The Visual Computer

Techniques in computer art

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The major techniques in computer art in use so far are classified into six categories and evaluated. Among these categories, we discuss the function method in detail by showing pictures generated by our system ART-3, a small system based on the function method. By this means we show the usefulness of mathematics in this area and demonstrate the enormous possibilities of computer art. Furthermore, on the basis of our experience of using ART-3 the role of artists in technology-aided art is briefly discussed.

Key words: Computer art – Function method – ART-3 system

Classification of the techniques

Current computer art is not so highly advanced that the computer is able to control the composition of a picture automatically, although there are several works in this direction [3]. In generating pictures thus far, the computer can be used essentially for transforming the input data and for "painting" a given area in various ways. The current major techniques may be classified from the viewpoint of data transformation and area painting as follows (listed approximately in the appearance order. For the actual works, see [1, 2]):

1. Wire-frame method,
2. data transformation method,
3. patchwork method,
4. function method,
5. algorithm method,
6. fractal method.

The wire-frame method draws a net of lines, freehand figures as well as curves, and a superposition of the lines constitutes a picture. This method is quite simple yet can generate beautiful pictures which often represent fascinating moiré patterns. In the data transformation method, a picture, such as a photograph of a human face, is digitized and transformed to produce another picture by a simple mapping function. The continuous transformation of a linear figure to another is also classified in this category. Although these two methods are widely used in commercial art, the resulting pictures are now considered of only low value because the methods are so simple.

In the patchwork method, the canvas is assumed to be divided into small regions, which are usually uniform rectangles, and the computer patches many of these regions to generate a mosaic-like pattern according to a simple program written by the user. The patchwork method gained fame when Knowlton generated circuit-like abstract patterns by his system EXPLOR [4]. (The EXPLOR is equipped with several techniques other than the patchwork method.) However, as an art technique, the patchwork method has not been developed as much as was expected in the early days, because the pictures generated by this method are not very different from each other. In the function method, a pattern is generated by drawing many element patterns on the canvas, where the type, size, location of each element pattern are controlled by a mathematical function. We call the pattern generated by this method a functional pattern. Note that most computer art works are generated using mathematical functions in some way, but such uti-

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lization is not called the function method unless the pattern is a direct mapping of a function.

Many people have developed algorithms for generating pictures including an area dividing algorithm, a stereographic algorithm, and so on. Different algorithms generate quite different pictures, and some simple algorithms are now used in commercial art. The algorithm method contains a weakness in that any one algorithm generates mostly similar pictures. Furthermore, the resulting picture is often not particularly beautiful although it may be interesting. Among many algorithms developed for generating pictures, the fractal method invented by Mandelbrot [5] has been given special status because it can generate complicated and irregular patterns which were considered hard to generate by computer. Therefore, we have listed the fractal method independently.

Several comments on the above classifications are necessary. Computer artists often use random numbers for determining the type, size, and location of the element pattern. We have omitted this technique in the above list because it is rather trivial. A second comment is that, in many cases, the picture is generated not by a single method but by a combination of several methods. Thirdly, we can observe a common feature of the methods listed above: the input data are generally in as small amount as possible and the pattern is generated by repeating elementary procedures many times. Therefore, the size of each system is not large with the exception of some algorithm-based systems.

These authors prefer the function method and have used it to generate pictures for a long time. The largest worry about the function method is that it might be unable to generate complicated and various patterns. One of the aims of this paper is to show that this anxiety is unnecessary and that the function method is extremely promising in computer art.

Actual pictures by the function method

Although many functional patterns are quite beautiful, a single pattern is not enough to constitute a picture and thus some complications are necessary. One such complication is to divide the canvas area into several parts and "paint" the parts with different patterns. If we use figures of natural things to divide the canvas, we hope the resulting picture will have strong aesthetic appeal. The series of ART systems (Artificial Realistic Technician) were based on this idea, aiming at combining both natural and mathematical beauty.

ART-3, the latest version of ART systems [6, 7], accepts hand drawn figures such as flowers or mountains, and it is equipped with hidden surface elimination capability. The procedure of picture generation in ART-3 is the repetition of outlining a figure and painting the inside of the figure by a functional or uniform pattern. In order to generate a functional pattern, we assume the canvas to be spanned by the $x-y$ Descartes coordinate system and consider a mathematical function $f(x, y)$ in this system. ART-3 calculates the value of f for each lattice point ($x=i$, $y=j$), with i and j integers, and if $f(i,j)>0$ then it draws an element pattern on the lattice point in the following way:

1. When the size of an element pattern is controlled, the element pattern of size $f(i,j)$ is drawn;
2. When the type of element pattern is controlled, the element pattern of type $[f(i,j)]$ is drawn, where $[n]$ is the maximum integer not greater than n;
3. When the density of the distribution of element pattern is controlled, the element patern is drawn with the probability $f(i,j)$, where the probability is 1 if $f(i,j)>1$, if $f(i,j)\leqq 0$ then no element pattern is drawn on the lattice point (i,j).

The function f is constructed by elementary functions such as "sin" or "exp", and each function contains three parameters. ART-3 contains a database of mathematical functions which seem to be useful for computer art.

In painting the canvas, ART-3 allows the following three modes:

1. The figure is treated as opaque, i.e., once a figure is painted it is not painted any more;
2. The figure is treated as transparent, i.e., multiple painting is allowed;
3. The figure is treated as semi-transparent, i.e., it is allowed to draw element patterns on lattice points which are blank even if they are inside a figure already painted (such a case occurs because the figure may be painted by skipping some lattice points); See Mt. Fuji in Fig. 7.

In addition to these facilities, ART-3 has several other capabilities such as the utilization of random numbers and figure transformation. However, motif making, such as the determination of figures and their locations, the selection of pattern functions, etc., is fully dependent on the user, and the system is very simple compared with modern computer graphics systems.

Here we show some pictures generated by ART-3. All the pictures shown were printed as monochromes by a CALCOMP plotter or a FUJITSU laser printer.

One may think that complicated mathematical functions are used in generating these pictures, but that is not the case. For example, mathematical functions $f_1(x, y)$ and $f_2(x, y)$ used for generating patterns in pictures 1 and 2, respectively, are as follows:

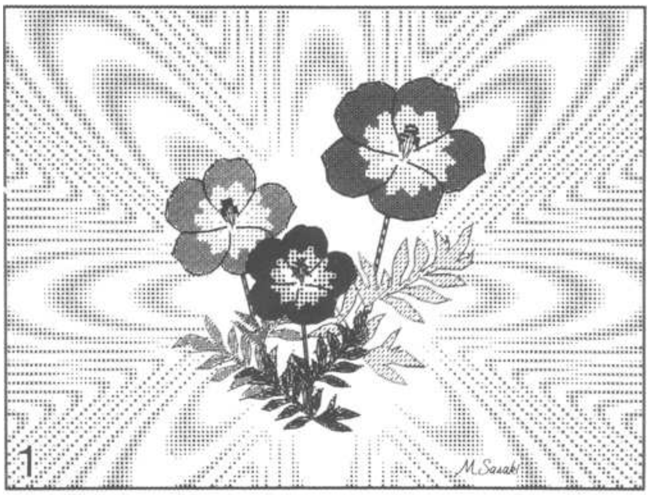
$$f_1(x, y) = -2\exp(-br) + c\cdot\cos\{ar/[1.2 - |\cos(4\,\mathrm{atan}(y'/x))|]\},$$

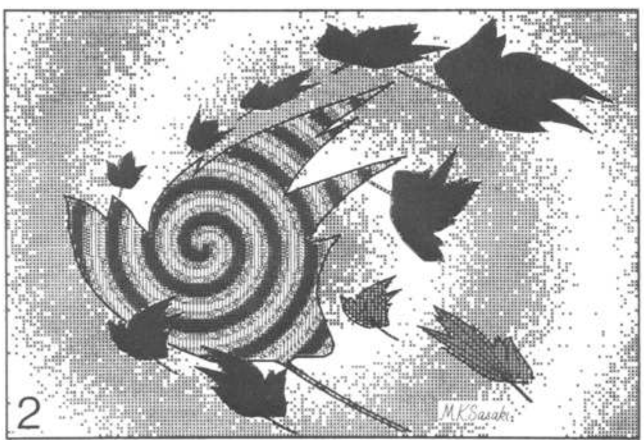
with $y' = 2^{1/2}y$ and $r = (x^2 + y'^2)^{1/2}$,

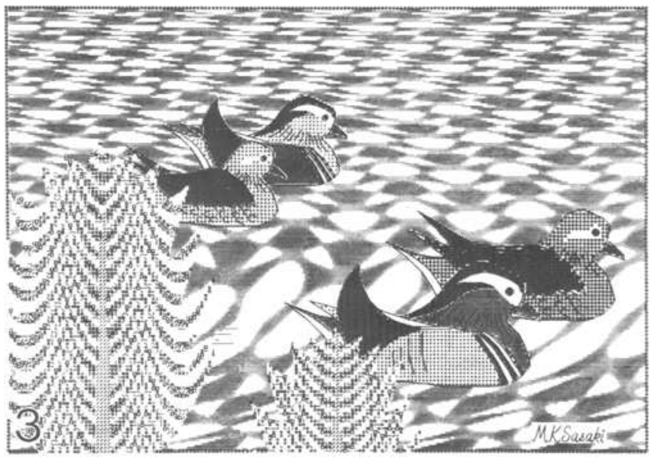
$$f_2(x, y) = c\cdot\cos\{a[\mathrm{atan}(y'/x) + br]\},$$

with $y' = 2^{1/2}y$ and $r = (x^2 + y'^2)^{1/2}$,

where a, b, and c are parameters to be specified by the user. Mathematical functions used in generating other pictures are not much more complicated when compared with the above functions.







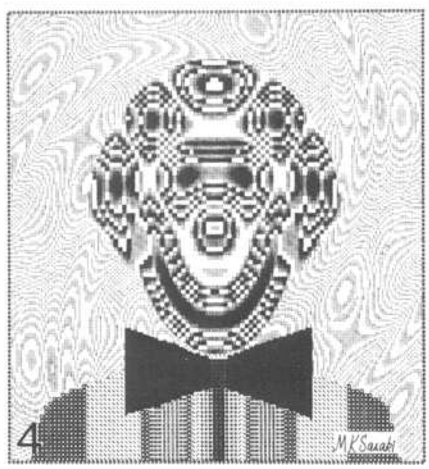


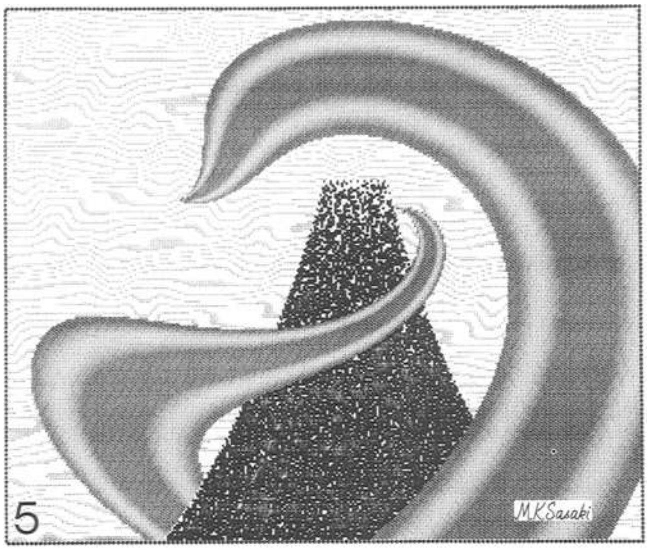
Fig. 1. Nemophila. In: Computers and People (1976) 25(8):23

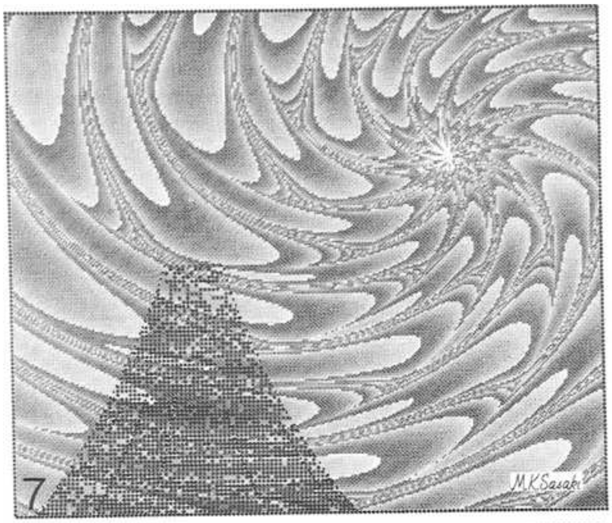
Fig. 2. Maples in Storm. Exhibited at Huntsville Museum of Art (Intn'l Invitation of Computer Graphics). Alabama, Jan. 14 – July 30, 1978

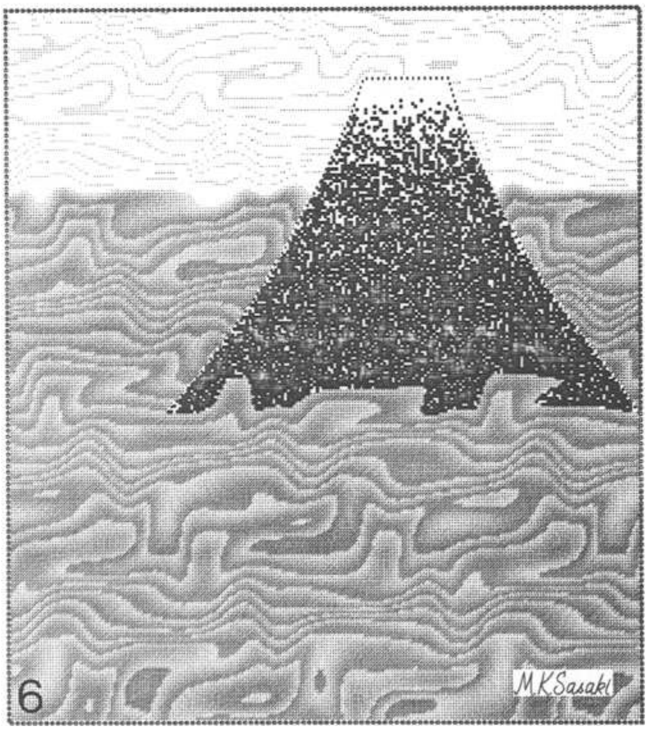
Fig. 3. Mandarin Ducks ...I. In: Computers and People (1978) 27(8–9):14

Fig. 4. My Portrait. In: Computers and People (1982) 31(1–2):17

We wish to emphasize that the above pictures were generated by ART-3 exclusively and that the outputs were not touched up. We explain how the pictures in Figs. 5 and 6 were drawn by ART-3 which accepts only two-dimensional figures and not three-dimensional ones. In Fig. 5, we drew the larger Kokuryu and the upper half of the smaller Kokuryu at first, then Mt. Fuji, followed by the lower half of the smaller Kokuryu, and finally the background cloud. In Fig. 6, the lower half of the







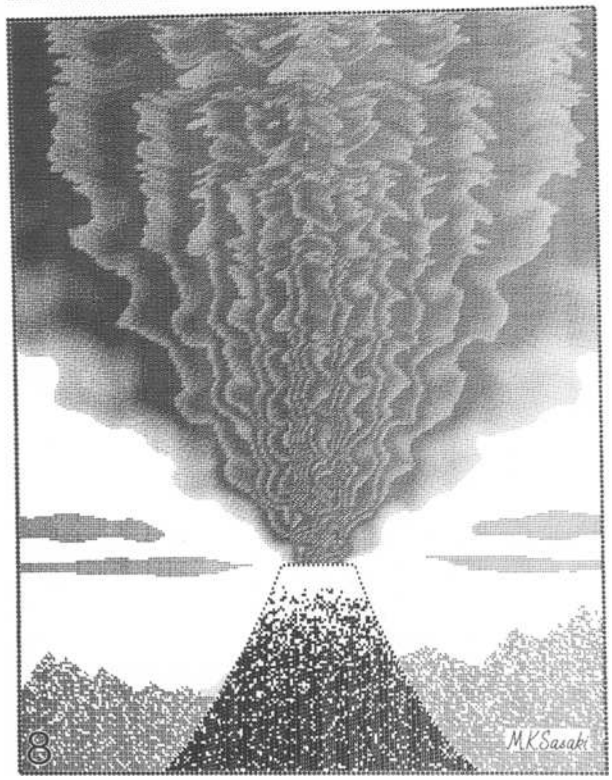


Fig. 5. Mt. Fuji with Kokuryu (black dragon), 1984

Fig. 6. Mt. Fuji in Cloud Sea, 1984

Fig. 7. Mt. Fuji in Storm, 1984

Fig. 8. Mt. Fuji in Eruption, 1984

cloud was drawn first, then Mt. Fuji, and finally the upper half of the cloud. The input figures for these pictures were the signature, the outline of Mt. Fuji, and a square as the outline of the canvas.

We cannot value the above pictures as highly as pictures by professional artists; in particular, our pictures lack sophistication of composition, delicate texturing, and local variations. However, these computer-generated pictures are of considerable interest because of their unusual quality and their fascinating patterns. Their unusual and fascinating appearance is a result of using mathematical functions and also due to the high accuracy of machines which is very hard to simulate by hand.

In our early years of using the function method, we were not good at generating functional patterns and thus we did not realize the great possibilities of the function method. Now, our skill at generating patterns has improved greatly, and we have broadened our horizons accordingly. We can say that mathematical functions allow us to generate quite a variety of patterns as Figs. 1–8 demonstrate, and we have illustrated only a very small number of many possibilities, with many fascinating and probably beautiful patterns left unpictured. We are now at the beginning of mathematical art and many new types of patterns will be created in the future. We want to improve our ART system for generating a greater variety of patterns. One improvement will be the implementation of the capability for semiautomatic determination of picture composition which we believe is an interesting problem for mathematics [8].

The role of artists in technology-aided art

About the middle of the twentieth century, technology began to invade the art world and is now creating a revolution in art techniques. The technological invasion has created and will create many new art genres. In this sense, technology is obviously beneficial for art. However, we note that each technique in this technological world is usually fated to be short-lived; the progress of technology is very rapid and the invention of a new and/or superior technique makes the previous techniques outmoded and often unused. Twenty years ago, computer art was an extremely modern art genre but, nowadays, the position of the most modern art genre is occupied by laser art and this may be unable to maintain its position long. As for computer art, the development of output devices is astonishing, and the use of plotters is now of only minor importance. The texturing technique in computer graphics is a typical example of the development of software techniques: the random number method in early days has been made obsolete completely by the appearance of the fractal method (realism) and the ray-tracing method (super realism).

Thus, we have what might be called the technology dilemma. Is the invention of new techniques the most important feature in technology-aided art, and is every such technique fated to be short-lived? The answers to these questions are inevitably YES if the technology-aided art is such that it can generate only restricted types of works which will be exhausted in a short period of time or simply because the art utilizes a new technique and nothing else. Whether these predictions are right or wrong, what role can artists play?

Fortunately, more than two decades of computer art has revealed that the possibilities of computer-aided art are so enormous that we cannot exhaust them within several decades. Our own feeling is that the utilization of computers is making the art world much richer than before. In particular, our one decade of experience of using ART systems has given us great confidence that mathematics is a very useful tool for pictorial art. Our experience also tells us that generating good art work is not easy and that it requires both experience and skill. New techniques, which obviously enlarge the possibilities of art, do not always generate good works and even the old fashioned techniques are quite useful because of their special roles as art techniques. The quality of art work depends not only on the specialized techniques but on the artist's ideas and how one uses these techniques, whether old or new. For example, ART-3 is an old type system using a plotter or printer as an output device and based on the outmoded function method. Yet, we can generate new and fresh works using ART-3. We think that what is presently most necessary, in the world of computer art, is the collaboration of artists and engineers.

In the world of technology-aided art, works have been created mostly by engineers or mathematicians, and they have usually been evaluated by the people in the technology world. Consequently often not the quality of the works, but the techniques and media of the art making have received most attention, as the names computer art and laser art indicate. If we look mainly at the media and the techniques, we will fall into the trap of the technology dilemma. The media and techniques are, after all, nothing at all from the viewpoint of appreciation of the art and the art work. Therefore, we must consider the art first, and artists can play essential roles in this area. From now on, the works of the technology-aided art must be evaluated by ordinary people from the viewpoint of art. This may be the best way to make technology-aided art into a genuine art form. Then, artists, engineers and mathematicians, will collaborate with each other to creat high quality works.

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