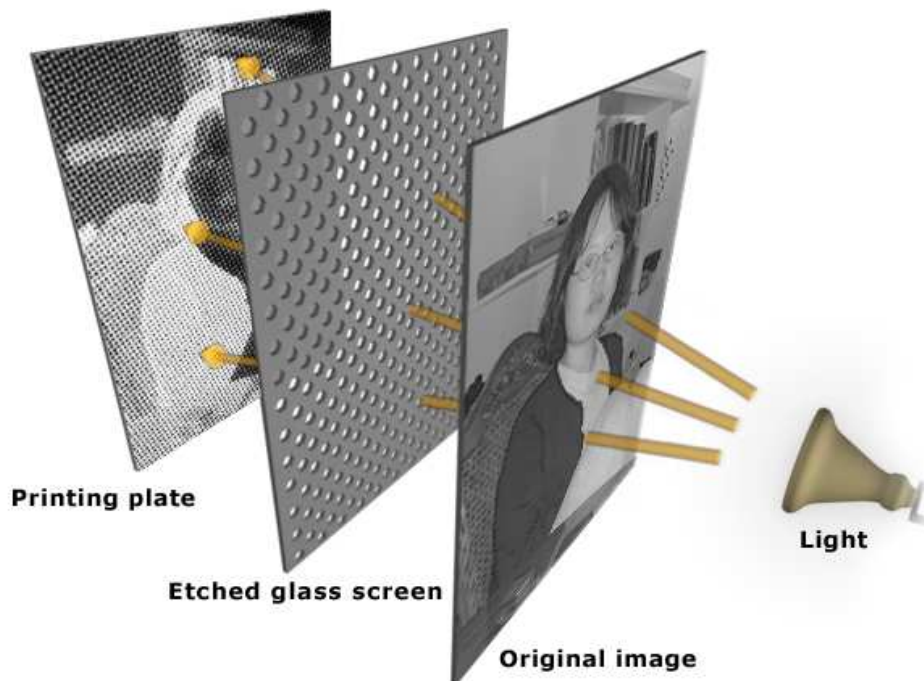


Fig. 1. Creating a traditional halftone.

## II.2. Digital Halftoning

Digital halftones were introduced to play a similar role to traditional halftone for digital media. Digital halftoning can create continuous gray tone by varying the size of bi-level small dots arranged in a regular grid of halftone cells. Halftone cells are used to create continuous gray tone by filling black pixels into halftone cells. Generally, through halftoning a high-resolution image converts to a low-resolution image for printing and display. In early computer graphics, only a limited number of palette colors and low pixel resolution were available. The colors, that didn't exist in a physical palette, of an original image needed to be displayed with a limited number of colors and pixels. Digital halftoning could be used to create variable intensity levels and colors by mixed pixels of colors that existed in a palette.

During the last two decades a variety of digital halftoning methods have been devel-

oped to create variable intensity level images using limited palettes and resolutions [13]. These algorithms can roughly be classified as dithering and error diffusion.

1. **Dithering** The dither algorithms are for generating digital halftoning images by thresholding an input image with threshold values or threshold matrixes which are generated by various methods. Each pixel value of the image is compared with the threshold value and if the pixel is smaller than threshold value, the corresponding pixel of the output image is filled with black. Therefore the average intensity and color in small areas of the dithered image is approximately the same of the original image.

Dithering can be categorized into two main classes, as clustered-dot dither and dispersed-dot dither.

The clustered-dot dither generates periodic (ordered) patterns that are generated by ordered threshold values. The dot sizes are determined by the cluster of pixels adjacent to each other. Dots are arranged in different manner on the screen, such as the spiral-dot, line screen and zigzag, into rectangular or hexagonal grids. These different screen patterns are generated by thresholding an input image with a dither matrix that can be defined by the user to create different patterns of pixel clusters. Clustered-dot dither algorithms are suitable for graphic display devices that cannot display isolated black and white pixels [14].

The dispersed-dot dithering approach was studied by Limb [15] and well known by Bayer [16] in 1973. Dispersed-dot threshold arrays produce better illusions of continuous tone pictures than clustered-dot arrays of the same resolution and period [17]. Unlike clustered-dot dither, pixels of dispersed-dot arrays doesn't need to be adjacent each other. The dispersed-dot dither algorithm drives homogeneous ordered dither threshold arrays. By using particular homogeneous threshold arrays, black

and white pixels of output dots are distributed homogeneously throughout the output image areas. Dispersed-dot dithering is used with low resolution devices such as CRT displays and bitmap displays [18].

2. **Error diffusion** The error diffusion approach was introduced by Floyd and Steinberg in 1975 [19] and has since been developed in many different ways. Error diffusion is successful for the neighborhood digital halftoning process [14]. It produces halftones of higher quality than classical screening. This algorithm computes the output value by comparing between the input value and a fixed threshold. The difference, called the error, between the output value and the original gray value of every pixel is distributed to neighbor pixels determined by an error filter which can use weights of any number, position and value. [14]. Thus, the error is over neighbor pixels.

The dot diffusion algorithm combines the ordered dither algorithm and error diffusion techniques to solve shortcomings of other halftone techniques. By using the dot diffusion algorithm, the original image is replicated to a matrix with certain class numbers and thresholded by the matrix to diffuse errors. Then the errors dispersed by the above processing in the one display cell are passed among neighbors in the cell [20].

### **II.3. Artistic Screening**

Although digital halftoning methods can also be used for printing images, there is a major difference between printing and digital media. In print media, the palette is extremely limited but there is almost no limit on resolution. Based on this flexibility of print media a new digital halftoning technique was developed to replace photographic (traditional) halftoning techniques.

Artistic screening, which was developed by Ostromoukhov and Hersch in 1995, completely revolutionized halftoning in print media [10]. Since there is no limit on resolution

of printed images, artistic screening allows adapting a wide variety of shapes as screen dots, such as letter shapes, artistic patterns and ornamental shapes, to generate halftones. This freedom of adapting any pattern allows images of high aesthetic quality to be created.

These techniques can be useful for large posters as advertisement or security (credit cards, bank notes, etc.) [10]. Since These techniques generate not only high resolution printed image but also conveying two layered information with screen dots and image itself.



## CHAPTER III

### METHODOLOGY

#### III.1. Video Dithering: An Introduction

This research extends the applicable area of Ostromoukhov-Hersch technique to moving images in the RGB color space. The concept of artistic screening applies well to our goal which is conveying two layered information into one screen. Motivated by both artistic and aesthetic concerns, we also develop a variety of techniques to create artistic video dithering. Figure 2 shows an example frame from our preliminary work on artistic video dithering.

Video dithering allows artists to combine three different animations to create one animation. These animations are the following:

1. **Goal animation.** What the final animation must look like,
2. **Dot animation.** The black and white animation that defines the shapes of the animated dots,
3. **Control animation.** This animation controls the color of the background.

Differences between printed artistic screenings and video dithering can be classified as follows: (1) The number of colors is severely limited in printed artistic screening images, but, in video dithering, there is no practical limitation in the number of colors. This freedom over the number of the colors allows us to control dot color and size using an animation. (2) The resolution of video images is severely limited. On the other hand, artistic screening images have good resolution and can be used simply for their aesthetic qualities. As a matter of fact, artistic screening images are particularly well-suited to the production of large-sized posters [21].

Here are five requirements we have identified for artistic video dithering. (1) The results should be aesthetic. (2) The results should show clearly the correlation between two animations on the screen. (3) At least two animations should be clearly visible. (4) There should be frame by frame coherence. (5) There should be no spatial or temporal aliasing.

These conditions present a variety of interesting and unique technical challenges for generating the video screen images.

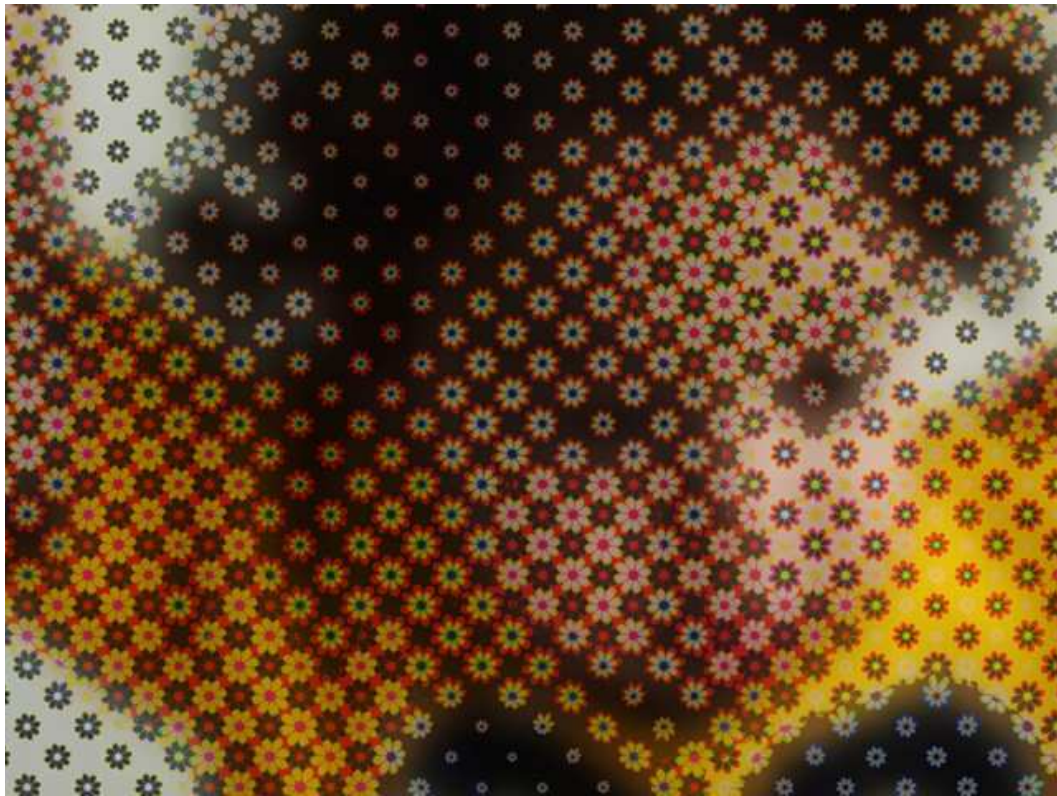


Fig. 2. Image of artistic video dithering.

### **III.2. Mathematical Foundation**

This section introduces mathematical foundations for the development of artistic video dithering. In our approach, for each frame of animation, the users provide three images; goal image, control image and dot image. The dot image is a black and white image that

defines the shape of the dot. Our goal is to generate the illusion of the goal image with varying sizes and colors of dot shapes. In order to create this illusion, we first assume that any image consists of a set of square regions. And we only consider the average color in each square region. Our goal is for any given (goal) image to create a final image that is made up dots in such a way that the average colors in final and goal images are exactly the same. To create this effect, in each square region of the final image we will control the size and color of the dot, and color of background.

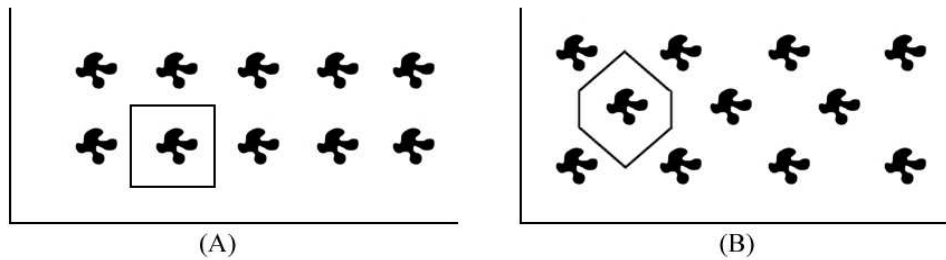


Fig. 3. Grid types. Rectangular (A) and Hexagonal (B).

In existing research on dithering, the dots in a final image are organized in two different ways, rectangular and hexagonal [14] (see Figure 3). Hexagonal grids are more desirable than rectangular grids for various reasons. The advantage of hexagonal grids is that 1) hexagonal grids are visually more effective in covering every square region of the image, 2) using a large number of dots in each square region creates higher complexity, 3) artifacts are less visible in the hexagonal grids than rectangular grids. Dot images are aligned in zigzags on the hexagonal grids, therefore it makes a complicated structure. The rectangular grids arrange dot images perpendicularly along the rectangular grids. This conveys a monotonous impression, and the spaces between the dots show the illusion of vertical or horizontal lines.

In video dithering, we place dot images into the repetitive regular square regions.

However we can simply create an illusion of hexagonal grids on the rectangular tiles by a very simple modification that arranges the two dots into each square region as shown on the Figure 4. The advantage of this placement is not only the easy creation of an illusion of hexagonal grids but also that the calculation is much simpler than hexagonal grids.

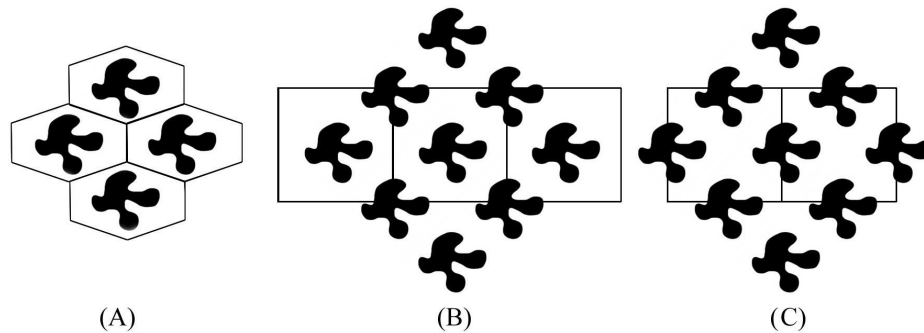


Fig. 4. Equivalent hexagonal grids. (A) Real hexagonal grid. (B) and (C) Fake hexagonal grids.

Figure 5 shows how to place dot images in video dithering. (G) and (H) in Figure 5 clearly shows an illusion of hexagonal grids on the square grids. The size and color of dots are adjusted without loss of the goal color. In order to generate the illusion of the goal image with dot images, both the black and white colors of the dot images are replaced by two colors, which we call the dot color and the background color.

We assume that an input image consists of a set of square regions in which the color is almost constant. Based on this assumption, the color of each pixel of the input image represents the color of the region where the pixel belongs, which is called the goal color. The size and color of dots are adjusted depending on the goal color. In order to generate the illusion of the goal color with dot images, both the black and white colors of dot images are replaced by two colors, which we call the dot color and the background color. Note that we use the RGB color space and compute R, G and B separately to compute these colors.

Note that we consider only three types of colors in square regions. The average color

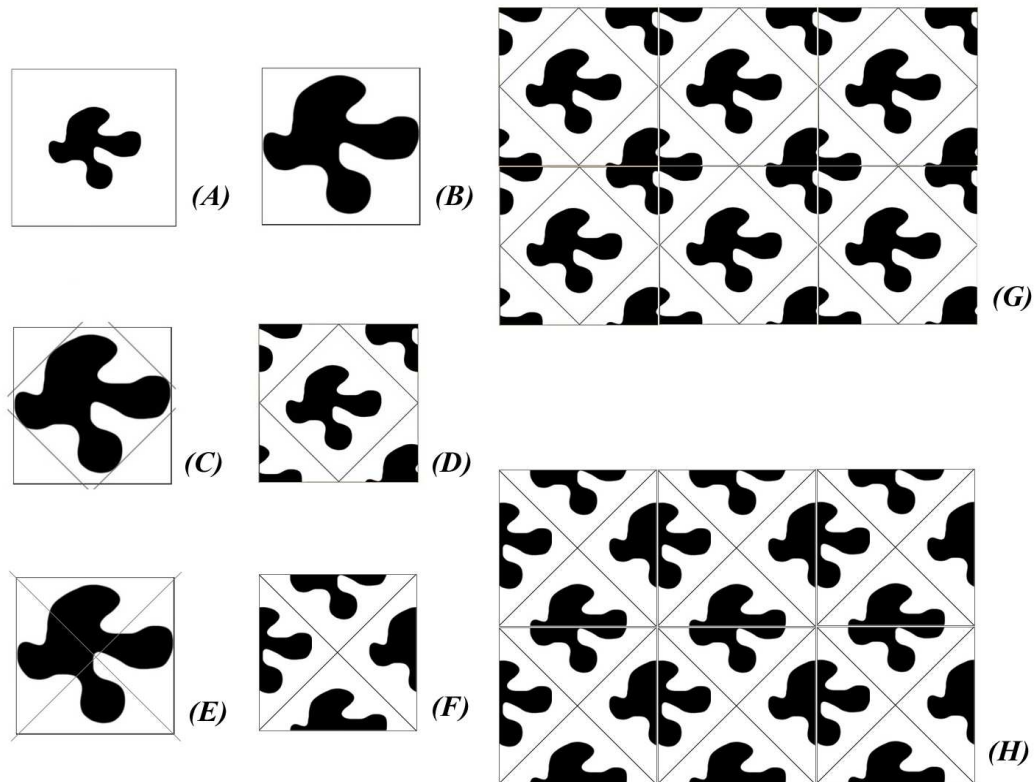


Fig. 5. Rectangular-hexagonal equivalent (A) dot image, (B) dot image placed in a rectangular region to create an illusion of hexagonal grid as shown in (G) and (H). The ratio between black and white regions can easily be changed by scaling as shown in (C) to (D) and (E) to (F).

in the goal image will be called goal color and be denoted  $C_G$ . In the final image, the color of the dot will be called dot color and will be denoted  $C_D$  and the color of the background will be called background color and be denoted  $C_B$ . In addition to these, let  $a$  denote the ratio of dot area to area of a square region in the final image.

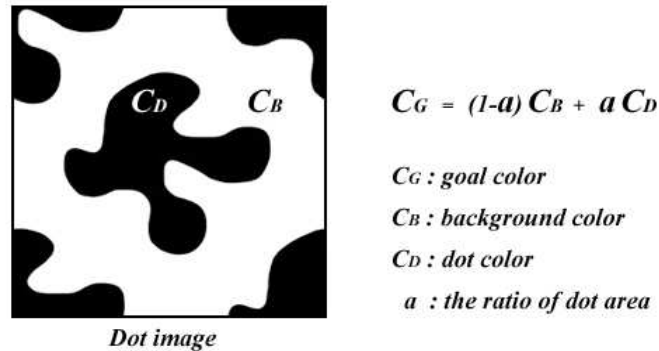


Fig. 6. The diagram of the relationship between three colors and  $a$ .

An example of square region of a final image is shown Figure 6. Without loss of generality, we can assume that each of these values are real numbers between 0 and 1. The desired relationship between these colors  $C_G$ ,  $C_B$ ,  $C_D$  and ratio  $a$ :

$$C_G = (1 - a)C_B + aC_D. \quad (3.1)$$

In this equation, only the goal color  $C_G$  is given. The other parameters  $C_B$ ,  $C_D$  and  $a$ , can be freely chosen as far as they satisfy the equation 3.1. At the first glance, it may, therefore, seem that we can let users freely choose any two of these parameters and compute the value of the third parameter. This first observation is not really correct. In the next section, we show that more than one parameters cannot be chosen freely.

### III.2.1. *More Than One Parameter Cannot be Chosen Freely*

If we let the users chose more than one parameters, the certain combinations of any two parameters may cause that the third parameter goes out of its range. For instance, let us assume that we let the users choose the values of  $C_B$ ,  $C_D$ , then the value of  $a$  will be computed as follows:

$$a = \frac{C_G - C_B}{C_D - C_B}. \quad (3.2)$$

In this equation, for certain combinations of  $C_B$  and  $C_D$ ,  $a$  can go to  $\infty$  and  $-\infty$ . For instance, let  $C_G > C_B$  and  $C_D \geq C_B$ , then

$$a = \lim_{C_D \rightarrow C_B} \frac{C_G - C_B}{C_D - C_B} \rightarrow \infty. \quad (3.3)$$

Similarly, if we let the users freely choose  $a$  and  $C_D$ , then the value  $C_B$ , which will be computed as follows, can go to out of range:

$$C_B = \frac{C_G - aC_D}{1 - a}. \quad (3.4)$$

For instance, let  $C_G > aC_D$ , then

$$C_B = \lim_{a \rightarrow 1} \frac{C_G - aC_D}{1 - a} \rightarrow \infty. \quad (3.5)$$

We can show the same result for free choice of  $a$  and  $C_B$ . As a result, we conclude that more than one parameter cannot be chosen freely.

We cannot also let the user choose the size of  $a$  freely.

### III.2.2. *The Value $a$ Cannot be Controlled Freely*

Controlling the values of  $C_B$  and  $C_D$  is straightforward; we can just choose colors, and any number between 0 and 1 will correspond a color value.

On the other hand, the value  $a$  can only be controlled by changing the size of the dot shape. This is easy if the dot shapes do not overlap; the value of  $a$  can easily be controlled by scaling the dot shape. In this case, scale value is directly related to the value of  $a$ . On the other hand, if dot shapes are overgrown and overlap, two problems occur:

1. the shape of the dot will not be recognizable and
2. computing the correct value of  $a$  will be more difficult.

In order to avoid overlapping, we have to choose  $a$  value smaller than a threshold value  $T$  which depends on the shape of the given dot. At the first glance, this may seem to be a limiting factor since  $a$  cannot take all possible values between 0 and 1. Fortunately, this is not the case. In the case that  $a > T$ , we use  $1 - a$  instead of  $a$ . In other words, the equation 3.1 becomes

$$C_G = aC_B + (1 - a)C_D. \quad (3.6)$$

This replacement means that in the areas  $a > T$ ,  $C_B$  becomes the color of the dot and  $C_D$  becomes the color of the background. In order to create better looking result, we also change the organization of dots as shown in Figure 7.

In another words, to keep from overlapping the dots, we first compute the ratio for the maximum size of a dot that does not result in overlapping. This ratio is denoted as threshold  $T$ . If  $a$  exceeds  $T$ , the ratio of the dot area is replaced by the ratio of the background area( $1 - a$ ), and there is a color inversion between the dot color( $C_D$ ) and the background color( $C_B$ ). There are two different ways of organizing dots in video dithering



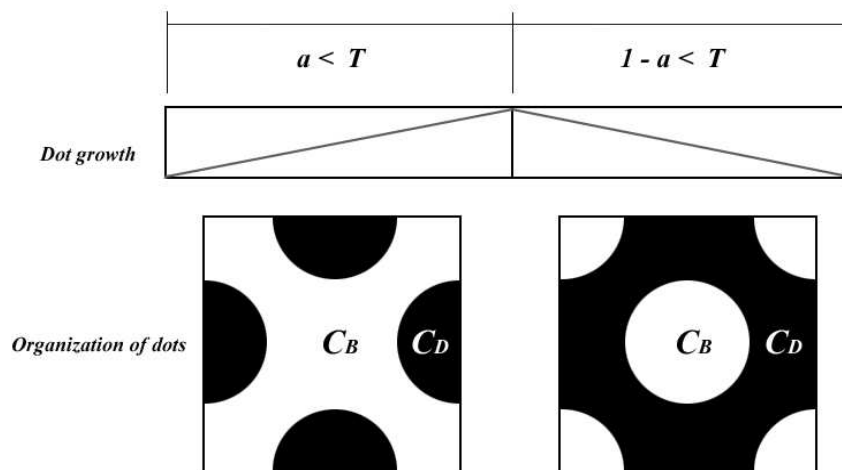


Fig. 7. The change of dot organization based on the  $a$  value.

technique. For smooth transitions, when the background and dot colors are inverted, the organization of dots is switched to another type of organization.

Based on these constraints, we have developed two methods to provide intuitive control to the users by (1) direct control of dot color, (2) direct control of dot size.

### III.3. Direct Control of the Dot Color

As we have shown earlier, we cannot control both  $C_D$  and  $C_B$ . As a solution to this problem, we let users freely choose only dot color  $C_D$  by providing a control image. Background color  $C_B$  is indirectly computed to guarantee  $a$  value is always between 0 and 1. In the equation 3.2, each color value and ratio  $a$  must be between 0 and 1, so that the equation itself is also between 0 and 1. According to this condition,

- if  $C_D > C_G$  then  $C_G$  must be larger than  $C_B$ .
- If  $C_D < C_G$  then  $C_G$  must be smaller than  $C_B$ .

Based on this observation, we can provide an additional control to define  $C_B$  as:

$$C_B = f_1(t_1) C_G \quad \text{if } C_D \geq C_G$$

$$C_B = f_2(t_2) + (1 - f_2(t_2)) C_G \quad \text{otherwise}$$

where

$$t_1 = \frac{C_G}{C_D}$$

and

$$t_2 = \frac{C_G - C_D}{1 - C_D}$$

and

$f_1$  and  $f_2$  are any two functions with

$$f_1 : [0, 1] \rightarrow [0, 1]$$

and

$$f_2 : [0, 1] \rightarrow [0, 1].$$

Note that  $f_1$  and  $f_2$  do not have to be continuous functions.

In our case, we simply choose  $f_1 = f_2 = t = \text{constant}$  in which  $t = 0$  gives a result like classical dithering and  $C_B$  gets the maximum value. On the other hand,  $t = 1$  makes  $a = 0$  and does not create any dithering. In other words, the value of  $t$  controls both the size of the dots and the amount of blending between the goal and dot images. As the dot size gets smaller it creates more blending. We generally use a  $t$  value around 0.5.

Note that discontinuities in  $f_1$  and  $f_2$  can cause sudden changes in color. We have observed that it is possible to avoid these sudden changes by dividing intensity levels in several different areas by creating a clear boundary between each of these different intensity regions. Each of these intensity regions can be defined by any implicit equation between  $C_G$ ,  $C_B$ ,  $C_D$  and  $a$ . This flexibility allows us to easily manipulate the range of dot growth in final images. For instance, for  $f_1 = f_2 = t = \text{constant}$  case, the discontinuity occur when  $C_G = C_D$ . To avoid sudden change, we divide intensity levels into two areas by using the related implicit equation  $C_G - C_D = 0$  as shown in the Figure 8 that illustrates how the dot sizes changes based on a given set of  $C_G$  and  $C_D$  images. Based on this implicit equation,

whenever the value of  $C_G$  is smaller than  $C_D$ , the background color( $C_B$ ) is darker than the dots. Whenever the value of  $C_G$  is larger than  $C_D$ , the background color( $C_B$ ) is brighter than the dots. Even in this simple case, we can easily manipulate the range of dot growth by simple modification of the control image and the final image can have more variation of dot sizes and colors than traditional halftone image.

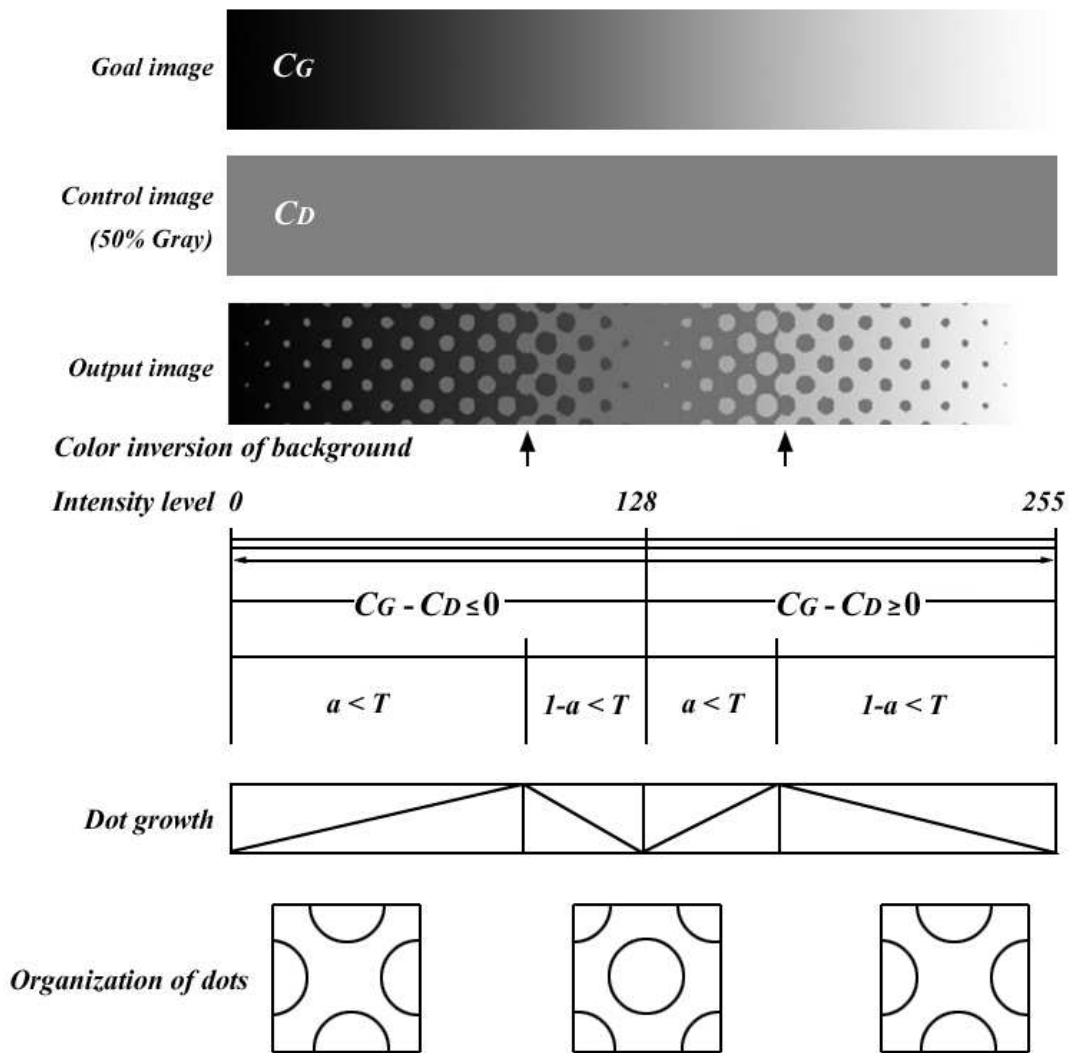


Fig. 8. The result of a dot growth and organization of dots by using the direct control method in a grayscale image. Here  $t = 0.3$  and  $C_D$  is a 50% gray control image.

Figure 9 is a video dithering image created by the direct control method with 50 % gray as the control image in a grayscale real photo. Figure 10 shows the simple comparison between traditional halftone and video dithering. Video dithering allows more levels of color and an enhanced the variation of dot images.

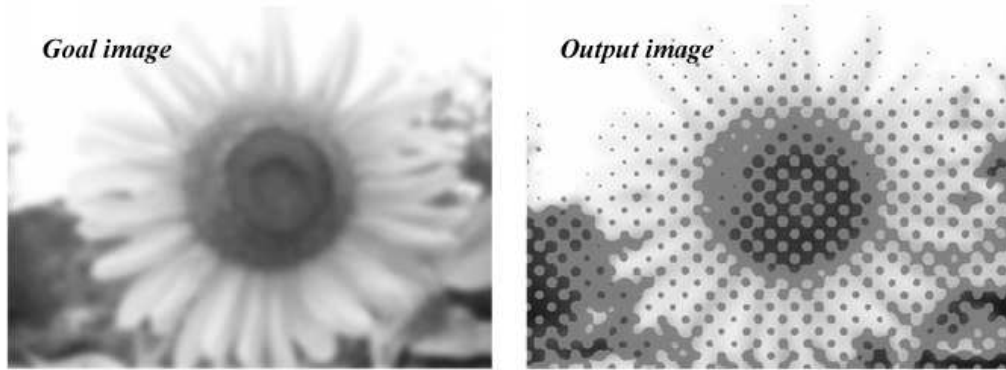


Fig. 9. Using the direct control method in a grayscale image with 50% gray as the control image.

#### III.4. Direct Control of the Dot Size

In the second method, the background color( $C_B$ ), as a control color, controls the size of dot images. In order to keep the value of the goal color, the size of dot images along with the background can be adjusted by the user. We have identified two cases. Without loss of generality, we assume that  $0.5 \geq a$  so that  $1 - a \geq a$ , also let  $b = 1 - a$ .

1. In the first case, we want to choose the maximum possible color for  $C_D$ . Then the equation becomes

$$C_D = 1 \quad \text{and} \quad C_B = (C_G - a)/b \quad \text{if } C_G \geq a$$

$$C_B = 0 \quad \text{and} \quad C_D = C_G/a \quad \text{otherwise}$$

2. In the second case, we want to choose the minimum possible color for  $C_D$ . Then the equation becomes

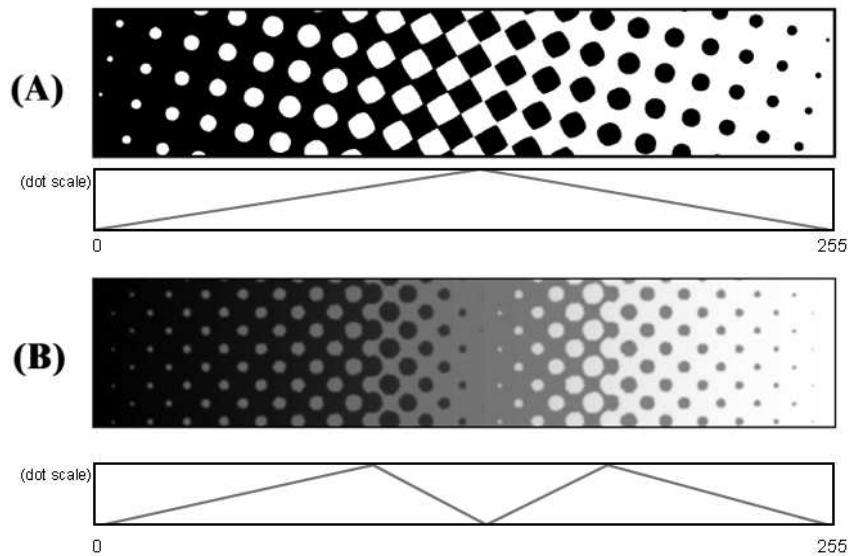


Fig. 10. The comparison between traditional halftone and video dithering.

$$C_B = 1 \quad \text{and} \quad C_D = (C_G - b)/a \quad \text{if } C_G \geq 1 - a$$

$$C_D = 0 \quad \text{and} \quad C_B = C_G/b \quad \text{otherwise}$$

The first case is organized so that the dots look brighter, the second so that the dots look darker. From these two cases, we can recognize that darker background colors decrease the ratio  $a$  so that the sizes of dots are shrinking, and brighter background colors increase the ratio  $a$  so that the sizes of dots are growing. Since we can apply a different method for each channel, we can make dots look red, green, blue, green+blue, red+blue and red+green in addition to white and black. This method enables us to create distinctive variations of dot size and coherent dot color through the whole image.

## CHAPTER IV

### IMPLEMENTATION AND RESULTS

We have developed a prototype system written in C++, to create artistic video dithering. It reads three image sequences: (1) goal image sequence, (2) dot image sequence, (3) control image. To compute colors, we use RGB space, i.e., we compute  $R$ ,  $G$  and  $B$  separately by using the equations presented earlier. Although other color spaces can effectively be used, we did not observe any problem with using RGB. We have developed three artistic methods to give intuitive control with acceptable video dithering over the results.

#### IV.1. Using Complementary Colors for Dot and Background

In this method, we create the control animation by reducing a complementary color from a given goal animation. This control animation directly controls dot colors. In this case,  $C_D \leq C_G$  then we compute  $C_B = t + (1-t) C_G$ . Let  $C_D = s C_G$  where the dot growth rate is a number smaller than 1. If we choose  $t \approx s$  then  $C_B$  becomes the complement of  $C_D$ , the color of the background automatically becomes  $C_D$ 's complementary. Figure 11 shows a grayscale goal image generated to a video dithering image using the complementary color method. A blue control image is created by eliminating yellow, complementary color of blue. The shape of dots is decided by black and white images, (C) and (E). This control image shows its complementary color in the dot images.

Based on equation 3.1, in order to generate video dithering images which have complementary colors for the dot and background, the method is as follows: One of the color channels among  $R$ ,  $G$  and  $B$  of the background color is totally eliminated to get homogeneous color of dots. The complement of the eliminated color from the background color generates in dot color in order to keep the value of the goal color and satisfy equation 3.1.

Therefore the resulting images are generated by complementary colors for the dot and background.

We applied this method to a grayscale image as the goal image as shown in the Figure 11. A blue image used as the control image is created by eliminating yellow, its complementary color from a goal image. The shapes of the dots are defined by the black and white image (C) and (E) in the Figure 11. Let's look at the output images (D) and (F) in the Figure 11 These output shows two complementary colors, blue and yellow. As same way, we can create different complementary colors by controlling each channel of colors.

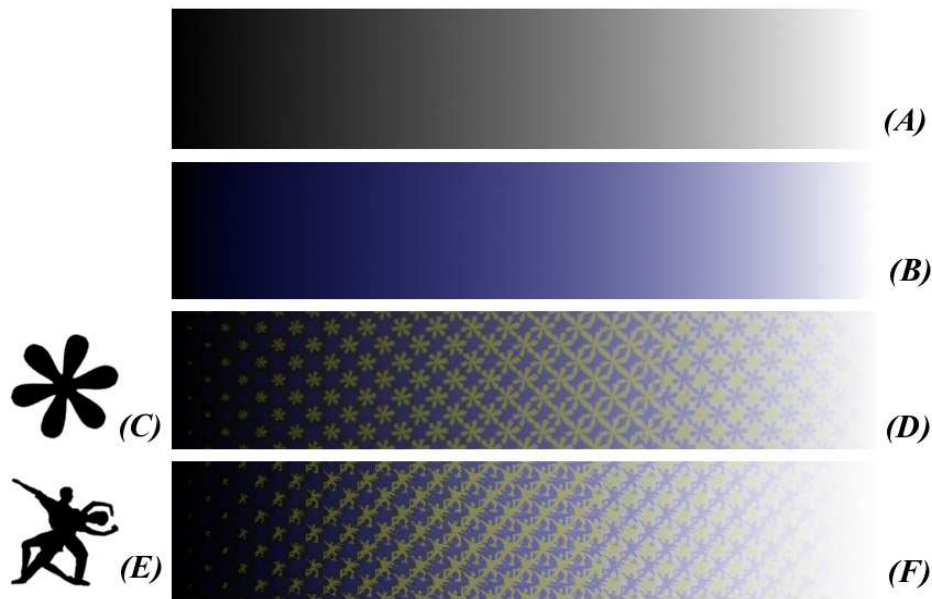


Fig. 11. Complementary colors for dot and background (A) goal image, (B) control image that is a blue image created by eliminating its complementary color, yellow. (C) and (E) dot images. (D) and (F) video dithering images show an eliminated color from a control image.

Figure 12 shows additional examples in which a color photograph is used as the goal

image. Each of the resulting images shows different effects caused by using either a blue, green, or red tone image as a control image, created by eliminating yellow, magenta or cyan from a goal image for each control image. From the resulting images, we can see that the eliminated colors from the control images appear in the dots.

Using complementary colors is a common method in painting [22] to create aesthetic results. As clearly seen in the examples in this section, this method creates a very good local palette, and video dithering images created by this method look more aesthetically interesting than the original goal images.

#### **IV.2. Indirect Control of the Dot Size**

It is possible to indirectly change the size of the dots by controlling the color of the dots. For instance, if the color of the control animation is the same as the color of the goal animation in a region, the dots shrink, become invisible, and are completely eliminated in that region. Examples on Figure 13 shows how to apply this method for generating images by using control images. They clearly show that dots eliminated in the regions have the same color as the goal color. On the first result image, there is no region where dots are eliminated. On the second result the dots on the edges of the object are eliminated, because the colors on the edges of the object on the second control image are the same as the goal colors. For the same reason, on the third result image, the center of the sunflower doesn't show dots. Using this idea we can eliminated the dots anywhere we want. We observed that it is good to eliminate the dots around the edges of the goal animation to create interesting animations.



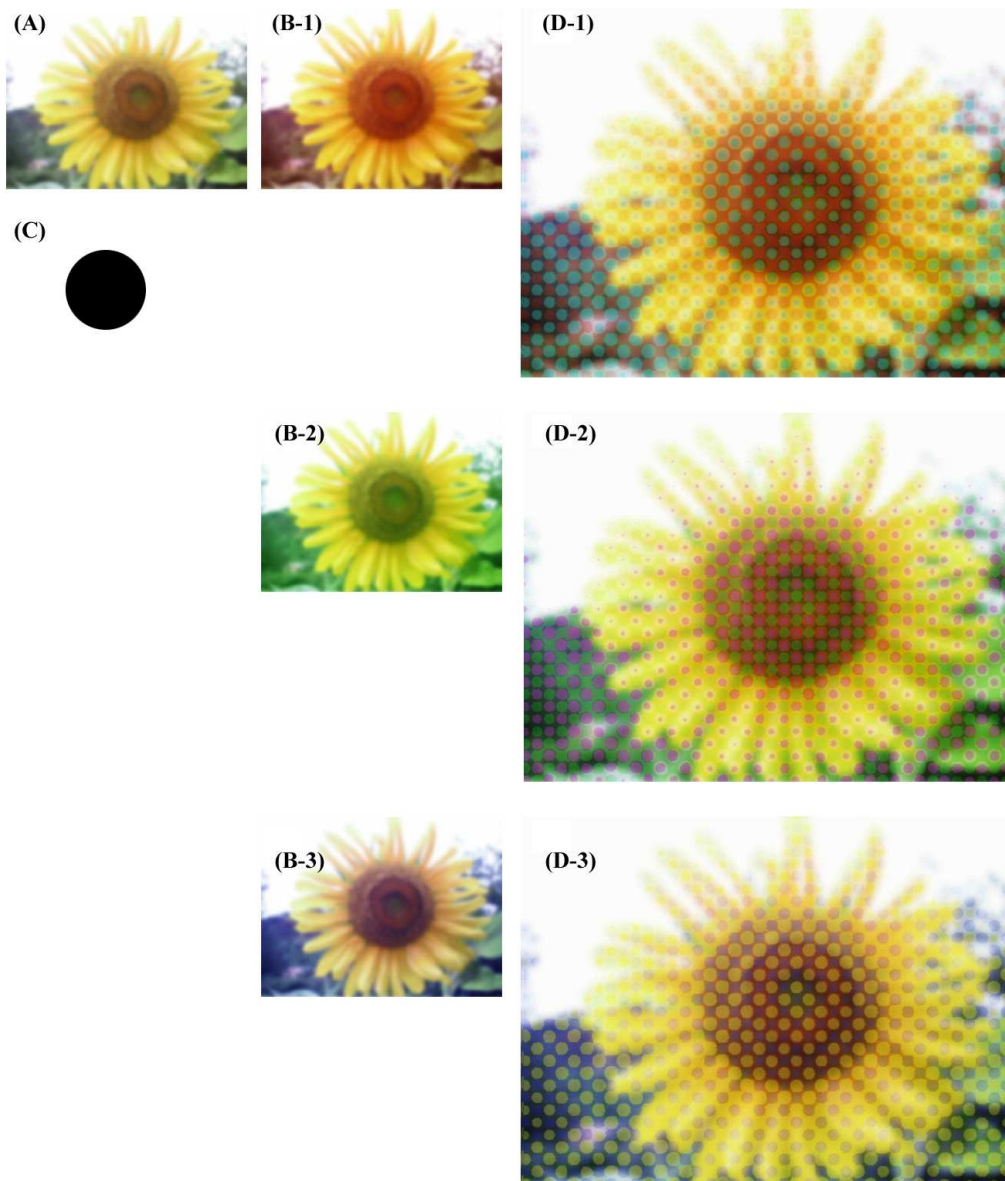


Fig. 12. Examples of complementary colors method (A) a goal image, (B) a blue, green or red tone image as control images from the top, (C) dot image and (D) each output image is created by eliminating a complementary color of each control image.

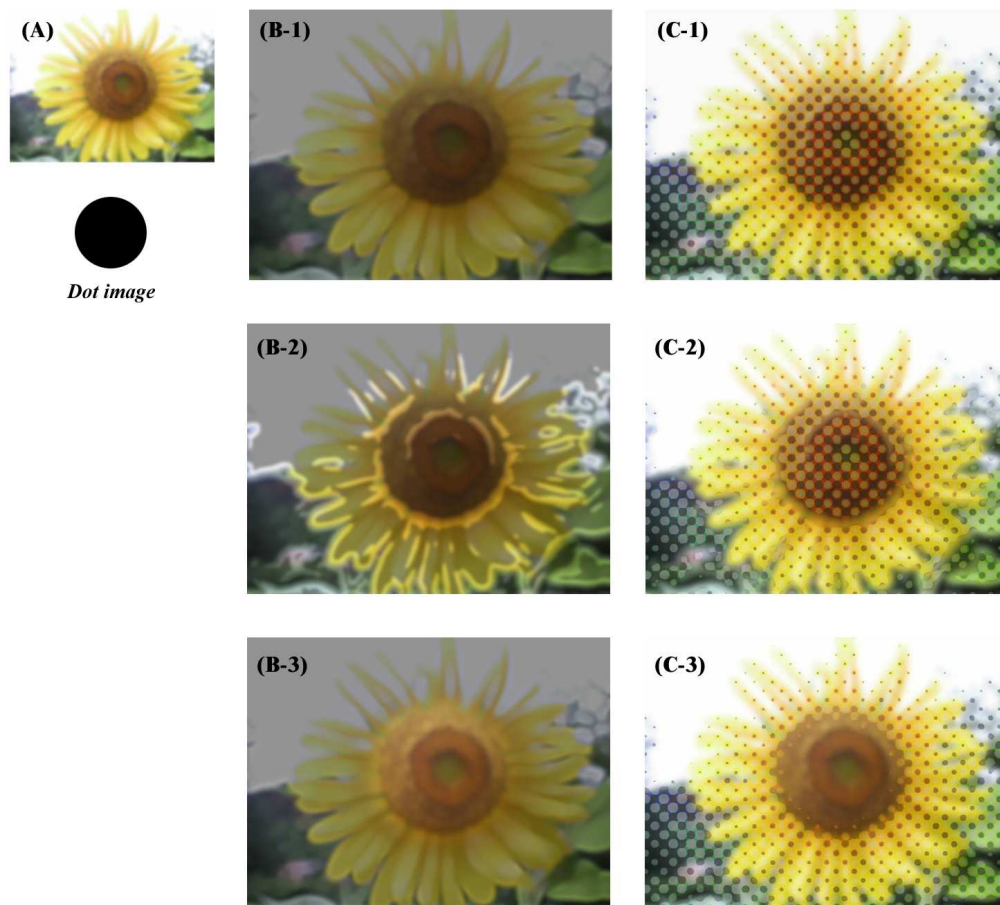


Fig. 13. (A) is a goal image. (B) images are control images. (C) images are result images.

### IV.3. Direct Control of the Dot Size

The sizes of dots are directly defined by the control animation, and the color of the background on each square region is calculated by the ratio of dot sizes. Figure 14 shows how this method works for generating images. In Figure 14 we choose the maximum possible color for a dot color, and generate three video dithering images by using different control images. In Figure 14(B), we do not use a separate control image. Instead, the goal image is used as the control image. The image in Figure 14(D) is generated by the same goal image (A) and control image(C). As seen in Figure 14(C), boundaries of objects on the control image are enhanced by the darker color. Based on our equations, the darker control color reduces the sizes of dots, so that our system creates very clear boundaries in the resulting images seen in Figure 14(D). The image in Figure 14(E) is one more example generated by the same goal image (A) and control image (F). This image also shows how dots on the part of the output image are controlled by image (E).

Note that this method does not efficiently use three color channels of control animation and we, therefore, choose either white or black as the dot color. We again eliminate the dots around the edges of the goal animation to obtain interesting motion. We can easily recognize that small dot images have coherent colors, which are brighter or darker than goal colors. This result gives clearer patterns and variation of the dot size.

Figure 15 shows two different cases by choosing dot colors. In Figure 15(D-1) we choose the maximum possible color for the dot color, and in Figure 15(D-1) we uses the minimum possible color for the dot color. The size of the dots is controlled by the control images, regardless of the dot color.

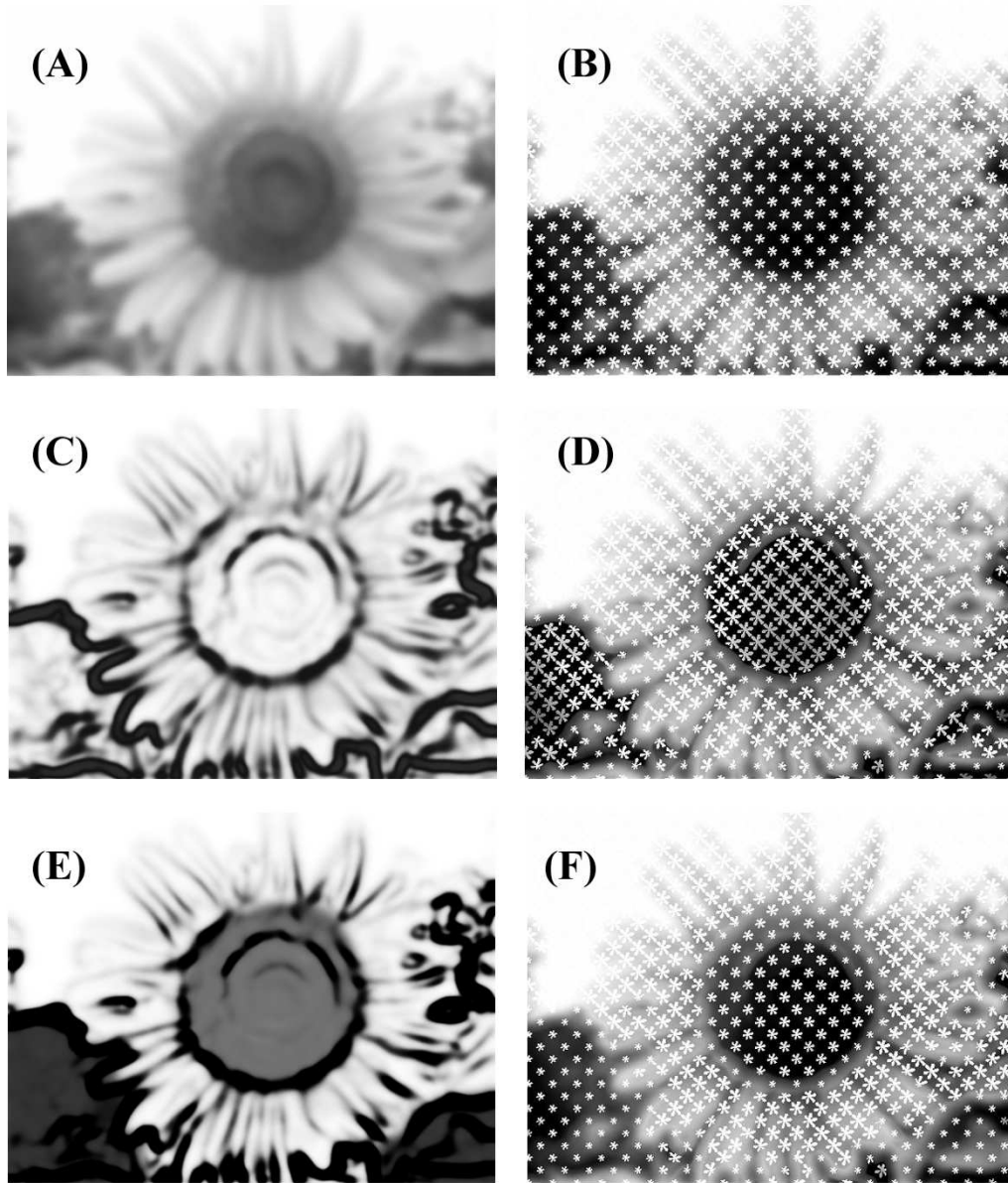


Fig. 14. Using maximum color for the dot. These images shows the effect of control images for direct dot size control in one channel(B&W)image. (B) is created by using (A) as both the goal and control image. (D) is created by using (A) as a goal and (C) as a control image. (F) is created by using (A) as a goal and (E) as a control image.

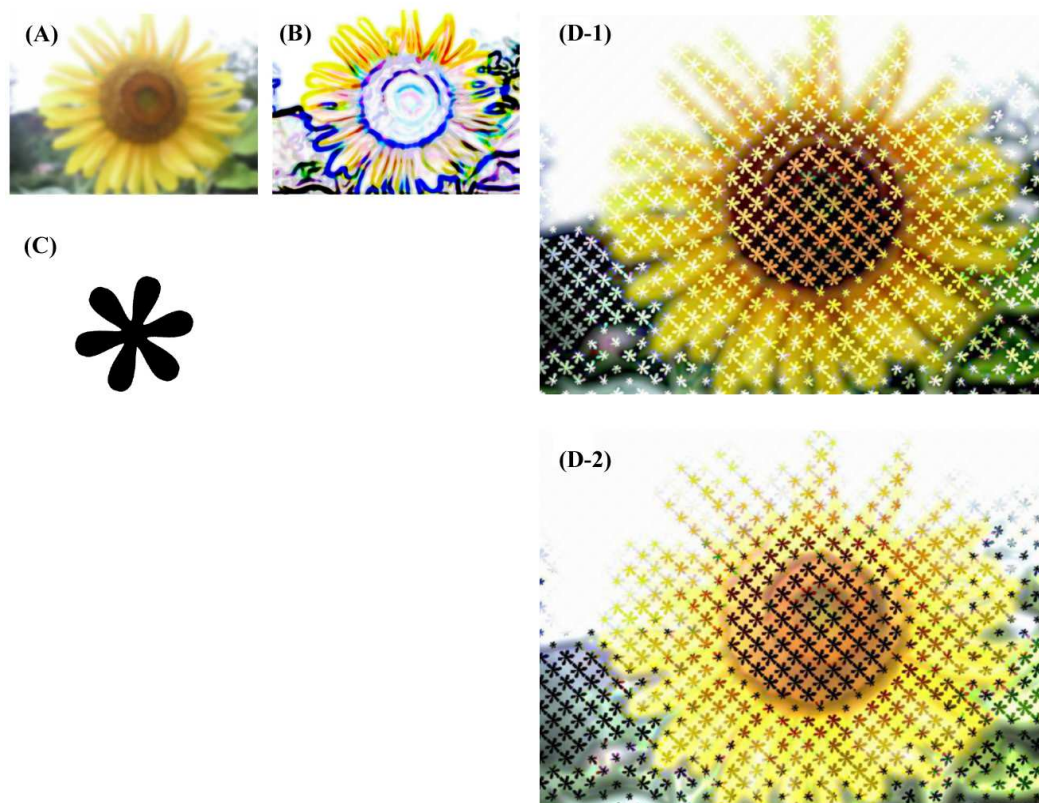


Fig. 15. Direct control of the dot size. (A) goal image, (B) control image, (C) dot image and (D) output images. (D-1) is created by using maximum color for the dot, and (D-2) is created by using minimum color for the dot.

#### **IV.4. Others: Multiple Artistic Methods**

By mixing several artistic methods which we have developed to control dot sizes and colors, we can create various results of video dithering images. The ways to adapt artistic methods are freely chosen by the user.

Images in Figure 16 and Figure 17 are generated by applying two artistic methods, using complementary color and indirect control of the dot size. By using a blue tone for control animation, resulting images in Figure 16 shows yellow dots, and the edges of objects in images are enhanced by using the indirect control of dot size method. As shown in Figure 17, each image frame can also have different complementary color dots by using different complementary colors throughout control animation sequences.



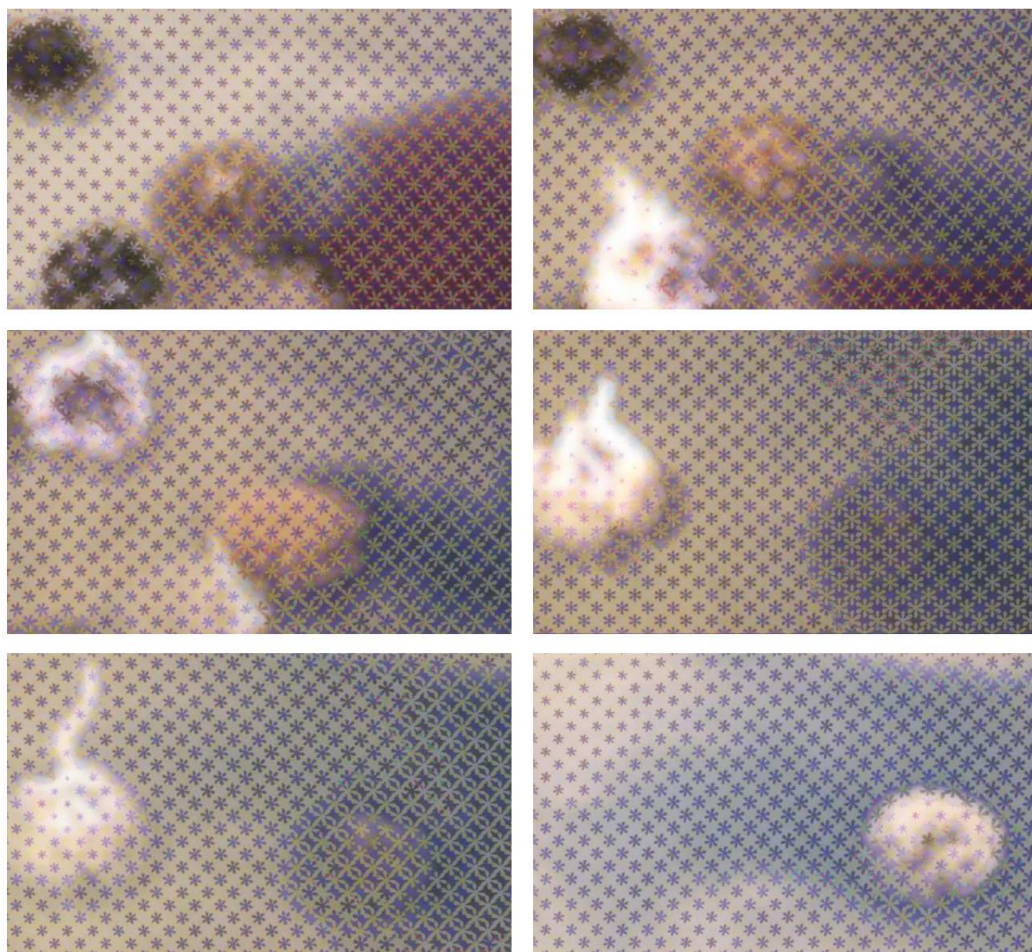


Fig. 16. Multiple artistic method: Using complementary color (blue and yellow) and indirect control of dot size.

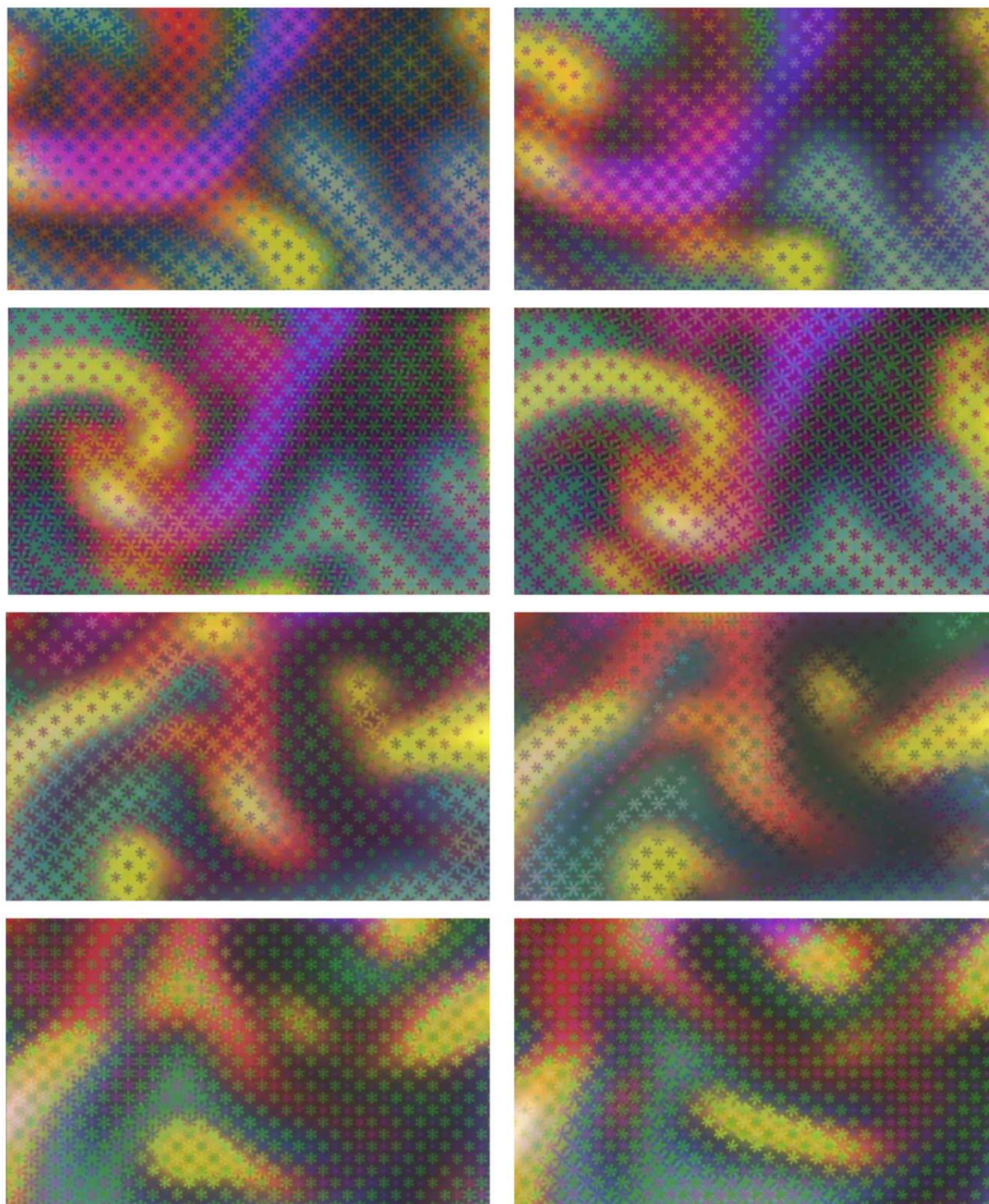


Fig. 17. Multiple artistic method: Using complementary color by various ways and indirect control of dot size.



## CHAPTER V

### CONCLUSION AND FUTURE WORK

Our video dithering technique is a unique and interesting graphic design tool for computer graphics. Unlike conventional halftoning techniques, this method allows an unlimited number of colors and animated shapes for elements at video resolution. The method enables the user to create complex moving screenings using three different animations that are freely chosen by the user. This artistic video dithering technique can produce a complicated artistic effect. Seeing several animations simultaneously can be an exciting experience. By using video image sequences as three input animations we can provide frame to frame coherence, and can avoid spatial and temporal aliasing by playing video dithering animation as real time, even though the resolution is severely limited compared to printed artistic screening.

In the future, we plan to use freely moving animated dots that go beyond the static regular tessellation where the dot images are placed. Video dithering which consists of repeatedly animated dots in static positions gives a monotonous feeling. On the other hand, if video dithering used freely floating animated dots, it would produce more variation with unexpected effects that would have a high aesthetic quality.

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