Digital Image Manipulation: an Interdisciplinary Approach

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Abstract

Image manipulation programs allow users to retouch drawings or photographs. Using these tools for artistic image manipulation is a demanding task. In this paper we present a novel methodology, based on efficient image processing algorithms in combination with Cellular Automata, to create a very versatile and autonomous means for altering digital images. The system presents a newly achieved level of autonomous creativity in addition to minimising the effort for retouching images from an artistic point of view. We present an evaluation of an experimental implementation of our method and provide suggestions for its applicability.

1 Introduction

Since the 1960s there has been a fascination with the combination of computing and art, in an attempt to develop artistic creation (Raimes 2006). This interdisciplinary approach to making digital artwork has continued to date, especially with the introduction of increasingly highly sophisticated home-computing software that allows anyone to combine their computing and artistic skills.

This paper presents an experimental approach to automatic digital image manipulation. We outline the contextual approach to the work, give an overview of the essence of the algorithm and present some initial findings from preliminary tests. We conclude by analysing these results and suggest further work and potential applications for this approach to digital image manipulation.

The novel method presented here involves interdisciplinary work. We take a computer science approach to create a program for image manipulation that requires an artistic, exploratory approach with which to experiment and create unique images (Spencer and Spencer 1987).

Our interdisciplinary approach merges computer technology with art (Grout, et al. 2000). We offer the artist the opportunity to use algorithms to create a piece of computer art. On the other hand, the computer scientist is given the chance to act as an artist, using an exploratory approach to adjust the parameters used in the digital manipulation process, to examine the creative results.

We consider a digital image as a form of representation with "its own vagaries and nuances as much as a painting, photograph or sculpture etc. It just happens to involve or rely upon computer technology" (Grout 2000, p.25).

2 Background

2.1 Computers and art

The use of computers in the 'artistic' creation of 2Dimensional (2D) images has been explored since the 1960s. 1965 saw the first two exhibitions of 'Computer Art', one at the Howard Wise Gallery in New York, 'Computer-Generated Pictures', and the other in Germany, 'Generative Computergrafik at the Technische Hochschule'. These exhibitions were key to establishing the development of computer art. From this point computer art gradually began to be considered an accepted form of art (Raimes 2006).

During the 1970s the Xerox Corporation designed the Graphical User Interface (GUI), and the use of graphical computer interfaces continued to develop. The introduction of the GUI on the Apple Macintosh in the 1980s made using a computer much more user-friendly, and more for the masses, rather than just the computer coders who had dominated computer use until this time.

To demonstrate the improvements and uses of computers in artistic image creation artists such as David Hockney and Larry Rivers were commissioned to use the Quantel Paintbox computer system in their work by the BBC television programme *Painting with Light* (Raimes 2006). Later, during the 1990s, artists were inspired by mathematics and increasingly explored this through computer art (Pickover 1994). Such artists included John Robinson who based a number of sculptures on Borromean rings, for example, *Creation*, *Genesis* and *Intuition*.

As home computing power has increased a greater range of people have access to creating high-quality computer art. The majority of image manipulation is

carried out explicitly by the user (the artist) in software packages, including Photoshop. The work presented in this paper offers an alternative way to create digitally manipulated 2D images. The artist provides guidelines, in the form of parameters, and these parameters autonomously manipulate the image.

2.2 Digital image creation

The creation of 2D images using a computer is similar to the creation techniques used by artists working with more traditional art forms, including painting and sculpture. It is generally considered that "good computer art combines logic, precision, and an artist's eye for beauty" (Spencer & Spencer 1987, p.2). Computer artists must possess artistic talent, knowledge of computer software and the ability to combine these to create new work.

Digital images created by computer artists can be presented on screen or in print, again likening computer art to traditional art presentation methods, such as paintings on canvas. Computer art is created through computer technology and artistic creation. The artist may or may not be aware of the technical processes involved, depending on the methods they employ in their creative processes.

Computers offer artists the opportunity to manipulate the 'description' of digital images. The 'description' given alters the image within a range of parameters; therefore the artist should experiment and become familiar with the effect of these parameters in order to achieve the best results.

2.3 Cellular automata

Cellular automata (CA) are idealisations of physical systems where space and time are discrete, and physical quantities take a finite set of values (Wolfram 1983). The cells form a regular array or lattice (often called colony, as we will in this paper), where each cell has a discrete variable. In discrete time steps the cell system evolves, with the evolution of each cell dependent on its neighbouring cell. Each cell can either die (the colony shrinks) or change state (differentiate) and new cells can be produced (the colony grows). As in biological systems, cell activity occurs simultaneously. It was von Neumann and Ulam who introduced CA as a way to model biological self-reproduction (Chopard & Droz 1998 & Gutowitz 1991).

2.4 Interdisciplinarity

The blend of computing and artistic creation encourages an interdisciplinary approach to the processes presented in this paper. Interdisciplinarity involves the transfer of methods between disciplines; an ethos thoroughly embraced within this research, as the artist works with computing code and the computing scientist develops a creative, exploratory approach to digital image manipulation.

3 Cellular automata in digital image manipulation

Given the nature of CA, inspired by biological cells, there is a natural suitability for CA to be used in the representation of 2D or 3Dimensional shapes that the computer can represent as images. In most CA research and work this is a preferred method of visualising them. Therefore, it is natural that images can be represented by developed CA colonies. The work in this paper is based on this principle.

3.1 Image representation

The most natural relation between an image and a CA colony is where each pixel in an image represents a cell in a CA colony. The states and/or attributes of each automaton can be represented by the colour and intensity of the image's pixel. The shape and size of the image represent the developmental behaviour in those same terms in a CA colony, and the colours and intensity of each pixel represent the differentiation of the states of each cell. Additional non-visually explicit states and/or attributes can also be saved within each cell's (pixel) memory structure. Although this "hidden" information does not contribute directly to the visual characteristic of the image representation, it does provide information for CA behaviour.

In this work we represent the image to be manipulated as a 2D CA colony where each pixel represents a cell. The state of each cell is fully described by the colour and intensity attributes of the pixel it represents. Additional global parameters are used as the collective rules of behaviour of the CA. It is these that the artist can adjust so that the autonomous system manipulates the image by triggering a development process in the colony.

A special characteristic of the representation used here is that the CA start as a fully developed and differentiated colony. We do not start from a single or small number of cells to grow and differentiate. We assume a colony that is already grown (to its full and constrained final size) and where only further differentiation can occur. No cells will die or new ones grow.

3.2 Image manipulation

As will be shown below, when the artist defines a set of parameters some regions of the image, complying with such parameters are masked, and it is in those regions where the CA can undergo cycles of further differentiation. The flow diagram in Figure 1 shows

the general process that is followed. The masking is defined entirely by the state of the CA, i.e. the pixel attributes. We use HSV space to describe these attributes as we believe this is the most intuitive approach from an artistic point of view (Arnheim 1954). As will be shown in the experiments, it results in a very powerful means by which to "select" sections of the image, providing a much friendlier means than the standard *selection* or *lasso* tool from standard image toolboxes.
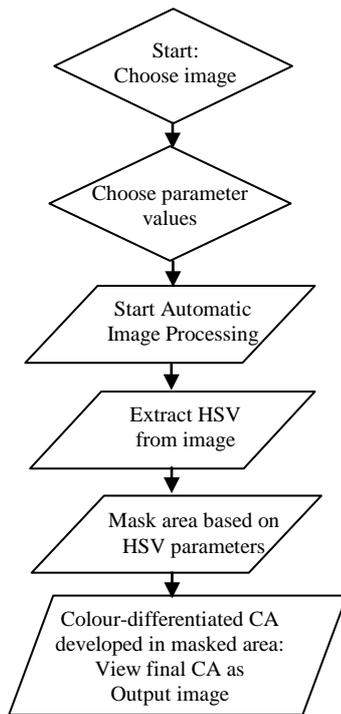
Figure 1. Flow diagram of the image manipulation process using CA

Once the sections are masked, another set of parameters defining the developmental behaviour of the CA are applied and the cells contained within the masked regions are allowed to exhibit these behaviours for a small number of "life cycles". The parameters which describe this behaviour are:

- Neighbour depth, which tells each cell how far away to look for it's neighbours states,
- Range of hue, saturation and value parameters (HSV) values available for differentiation, which limits the colours and intensities that the cells can change to,
- Direction of neighbours, which tells each cell whether the direction the neighbour is in matters or not for the final decision about changing state,
- This works in conjunction with logical operators (AND and OR), and threshold operators ('less than' and 'greater than') which are used to define what decision is made given the state (HSV values) of one or various neighbours.

The third parameter is particularly important, as will be shown later in the paper. By changing the way the cells view their orientation within the colony, and taking into account this orientation, a very versatile behaviour emerges which provides the CA with creative capabilities. This effect can be seen in biological terms, in the ability that some systems have to organise their asymmetry (Levin & Mercola 1998). This ability has been shown to be critical in providing additional complexity and applicability to developmental systems (Gongora & Rodas 2009). In this work we have harvested the potential to achieve a *creative* aspect to the differentiation process that manipulates the images.

The image manipulation is achieved through this differentiation process in the masked areas. The CA apply their rules of behaviour as directed by the above parameters, and change the colours (which in a collective behaviour results in whole textures) of such regions. As we have said, the cells can only differentiate, not die or reproduce. The shape and size of the image or the masked regions are not altered.

4 Implementation

4.1 Digital image manipulation process

The program was developed and tested using MATLAB, which allows us to explore the creation and manipulation of 2D images. MATLAB offers a range of technical capabilities and applications, including image processing.

The program allows the user to manipulate digital photographic images. In simple terms, the program extracts and masks a defined area within a 2D image, and applies the given CA effect as defined by the artist using the program.

Two sets of parameters are used in this image manipulation process; the first specifies the digital image file to be used and defines threshold values for the HSV, used in the image manipulation, the second set of parameters offers a platform for changing the created effect. The artist may alter the numeric variables representing the colour advance parameter settings to alter the texture or pattern created through the manipulation of the image.

The program reads the user specified image. The higher and lower range settings of the hue are then set; the hue within this range will be extracted for digital manipulation. Logical and relational operators are available to select the area to work with, either greater or lower than these values. The same process is used for the saturation level.

A typical rule applied to CA development would be evaluated as follows:

$\forall CA(\in masked\text{-}area) \rightarrow$

if neighbor($_{I,d}$)

$\quad\quad\{(H_{state}>0.2) \wedge (S_{state}<0.1) \vee (V_{state}>0.5)\}$

$\quad\quad$ then $\{action(H,S,V,new)\}$

where (I,d) define which neighbour I at distance d to each cell, and the H, S and V states are compared with 'less than' or 'greater than' operators to the thresholds defined, and are combined with the desired logical combination operators ($\vee,\wedge$).

To demonstrate the processes involved we provide a floral example (Figure 2), with the subject of this photographic 2D image a flower and butterfly. This original digital image is loaded and manipulated using our program.

For analysis purposes and to help the artist clearly see the effects as the manipulation occurs, three different windows appear on the screen showing the stages of manipulation. The first stage extracts the HSV parameters from the original image (Figure 3), before the first set of parameters are applied.

The second stage calculates the desired masked area from the HSV parameters (Figure 4). The HSV threshold values set by the artist create the masked area. This masked area acts as an alpha channel, identifying the areas of the original HSV image (Figure 3) to be manipulated.

When the masked area (Figure 4) is defined the colour advance parameters outlined in the second set are used to enable the CA to manipulate the masked area, creating the third stage and final output image.
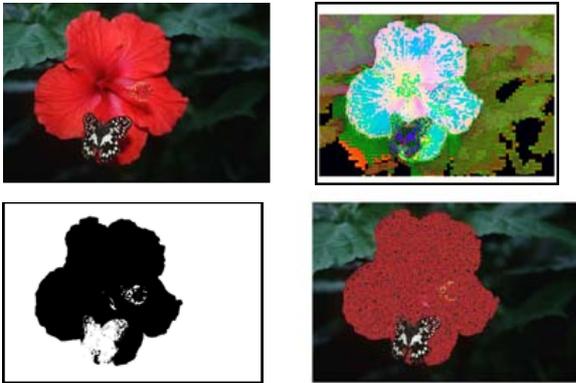
First row:
Figure 2. Original image (left)
Figure 3. Stage 1, extracting HSV space (right)
Figure 4. Stage 2, the masked area (left)
Figure 5. Stage 3, the final output image, based on the parameters outlined in the two files (right)

5   Experiments

In this section we present a set of experimental examples performed to analyse the method. In addition, it is important to note that experimentation is also essential from the user point of view. To illustrate the process in this section, the same original image (Figure 2) was used, and later in the paper, additional examples represent a small number of our experiments.

We began by testing the effect of using a large hue range in the masking process. Setting a large hue range (0.1-0.9) and a logical 'and' operation results in a large area of the image being masked, and then altered by the CA. Only the very dark areas of the image are excluded from the masked area (Figure 6). Keeping the large hue range but changing the logical operation to 'or' produces a masked area that includes the butterfly and lighter areas of the background, yet excludes the flower (Figure 7). Using the logical 'or' the flower and background image are separately defined by the mask, unlike when the logical 'and' is used.

We were interested in using the flower area of the image to be the area affected by the CA differentiation. In returning to using the logical 'and' and the same settings (Figure 6), tests continued by changing the value operation to the 'more than', as opposed to the 'less than' option which had been used until this point. Using 'more than' masked the darker areas of the background foliage, the inverse of the areas that had been previously masked (Figure 8).

Returning to using the 'less than' option for the value setting, and then changing the saturation option from 'less than' to 'more than' results in very little of the image being masked, therefore little CA development occurs (Figure 9) and the image looks like the original image (Figure 2).

Continuing with the tests, the following settings were used, a smaller hue range (0.4-0.6), logical 'and', a value of 'less than' 0.6 and a saturation level 'less than' 0.1. The second stage develops by altering the colour advance parameter settings in the second set of parameters. Until now the colour advance parameters had both been set at 1.0. It is the two 1.0 values that affect the CA and therefore the final visual appearance of the output image. In the first experiment changing these parameters we changed the first 1.0 value to 0.1. There is a noticeable change in the appearance created by the CA, a vertical striped effect (Figure 10). In changing the same value to 0.5, the striped effect is formed from top left to bottom right, though it is less noticeable (Figure 11). Our tests show that a similar visual effect is produced when the value is once again changed, to 1.5.

Figure 6. Large hue range and logical 'and' (left)
Figure 7. Large hue range and logical 'or' (right)
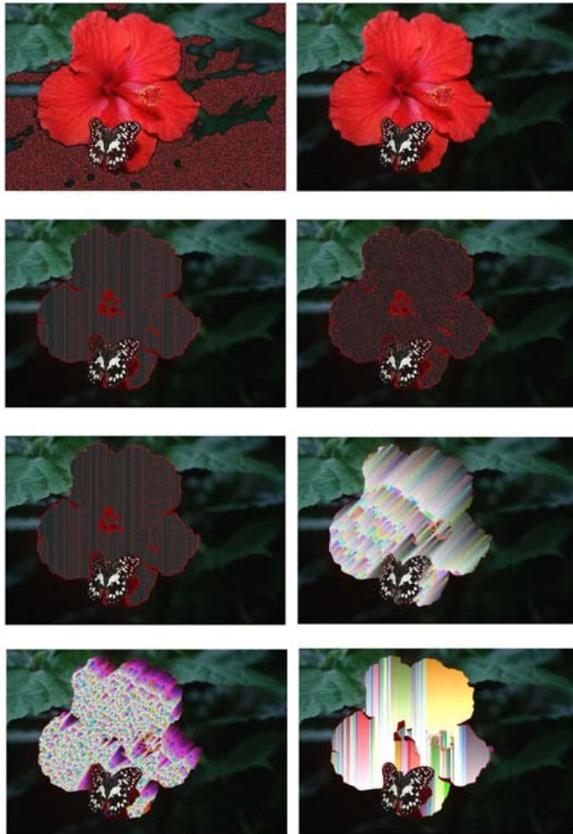
First row:
Figure 8. Large hue range, logical 'and' and value operation set to 'more than' (left)
Figure 9. Large hue range, logical 'and', value operation set to 'less than' and saturation operation set to 'more than' (right)
Second row:
Figure 10. First parameter set to 0.1 (left)
Figure 11. First parameter set to 0.5 (right)
Third row:
Figure 12. Both parameters set to 2.0 (left)
Figure 13. Diagonally striped appearance (right)
Fourth row:
Figure 14. Cellular appearance (left)
Figure 15. Vertically striped and colour block appearance (right)

We were keen to explore what happened when the two parameters had the same value. Setting both parameter settings to 2.0 produced a vertical line effect (Figure 12). Very similar visual effects were created as both settings were increased equally.

6 Results

The tests have shown that very selective areas can be masked and manipulated by setting a large hue range and using the logical operation 'and', to mask different areas within an image, if the logical 'and' does not include the areas the user wishes to work with, the logical 'or' operation should instead be used. When 'more than' the value set is applied the mask inverts completely. Changing the colour advance parameters changes the final output image, as the CA changes. There is a greater change to the pattern created by the CA when the values are different from one-another.

This method for area masking has proved extremely effective. There is a great deal of accuracy when masking using this method. The user, from a computing or art background, can ensure that only the desired area is affected by the image manipulation. Related Objects, even those separated across the image, can be selected in a single action with no need to define them with explicit actions.

Creating similar effects and making these alterations to texture-effects in images would be a time-consuming process in some other software packages. In contrast, this method offers a quick and simple way to mask an area, fill it with a textured effect and then change this to create the overall desired visual effect.

The experiments detailed above are a small sample of our testing, and below we present some further examples. The first three images (Figures 13-15) use the same original image as used in the experiments above (Figure 2). The following examples show just one of the possible visual effects in a digital photograph of a rose (Figures 16 & 17). The final examples are presented on a gerbera (Figure 18), where two quite different and quite striking effects are shown, the first shows a cellular effect (Figure 19), whilst the second offers a geometric, stripy visual appearance (Figure 20).

First row:
Figure 16. Original rose image (left)
Figure 17. Rose after manipulation (right)
Second row:
Figure 18. Original gerbera image (left)
Figure 19. Gerbera, cellular appearance (right)

Figure 20. Gerbera, geometric appearance

7 Conclusion

Altering digital images creates greater intrigue and depth to their visual appearance. Depending on the effect the user wishes to create, a pleasantly aesthetic effect may be added to the image.

They say that beauty is in the eye of the beholder, so everyone will have their own opinions and reactions to these digitally manipulated images. The final output is the work of the user as determined by the choice of parameters to determine the areas to affect and the effects to produce using the CA. The novel aspect of our work is that the actual image manipulation at the pixel level, over any proportion of the area of the image, is performed autonomously using this method.

Experimenting with minute changes in variable settings is key to working with this algorithm. The user must learn to take their time, refining the manipulations by changing the settings being applied.

The results from our tests to date suggest a number of possible uses for this image manipulation method. The masking tool is very efficient and may be use to mask areas within a range of images, from cartoon drawings to intricately detailed photographs.

The created effect would be suited for use in scientific images, due to the natural, biological texture effects that may be created. This method of digital image manipulation could for example be used to fill blocks of colour in cartoon images with a desired textured effect that enriches the image.

The tool, being based on a logic and rules driven CA algorithm has a predictable behaviour, thus if the users are familiar with its implementation details, they could in theory control the effects directly; although the solution space is huge and many variations possible in minute detail. On the other hand, the intended application for artistic manipulation means that an artist can learn by experimentation to control the effects of the tools provided by this novel interdisciplinary method. The artist must experiment and try different settings in combination with the original image to achieve the best or most suitable visual results. This method offers the user the chance to create effects that they may not be able to create elsewhere. The ability to manipulate an image in a controlled manner comes not only from understanding the algorithm, but also developing an understanding and awareness to predict the synergy with the pictures' original features. Once users are able to predict the potential visual outcome they can then manipulate the image to a desirable outcome with few attempts.

8 Further investigation

In considering possible applications for this method we will further explore the idea of adding texture effects to cartoon images. Cartoon images, especially cartoon-strips, often use solid blocks of colour, with little or no pattern.

To date, we have used still stand-alone images; however, it may be a natural progression to apply this technique to still images that are used in moving cartoons, animations.

Other tests have also begun in using different subjects as the target for the CA manipulation. We will continue to test this method and its effects on images including cityscapes, animals and portraits.

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