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Intelligent Pattern Design Based on Fractal Theory of Gene Expression Optimization

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Abstract. *Fractal art patterns are the result of a combination of mathematical formulae and computer graphics. A large part of the work in apparel design is artistic pattern design. Fractal theory is therefore well suited to assist in the design of clothing patterns. Gene Expression Programming (GEP) is a new evolutionary computational technique based on genetic algorithms, which draws on the laws of gene expression in biological inheritance. GEP has attracted much attention at home and abroad because of its strong optimisation capability, simple operation and unique coding method. Therefore, this paper investigates the method of generating fractal art patterns based on GEP optimisation, so as to provide more innovative materials for garment design. In order to enrich the expressive effect of garment patterns, it is necessary to maintain the diversity of populations while improving the optimisation ability. Therefore, in this paper, the standard GEP algorithm is improved according to Niche ideas. The experimental results show that the proposed method can generate unique fractal art patterns for clothing in line with visual aesthetics, verifying its effectiveness.*
Keywords: Gene expression programming; Artistic patterns; Fractal theory; Niche

1. **Introduction.** With the improvement of the level of material and spiritual civilisation, people's concept of consumption and aesthetics is gradually changing. Consumers are paying more and more attention to the artistic appearance of goods, especially in the field of clothing. Vigorously carrying out artistic design innovation of clothing has become one of the important means for many clothing enterprises to improve their brand awareness and market competitiveness. With the development of computer technology, advanced design software programs have been able to provide good auxiliary support for designers [1,2].

In order to explore innovative ways of designing clothing, designers need to think outside the box. However, fractal graphic design can inspire designers and help them to do their job better. In the traditional art design process, people can only use tools such as paper and pen to express their imagination within the brain, thus resulting in low efficiency, long lead times and single forms. However, with the continuous development of computer technology, the combination of computer programming and fractal theory can produce fractal art patterns in a variety of forms [3,4]. Fractal art patterns are an emerging form of digital art [5,6]. The combination of computer programming and fractal theory can produce a variety of complex shapes. This is because fractal theory is associated with algorithms such as recursion and iteration [7,8], resulting in the generation of fractal graphics with infinite self-similar structures, resulting in brilliant and colourful high-resolution art patterns. It is difficult to achieve such a strong visual effect with traditional garment pattern design methods [9].

Fractal graphics are a unique graphic that breaks away from the traditional concept of graphics and is a visually striking art form [10,11]. Using the self-similarity and self-growth of fractals, complex art patterns with high-resolution structures can be constructed. Fractal theory is therefore very applicable to the design of apparel art patterns. A large part of clothing design work is artistic pattern design. By making slight changes to the parameters of the computer programme, a variety of different forms and artistic patterns can be produced, thus satisfying people's higher and newer aesthetic apparel needs [12]. As a result, fractal graphic art, as an emerging design concept, has attracted the attention of clothing designers. Fractal graphic art has great application prospects and economic benefits in terms of garment design innovation. The purpose of this research is to combine fractal theory with computer graphics to produce a new fractal pattern generation method based on complex dynamics system in order to provide more innovative materials for apparel design.

1.1. **Related Work.** Fractals are an emerging discipline that is still in a constant state of development. The concept of fractals was first introduced by B.B. Mandelboot, an American scientist who was the founder of fractal geometry. In contrast to traditional geometry, fractals are a powerful tool for describing irregular geometric forms [13,14]. Fractal theory focuses on the study of unsmooth and irregular geometric forms that occur in nature (non-linear systems). Fractal theory has been used in a wide variety of fields in the natural and social sciences and has become one of the frontier research directions in many disciplines internationally today.

Current research on fractal theory is divided into three main types [15,16]: (1) research on the basic theory of fractals, including the nature of fractal dimension, estimation of fractal dimension, and analysis of fractal local structure [17]; (2) research on fractal theory in practical applications, including applications in mathematical modelling [18], computer graphics, physics, chemistry, seismology, biology, architecture, art, etc.; (3) research on fractal graph generation methods research [19,20], which is currently the more popular type of research and the research content of this paper . At present, fractal graphics have been widely used in the Goodwill film and television industry. For example, In Lucasfilm's films "Star Trek II: The Wrath of Khan" and "The Last Starfighter", the director used fractal theory to create many fractal landscapes. In addition, a number of art images created using the fractal method are easily available on numerous art-related websites.

At this stage, the research and application of fractal theory in garment design is in its infancy. Wang et al. [21] proposed a method for designing garment paper patterns based on fractal graphics, mainly analyzing the generation principles and graphic characteristics of fractal graphics based on complex dynamical systems. An improved Gauss-Newton iterative method was proposed by Chen and Zheng [22] to generate fractal art patterns with special texture effects. Since genetic algorithms have the advantage of diversity in fractal pattern generation, Chen [23] proposed a genetic algorithm-based fractal technique to assist in the innovative design of artistic patterns.

The Gene Expression Programming (GEP) algorithm [24,25] is a new evolutionary computational technique based on genetic algorithms by drawing on the laws of gene expression in biological inheritance [26]. The GEP algorithm combines the advantages of Genetic Algorithms (GA) [27,28] and Genetic Programming (GP) [29]. Rostami and Shokrollahi [30] used the GEP algorithm to develop an accurate prediction model for water dew point temperature. The results showed that, compared to traditional genetic algorithms, the prediction models constructed based on the GEP algorithm were significantly better than traditional GA model.

1.2. Motivation and contribution.

GEP has attracted much attention from domestic and international researchers due to its strong optimisation capability, simple operation and unique coding. Therefore, this paper attempts to use GEP algorithm instead of genetic algorithm to optimise fractal technology. This paper investigates the method of generating fractal art patterns based on GEP optimisation, so as to provide more innovative materials for garment design.

The main innovations and contributions of this paper include.

(1) For the first time, the fractal theory and GEP algorithm are combined to propose a generalized Mandelbrot-Julia (M-J) set fractal pattern generation method based on the GEP algorithm on top of the fractal pattern generation method based on complex dynamical systems.

(2) In order to enrich the expression of clothing patterns, the diversity of populations needs to be maintained while improving the optimisation ability. Therefore, in this paper, the standard GEP algorithm is improved based on the idea of Niche.

The rest of the paper is organised as follows. In Section 2, the basic knowledge of fractal theory was studied in detail, while Section 3 provides the fractal pattern generation method. In Section 4, the proposed Niche-GEP-based method for generating generalized M-J-set fractal patterns was studied in detail, while Section 5 provides the Experimental results and analysis. Finally, the paper is concluded in Section 6.

2. Basic knowledge of fractal theory.

2.1. The emergence and development of fractal theory.

Fractal theory is a product of the development of human cognitive abilities in the process of understanding nature.

There are many non-linear problems in nature that cannot be described by traditional geometry, such as the structure of blood vessels in the human body, the villi tissue of the small intestine, the folds of the cerebral cortex, the traces of lightning, the shape of snowflakes, the shape of plants, the structure of crystals and so on. These non-linear phenomena are commonly found in nature. However, for a long time there has been no theory to describe these widespread phenomena. So there was an urgent need for a different approach to the traditional geometry to describe the richness of nature. This led to the creation of fractal geometry. The introduction of fractal geometry not only provided a tool for describing non-linear problems, but also marked the formal birth of fractal theory. Fractal theory can be used to describe not only natural phenomena, but also various irregularities prevalent in human society, such as fluctuations in prices, changes in the stock market, epidemic processes of infectious diseases, etc.

The earliest fractal shapes can be traced back to the 'pentagonal fractal' proposed by the famous Renaissance artist and scientist Albert Durer (1471-1528). The theory of fractals was first proposed by the French-American mathematician B.B. Mandelbrot. Most researchers have defined a fractal as a phenomenon, image or physical process with self-similarity properties. For example, a typical example of a fractal graph kohn snowflake is shown in Figure 1. There is also a more complex and typical example of a Sierpinski triangle [31,32], as shown in Figure 2. As can be seen from both examples, they both have the self-similarity property. Fractals always have complex details at arbitrarily small scales, i.e. fractals have fine structure. The fractal cannot be described locally and as a whole in traditional geometric terms, and therefore the fractal is irregular. A fractal is neither a trajectory of points satisfying certain conditions, nor a set of solutions of some simple equation. A fractal is neither a trajectory of points satisfying certain conditions, nor a set of solutions of some simple equation. Fractals are self-similar in an approximate or statistical sense. The definition of a fractal is often very simple or recursive.

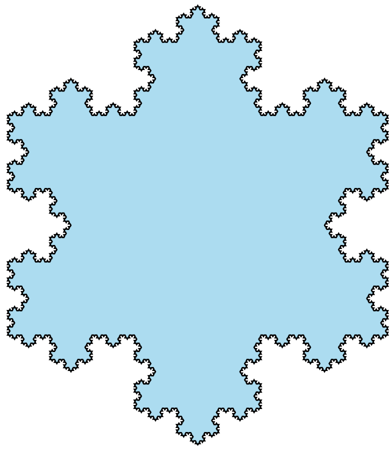


Figure 1. Kohn snowflake

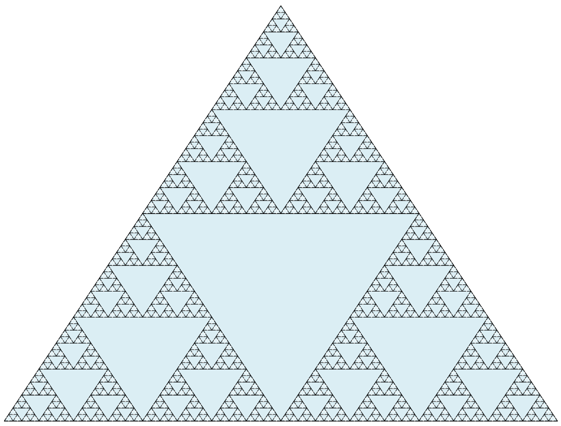


Figure 2. Sierpinski triangle

2.2. **Fractal geometry versus traditional geometry.** Traditional geometry is what we often refer to as Euclidean geometry. Euclidean geometry is a branch of mathematics with a history of over 2000 years, which uses regular geometric figures as objects of study. Objects in Euclidean geometry consist of basic elements, such as points, lines, circles, etc. Fractal objects, on the other hand, do not have elementary elements, so fractals are a geometric language. Fractals are not described by elementary elements, but by algorithms and sets of mathematical programs. These algorithms can be converted into some geometric forms with the help of computer technology.

Because the objects studied in fractal geometry are non-linear irregular figures, the figures studied in fractal geometry are much more complex than those studied in Euclidean geometry. For example, if mountains were all conical, Euclidean geometry would be able to describe mountains. However, mountains are irregularly shaped, so they cannot be described using Euclidean geometry. All objects in nature are made up of irregular fundamental elements, such as the shape of a snowflake, the trajectory of a lightning bolt, etc., so these objects in nature are difficult to describe in Euclidean geometry. Fractal geometry, on the other hand, can be used to study objects in nature because the objects studied are irregular geometric forms.

2.3. **Applications of fractal theory.** In the last two decades, the study of fractals has made great progress. Because of its enormous usefulness, fractal theory has gradually gained widespread interest in various fields. Fractal geometry has not only led to many new problems, but has also brought new hope for solving old puzzles.

(1) Applications in the economic field.

The use of fractals allows the analysis and study of stock market and financial market fluctuations, deepening the understanding of the laws of capital markets. Fractals have also been used to study the management models of companies. By using a management model based on fractal theory, companies are significantly more able to adapt to the external environment and adjust their organisational structure to cope with changes in the market environment. In heavy industry production, fractal theory can be used to study the microscopic characteristics of metal fracture surface patterns and thus improve machining processes.

(2) Applications in the field of meteorology and geography.

Fractal theory can be used to analyse and compare historical temperatures and historical climate indicators to predict the patterns of climate change. The fractal theory can be used to predict the distribution patterns of natural disasters such as typhoons and floods in time and space in order to mitigate their hazards to humans.

(3) Applications in the growth field.

In physics, chemistry, biology, materials science and medicine, there are numerous examples of growth which can be studied by fractal theory for the purpose of controlling the final shape.

(4) Applications in the field of computer graphics.

Fractal theory can be used in computer simulations of natural scenes such as mountains, clouds, lightning, water, plants, etc., resulting in very realistic scenes. Computer simulation technology based on fractal theory has been applied to Hollywood movies. In addition, fractal theory has been applied to the field of image compression. Fractal theory can be used to describe the similarity or affine between regions of an image in order to compress the image.

(5) Applications in the arts.

The combination of fractal theory and computer technology can produce a variety of colourful fractal patterns that are highly artistic and are therefore widely used in art fields such as painting design, sculpture design, architectural design, clothing design and advertising design. Figure 3, for example, shows an example of a fractal pattern being used in the structural design of a building.

3. **Fractal pattern generation method.**

3.1. **A fractal pattern generation method based on generative element recursion.** A large part of the fractal pattern is traced out by generative elements. The generative element mentioned here refers to the operation rules followed by the original graphics in the recursion when the fractal pattern is generated by the recursive method. The fractal pattern is the result of multiple recursive (iterative) operations according to

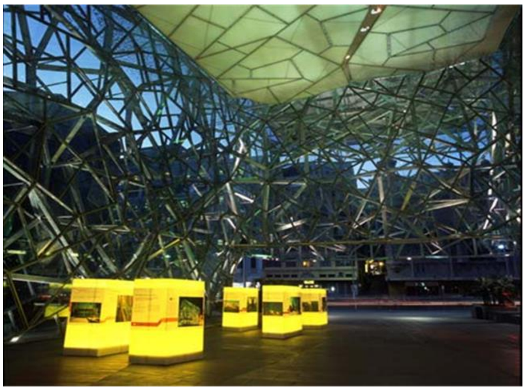


Figure 3. Application of fractals in the design of building facades

the rules of the generative element, as shown in Figure 4. The first graph is both the generating element and the original graph, the second graph is the graph after one recursion, the third graph is the graph after two recursions, and the fourth is the result of several iterations.

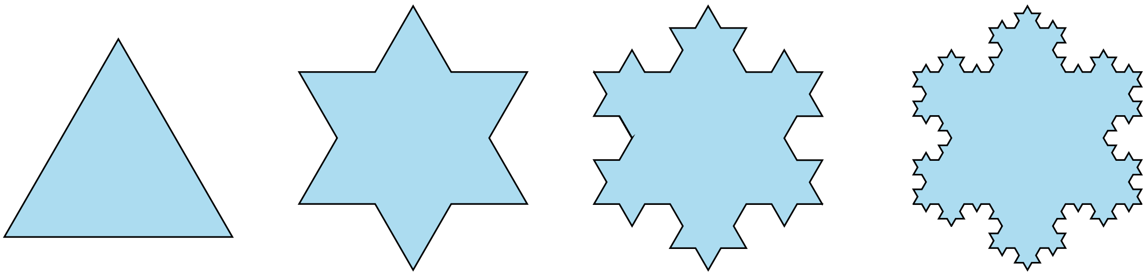


Figure 4. Example of generative element recursion

3.2. **Fractal pattern generation method based on complex dynamical systems.** Currently, fractal pattern generation methods based on complex dynamical systems are mainly implemented using fugitive time algorithms.

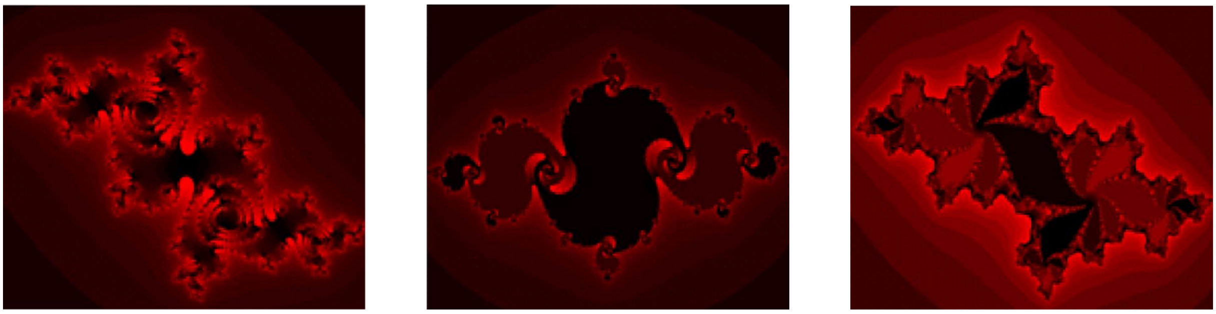
The fugitive time algorithm is a drawing method based on the iterative method. The fugitive time algorithm is capable of generating many beautiful fractal patterns, which are strongly modern and colourful in appearance. Suppose a function $F(z) = z^2 + c$. Given an initial value z_0, a value z_1 is obtained from $F(z) = z^2 + c$. Using the value of z_1 as the new z_0, iterative selection gives $z_2, z_3, \ldots, z_n$. By the iterative computations of this function, we can produce a lot of very wonderful fractal pattern. In the follow-up research, the fractal patterns of Julia set and Mandelbrot set are both generated by the iterative computations based on a certain function.

For a point $z_0 = x_0 + y_0 i$ in the complex plane, since z is complex when $c = 0$ $F(z) = z^2 = (x^2 - y^2) + (2xy)i$. Thus, the complex plane can be divided into two regions. All the points in one region approach to 0 after the iterative computations, while all the points in another region escape to ∞ after the iterative computations.

3.3. **Classic Julia Set.** The classical Julia set is generated by the iterative computations of a complex function $F(z) = z^2 + c$.

The complex numbers $z = x + yi$ in which x and y are arbitrary real numbers. i satisfies $i^2 = -1$, x and yi are called the real and imaginary parts of the complex number z, respectively. A complex number $z = x + yi$ is essentially uniquely determined by an ordered pair of real numbers (x, y). Thus, we can establish a correspondence between all the points on the plane and all the complex numbers. The complex plane is often represented by $\mathbb{C}$. On the complex plane $\mathbb{C}$, the function is defined by $z_{n+1} = z_n^2 + c$. For different values of c, various complex sets of fractals can be generated, and these are called Julia set (J-set).

From the perspective of the escape time algorithm, for a Julia set, a point always converges or diverges after a number of iterations. The interior of the Julia set converges at a point or points, while the exterior of the Julia set diverges to ∞ as the number of iterations increases, hence the escape boundary is the Julia set. The Julia set has an extremely complex morphology and fine structure. Depending on the value of c, different Julia sets with different structures are generated, resulting in different fractal patterns, as shown in Figure 5.



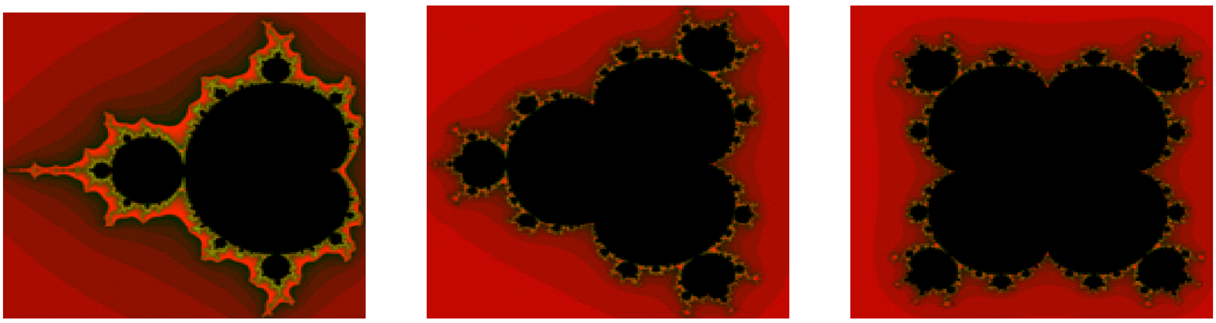
(a) $C = -0.199 - 0.66i$ (b) $C = -0.77 - 0.08i$ (c) $C = -0.615 - 0.43i$

Figure 5. Fractal pattern generated by J-set algorithm

3.4. **Classic Mandelbrot Set.** The mathematical expression of the Mandelbrot set is very similar to the J-set in that both use a two-dimensional iterative relation on the complex plane $F(z) = z^2 + c$.

However, unlike the J-set, the Mandelbrot Set is actually the image of the composition of the constant c. In an iteration, let the initial value $z_0 = 0$, i.e. $z_0 = 0 + 0i, c \neq 0$. Iterating over the formula $F(z) = z^2 + c$ gives a set, called the Mandelbrot set (M-set).

The generative diagram of the M-set is shown in Figure 6. We can see that the M-set has a very complex structure and also has some distinctive features. The complex structure of the M-set is revealed between the chaotic region inside the set and the ordered region outside the set, which is also known as the edge of chaos.



(a) $F(z) = z^2 + c$ (b) $F(z) = z^4 + c$ (c) $F(z) = z^6 + c$

Figure 6. Fractal pattern generated by the M-set algorithm

4. Niche-GEP-based method for generating generalized M-J-set fractal patterns.

4.1. The proposed Niche-GEP algorithm. GEP is a new evolutionary computational algorithm based on genetic algorithms by drawing on the gene expression laws of biological inheritance [33,34].

The research object of GEP is chromosome composed of single gene or multiple genes. A gene consists of a head and a tail. The head length of a gene is assumed to be h, the tail length to be e, and the maximum number of operations to be n.

$$e = h * (n-1) + 1 \tag{1}$$

Suppose a gene consists of elements in the set {q,+,-,*,/,a,b}, then the maximum number of operations $n = 2$. If the head length $h = 10$ and the calculation yields the tail length $e = 11$, then the length of the gene is equal to 21 and its gene expression is shown as follow.

$$\begin{array}{ccccccccccccccccccccc} 0&1&2&3&4&5&6&7&8&9&0&1&2&3&4&5&6&7&8&9&0\\ *&q&+&*&a&/&a&a&q&a&b&b&a&a&b&a&b&b&b&a&a \end{array} \tag{2}$$

The expression tree corresponding [35] to this gene is shown in Figure 7.

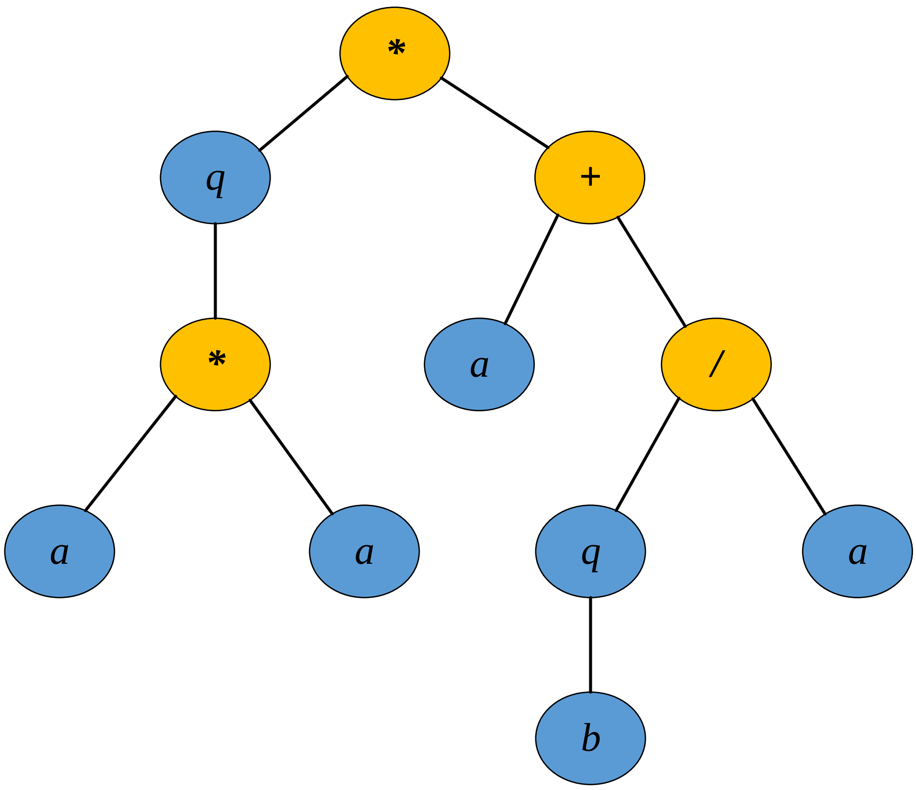


Figure 7. Expression tree corresponding to Equation (2)

To solve common complex problems, chromosomes are often used in GEP. Chromosomes are usually made up of multiple genes that are linked together using connectors. For example, a chromosome consisting of 2 genes with a head length of 4 and a tail length of 5. The connector between the genes is assumed to be "+" and the chromosome is shown in Figure 8.

$$\begin{array}{cccccccccccccccccc} 0&1&2&3&4&5&6&7&8&0&1&2&3&4&5&6&7&8\\ +&a&/&b&\mathbf{a}&\mathbf{b}&\mathbf{b}&\mathbf{b}&\mathbf{a}&/&q&b&-&\mathbf{b}&\mathbf{a}&\mathbf{b}&\mathbf{a}&\mathbf{b} \end{array} \tag{3}$$

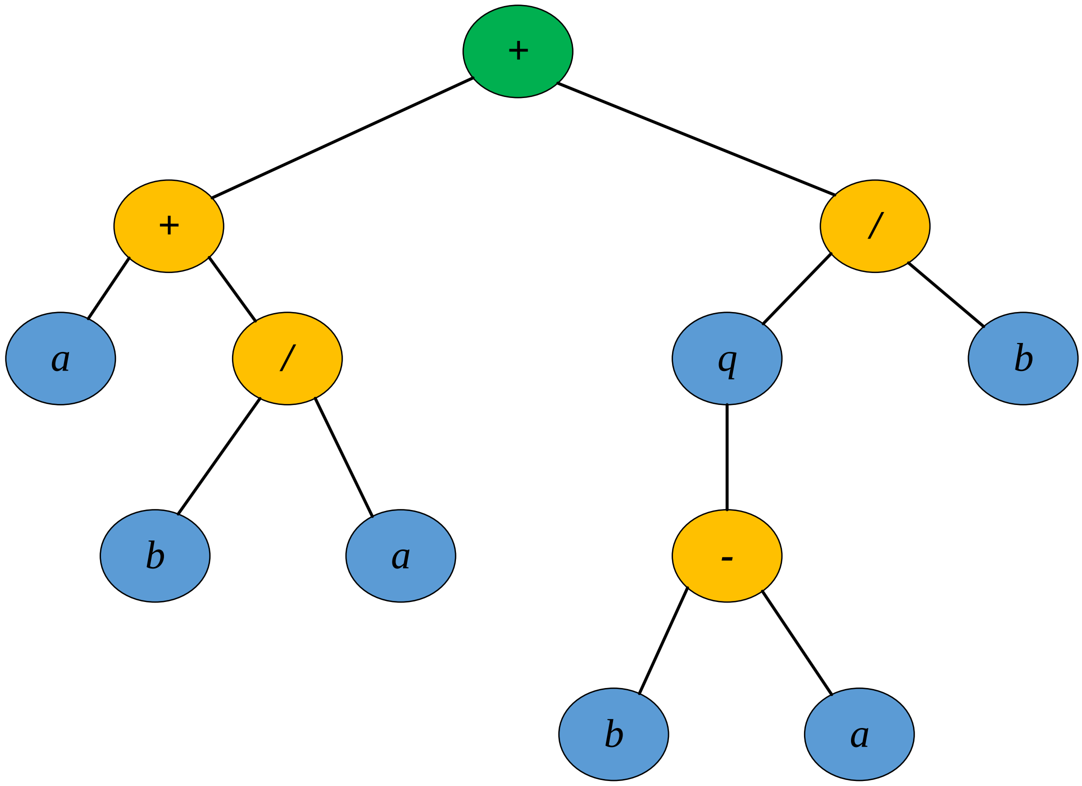


Figure 8. Chromosome formed by two genes through the ligand "+"

There are four main categories of basic genetic operators in GEP: selection operators, point mutation operators, string mutation operators and recombination operators. Variation acts on a single chromosome. Select a symbol on a random chromosome, and if the mutation probability is met, the symbol at that position will mutate. For example, a parent chromosome P mutates in the sign at position 4, from b to a, giving the offspring chromosome S, as shown in Figure 9. The fitness value is a measure of how well a species

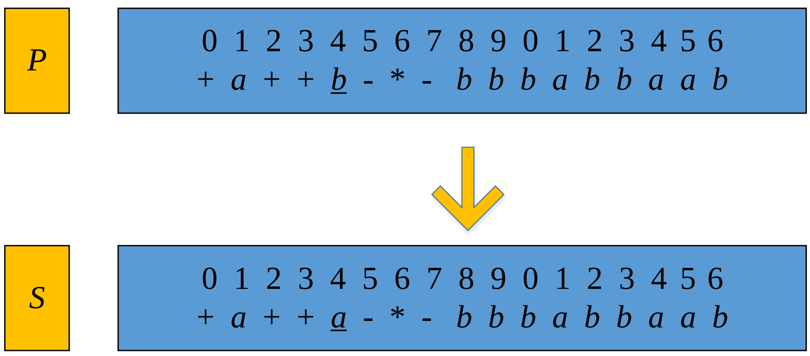


Figure 9. The process of chromosomal variation

is adapted to its environment. In general, chromosomes are evaluated on the basis of their fitness value. Absolute and relative errors are usually used to assess the fitness function of an individual.

$$fitness = \sum_{j=1}^{m} (M - |y_j - \hat{y}_j|) \tag{4}$$

where y_j denotes an observation, $\hat{y}_j$ denotes an estimate and M denotes a constant.

In the course of their evolution, organisms in nature have generally always lived with species similar to themselves, and they have also all competed for survival in a particular geographical area, which is the phenomenon of Niche. The basic idea of Niche is to divide the whole population into small niches in a certain way. Firstly, within and between the small niches, a new generation of populations is generated through hybridisation and mutation. Then, various methods (pre-selection, exclusion, sharing function, etc.) are used to protect the optimal individuals among the small niches and maintain the diversity of the population. In order to further improve the performance of GEP, this paper improves the GEP algorithm and proposes a Niche-based Gene Expression Programming algorithm (Niche-GEP). The flow of the Niche-GEP algorithm is shown in Figure 10.

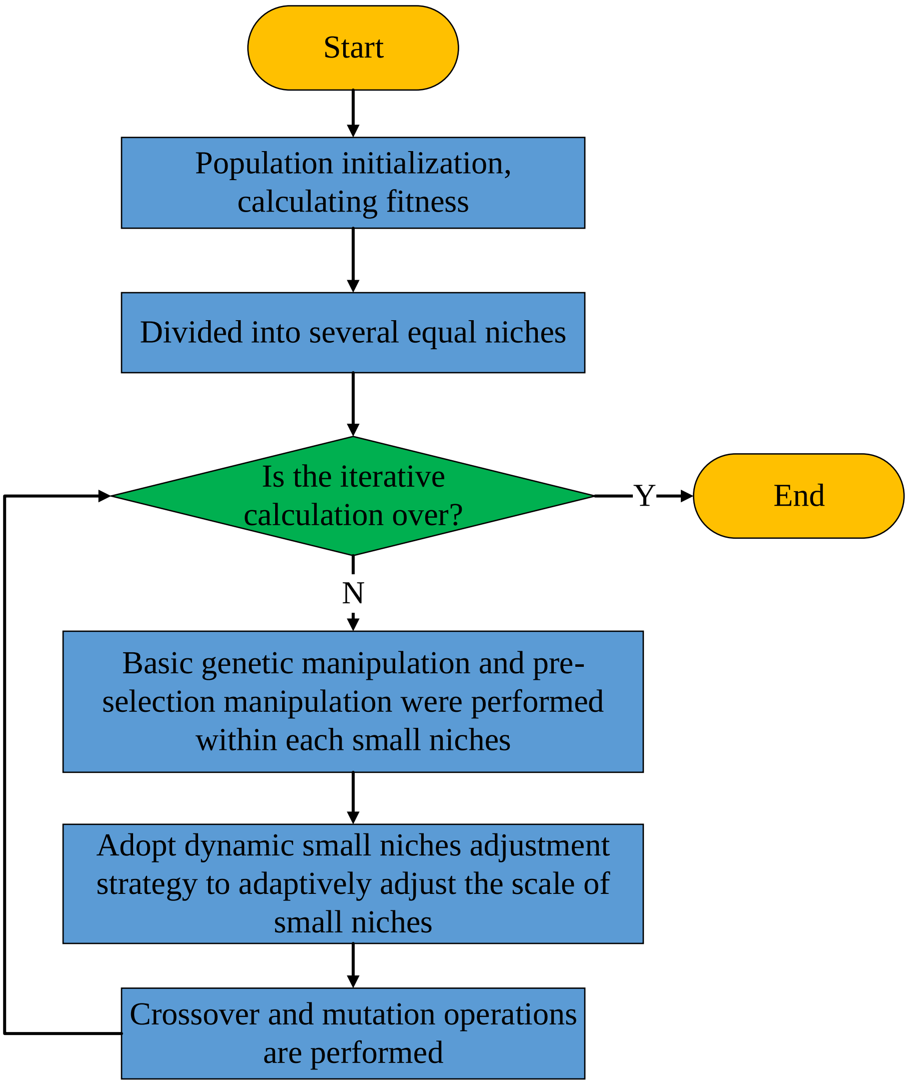


Figure 10. Flow of the Niche-GEP algorithm

4.2. **Chromosome coding.** Both the M-set and the J-set are regions on the negative plane $\mathbb{C}$. The c in the M-set is not fixed, while the c in the J-set is fixed. Since M-set and J-set originate from the same transformation, there is a very complex association between them, so they are often combined for study and called M-J-set. The current study for M-J-set has broken away from the simple $z \to z^2 + c$ and has seen the emergence of $z > \cos(z) + c$, $z \to \arctan(z + \sin(z)) + c$ and other similar various complex mappings, so we can call the M-J-set the generalized M-J-set.

By generalized the M-J-set, we can obtain thousands of iterative functions. Thousands of fractal art patterns can then be obtained by applying the escape time algorithm. Each pattern corresponds to an iterative function. But how can the designer quickly dig through the many patterns to find the ones that meet the needs of different users? In order to meet the needs of different users, the designer is forced to constantly change the parameters to generate new patterns. This approach is not only time-consuming and labour-intensive, but also purposeless and unfocused, often making it difficult to meet the user's requirements.

In order to solve these problems, this paper attempts to apply the Niche-GEP algorithm to the field of fractal art design. The human-computer interaction process is added to the Niche-GEP algorithm, and user preferences are incorporated into the genetic operation process of GEP to evolve fractal art patterns that meet user needs better and faster. Here we consider the generalised M-J-set generation selection function as an individual from the population in the Niche-GEP algorithm and encode it. Due to the great flexibility of mathematical expressions in LaTeX based on binomial tree structures [36,37], this paper adopts a binary tree structure encoding method, specifically, the solution of the problem is represented as a binary tree form, where each tree is a chromosome.

4.3. **Fitness function.** In order to evaluate the merit of different chromosomes in the Niche-GEP algorithm, we need to construct a fitness function for genetic manipulation. Here, we use user 'satisfaction' and 'consensus' with the design as indicators of the level of genetic chromosome merit.

The fitness function in this paper uses a common group rating model. The common group rating model classifies users' preferences into "satisfied", "average" and "dissatisfied". The user rating for "Satisfied" is 3, for "Average" is 2 and for "Dissatisfied" is 1, as shown in Table 1. If there are n users involved in the rating, then the interval for the satisfaction rating is $[n, 3n]$. The ratings of each user are summed up to give a consensus satisfaction rating for the group of users. If the satisfaction scores are the same, the fitness function is determined by calculating the consensus degree criterion. For example, although both artistic pattern A and artistic pattern B have a common rating of 13, there is no 'dissatisfied' attitude in pattern B (a high degree of consistency in the ratings). Therefore, B is more capable of meeting the individual needs of users than artistic pattern A.

Table 1. User ratings of the work

Artistic patterns	**Individual user ratings**						**Common group rating**
A	2	3	2	3	1	2	13
B	3	2	2	2	2	2	13
C	2	3	1	1	2	2	11
D	1	2	2	1	2	1	9
E	3	1	2	3	3	2	14
F	3	1	2	2	1	3	12

$$S\left(V_i\right)=\frac{V_i-V_{\min}}{V_{\max}-V_{\min}} \tag{5}$$

where $V_{\max}$ denotes the highest score, $V_{\min}$ denotes the lowest score, $S(V_i)$ denotes the normalized value, and V_i denotes the user evaluation score.

This paper uses the standard deviation method to calculate the consensus degree T and satisfaction $S(V_i)$.

$$T = 1 - \sqrt{\frac{\sum_{i=1}^{n} (V_1 - V)^2}{n}} \tag{6}$$

$$\overline{S}(V_i) = \frac{\sum_{i=1}^{n} S(V_i)}{n} \tag{7}$$

Assuming that the ratios between consensus T and satisfaction $S(V_i)$ are u and v $(u + v = 1)$, respectively, consensus satisfaction as a function of fitness is calculated as follow.

$$Fitness = u\overline{S}(Vi) + vT \tag{8}$$

In the traditional GEP algorithm, the fitness value is determined by the fitness function. However, since each user's subjective evaluation varies. Therefore, it is not possible to have an objective fitness function. Therefore, the fitness value used in this paper is represented by the user's rating. The way in which the user's 'satisfaction' and 'consensus' are extracted from the user's ratings to construct the fitness value is a good example of interactive thinking.

4.4. **Algorithm flow.** The flow of the fractal pattern generation method based on Niche-GEP is as follows:

Step 1: Initialize the population. First, the population randomly generates valid mathematical expressions as the iterative function for generating the fractal pattern. Then, the expression string is represented as a corresponding binary tree using the encoding of a binary tree structure.

Step 2: Generate fitness values for chromosomes in the initial population by interacting with the user. The user can then evaluate and score the chromosomes in the population to modify their fitness values for genetic selection of the next generation.

Step 3: Generate new populations based on the fitness values of the chromosomes in the Niche-GEP algorithm.

Step 4: Perform crossover and mutation operations on the population.

Step 5: After multiple rounds of evaluation and elimination, if there are results that meet the user's satisfaction then end, otherwise go to Step 2.

5. Experimental results and analysis.

5.1. **Performance analysis of the Niche-GEP algorithm.** In order to verify the effectiveness and advancement of the proposed Niche-GEP algorithm, it was compared with the GEP algorithm. The experimental environment is Matlab R2010b, Windows 10 operating system, i5-2310@2.9Ghz CPU and 6G memory. The experimental parameters were set as shown in Table 2. In the operator set S is square, Q is open square and exp is e^x. Each algorithm was repeated 50 times and averaged to avoid the interference of random bias.

Three standard test functions [38,39] were used to verify the performance of the GEP algorithm and Niche-GEP algorithm, respectively.

$$F1 = 8 + 2e^{1-x^2}\cos(2\pi x), x \in [0, 5] \tag{9}$$

$$F2 = \cos^2\left(x^2\right), x \in [0, 3] \tag{10}$$

$$F6 = \cos\left(10^x\right), x \in [0, 2] \tag{11}$$

Table 2. Parameter settings for the experiments

Parameters	**Numerical values**
Number of experimental runs	50
Maximum number of evolutional generations	200
Population size	200
Operator set	+,-,*,/,ln,exp,S,Q,sin,cos,tan,ctg
Terminator Set	a
Connection functions	+
Gene head length	6
Number of genomes	5
Variation rate	0.4
Crossover probabilities	0.3
Number of niche	5
Niche's minimum threshold	10
Niche's maximum threshold	60

Taking the *F1* test function as an example, the evolutionary curves of the GEP algorithm and the Niche-GEP algorithm are shown in Figure 11 and Figure 12, respectively. The performance comparison of the two algorithms on the F1 test function is shown in Table 3.

Table 3. Performance comparison of GEP and Niche-GEP on *F1*

Compare items	**Niche-GEP**	**GEP**
Number of experiments	50	50
Optimization rate	96%	82%
Number of hits	48	41
Number of iterations for mean convergence	41	87

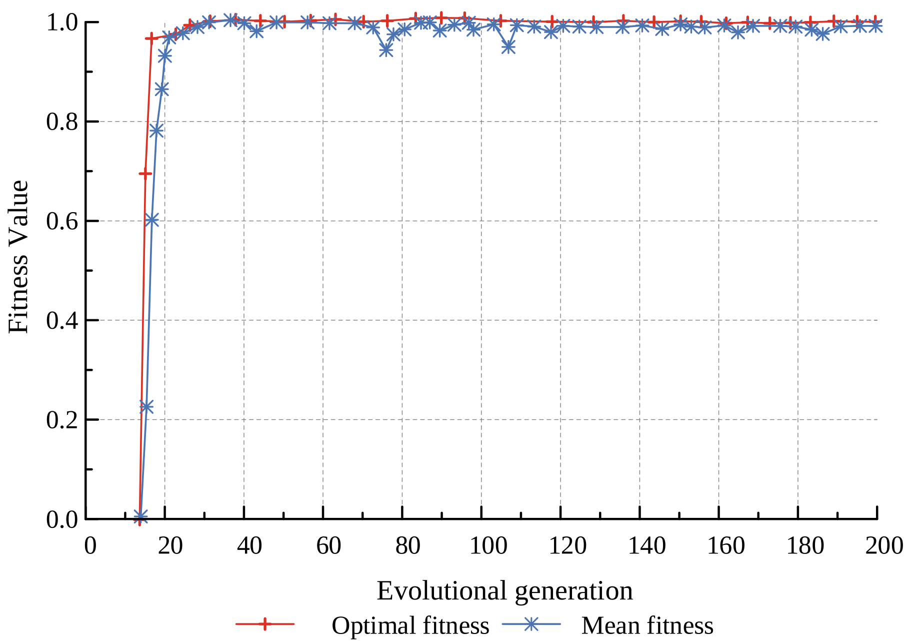


Figure 11. Evolutionary graph of the GEP algorithm

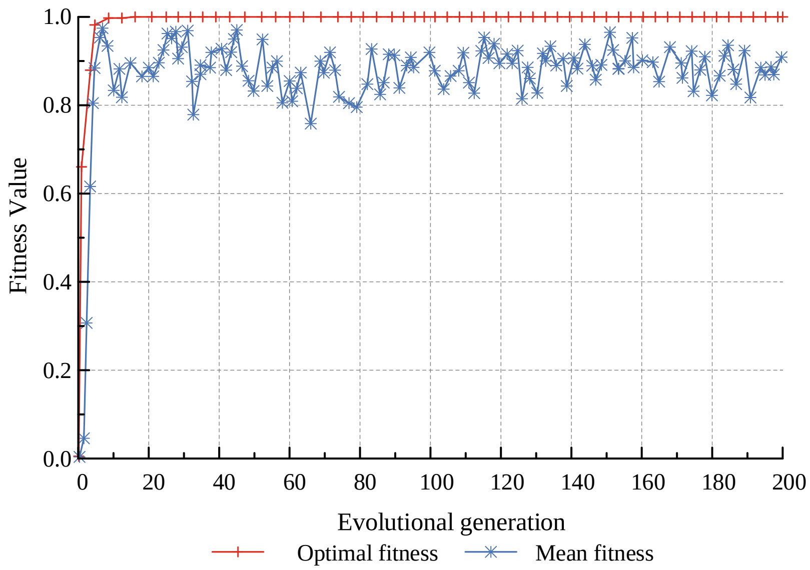


Figure 12. Evolutionary plot of the Niche-GEP algorithm

It can be seen that the number of generations of convergence for the Niche-GEP algorithm to reach the optimal solution is smaller than that of the standard GEP algorithm, which indicates that the convergence speed of Niche-GEP has increased compared to the standard GEP algorithm. The evolutionary curves show that the average fitness value of the Niche-GEP algorithm is more volatile than that of the standard GEP algorithm, which indicates that the variability of individuals in the population is greater in the Niche-GEP algorithm, i.e. the diversity of the population is higher. Niche-GEP is therefore significantly effective in improving population diversity and convergence speed.

The results of the combined comparison of the three standard test functions are shown in Table 4. From the combined comparison results, it can be seen that the performance of the Niche-GEP algorithm is significantly improved on all three test functions compared to the standard GEP algorithm, which shows that the Niche-GEP algorithm is more competitive. Among them, function *F2* and function *F3* were able to take the optimal solution, which illustrates the effectiveness of the Niche-GEP algorithm.

Table 4. Combined comparison results of the 3 standard test functions

Functions	Algorithms	Maximum fitness	Minimum fitness	Mean fitness
F1	GEP	0.9675	0.8231	0.9263
	Niche-GEP	0.96825	0.8782	0.9334
F2	GEP	0.9991	0.7865	0.9371
	Niche-GEP	1	0.8112	0.9446
F3	GEP	0.9954	0.8237	0.9465
	Niche-GEP	1	0.9603	0.9913

5.2. **Example analysis.** A concrete example of the Niche-GEP-based generalized M-J set fractal pattern generation method is analysed in a complex dynamical system.

Assume that set of operands is given as $\alpha(z, z^2, z^3, z^{-1}, z^{-2}, z^{-3}, z^{-4}, e^z, e^{-z}, \sin z, \cos z, \tan z, \cot z, a)$, where $z = x + yi$, a is an arbitrary constant and the operator set is $\beta(+, -, \times, /)$. To construct the initial population, we need to randomly select the required elements from the operand set and the operator set and form them into multiple binary trees. A number of elements are randomly selected as intermediate nodes in the operator set. A number of elements are randomly selected as the final node of the binary tree in the operand set. Each binary tree represents an iterative function.

Two trees are selected from the initial population generated according to the set α and the set β: A and B, as shown in Figures 13 and 14, respectively. The fractal patterns of tree A and tree B are shown in Figures 15 and 16 respectively.

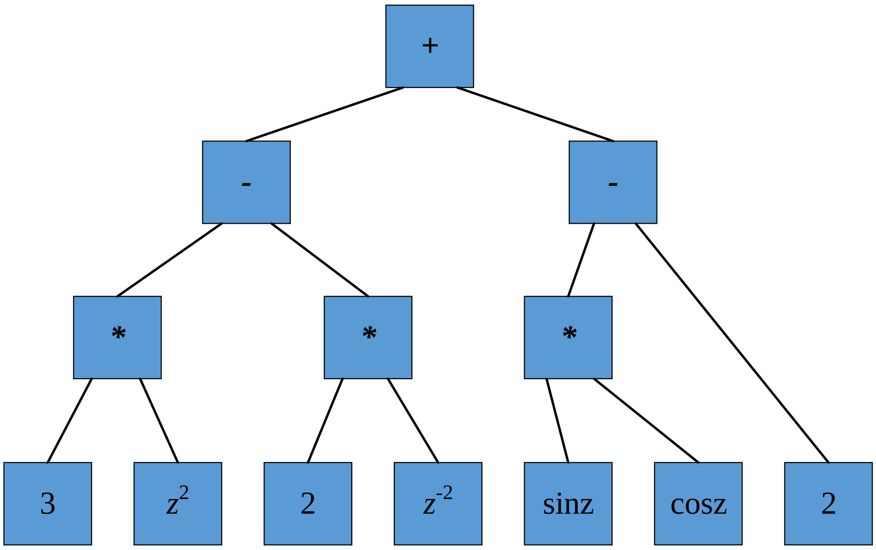


Figure 13. Tree A

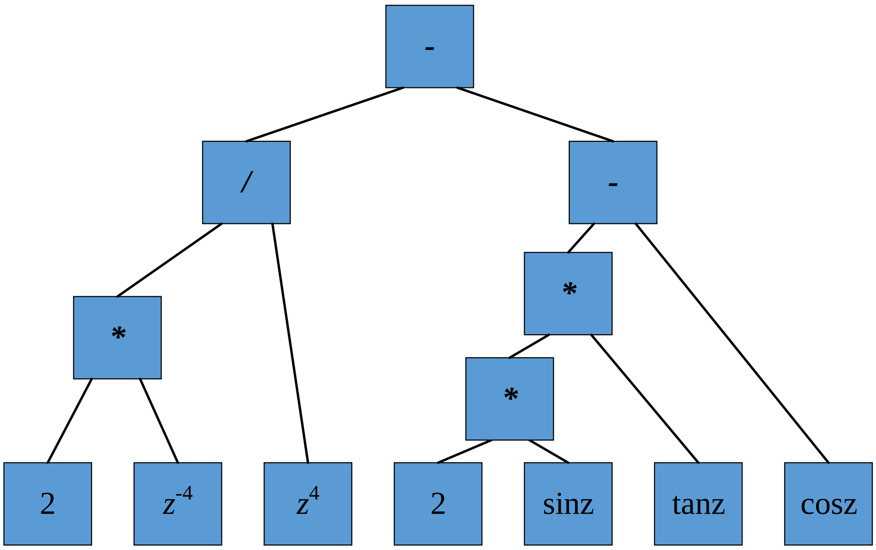


Figure 14. Tree B

The iteration function for tree A is $3z^2 - 2z^{-2} + \sin z \cdot \cos z - 2$, while the iteration function for tree B is $2z^{-4}/z^4 - 2\sin z \cdot \tan z - \cos z \cdot z$. Let 100 users evaluate the fractal patterns generated by the two selected generation functions. After calculating the consensus and satisfaction of the users, we can calculate the fitness value of each fractal design pattern. The chromosomes are selected based on the fitness values, and the next generation is generated. The selected chromosomes are crossed over and mutated to produce individuals in the new population. In the mutation operation, a new subtree is first generated randomly by the program, which replaces the part of the subtree under

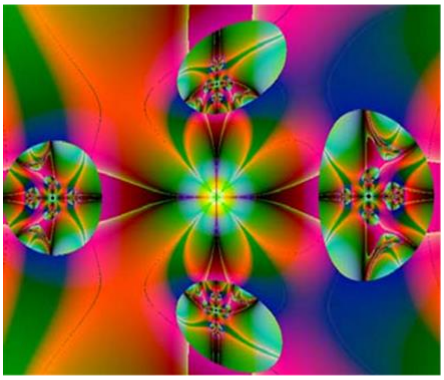


Figure 15. Fractal pattern of tree A

Figure 16. Fractal pattern of tree B

the selected node with this subtree. After these steps, the operation is stopped if a fractal pattern design is generated to the user's satisfaction, otherwise it returns to continue with the genetic operation. After 14 iterations, the final fractal design generated to the user's satisfaction is shown in Figure 17, and the corresponding real clothing pattern is shown in Figure 18.

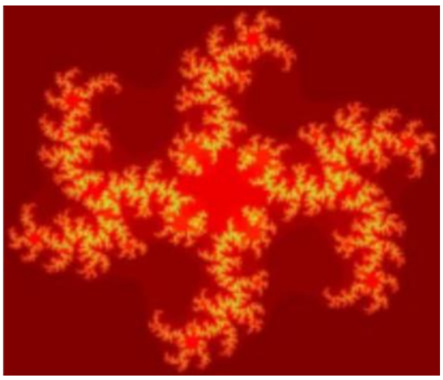


Figure 17. User-satisfactory fractal pattern

Figure 18. Real clothing pattern

6. **Conclusion.** This paper focuses on the fractal theory, the theory of GEP algorithm and the method of fractal pattern generation. Based on the above, the fractal theory and GEP algorithm are combined to propose a generalised M-J-set fractal pattern generation method based on Niche-GEP algorithm on top of the complex dynamical system. In addition, in order to enrich the expression effect of clothing patterns, it is necessary to maintain the diversity of populations while improving the optimisation ability. Therefore, in this paper, a Niche-GEP algorithm is proposed based on the Niche idea and the standard GEP algorithm is improved. Experimental results on the standard test function show that the Niche-GEP algorithm is more competitive than the standard GEP. Ultimately, the feasibility of the proposed method is verified through programming experiments. The proposed method can broaden designers' design ideas while meeting the individual needs of different users better and faster.

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