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Application of Patterns Based on Cellular Automata in Carpet Design

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***Abstract*—*To augment the design resources of contemporary carpet patterns and innovate the expressive forms of carpets, this paper centers on the application of patterns based on cellular automata in carpet design. Drawing upon the randomness and diversity characteristics in the evolution of cellular automata, this paper utilizes Visual C++ software to generate an abundance of fractal patterns, adopts XFader software for seamless splicing of these patterns, and ultimately applies the generated distinctive fractal patterns to carpet design.*

***Keywords*—*Cellular automata, pattern design, carpet design.*

I. INTRODUCTION

With the rapid development of computer technology and the continuous improvement of fractal theory, its application fields have been expanding. The perfect integration of fractal theory and computer technology can generate a large number of magnificent fractal art patterns [1]. Applying these fractal patterns to carpet pattern design can break the ideological constraints of traditional pattern design, create a unique style. Moreover, the infinitely delicate graphics exhibit a high degree of self - similarity, which offers a new interpretation of visual aesthetics [2], and helps to break through the "bottleneck" caused by the limitations of human thinking in pattern design.

Based on the randomness and diversity characteristics of cellular automata, this paper uses Visual C++ software to generate a variety of unique fractal patterns, producing visual effects that cannot be simulated by human imagination alone. It creates a unique "Chinese style" applicable to the field of carpet design.

II. CELLULAR AUTOMATON THEORY

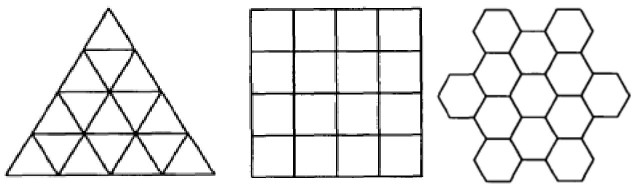
Cellular Automata (CA) [3] can be simply defined as a computational model for simulating complex systems with self-replication properties. The basic structure of CA consists of four core components, which are briefly elaborated as follows:

A. Cellular

A cell, also termed a primitive or unit, acts as the fundamental building block of cellular automata (CA). Such cells are distributed at lattice points within discrete one-dimensional, two-dimensional,or multi-dimensional Euclidean spaces. At any given time, each cell typically holds a single state variable (e.g., alive or dead, black or white). Nevertheless, certain studies have investigated cells with multi-state sets—for instance $S=\{s_0,s_1,...,s_{k-1}\}$, discrete integer sets composed entirely of integer elements. Binary states represent the most extensively studied type, and the research in this paper focuses on binary states.

B. Cellular Space

This study focuses on two-dimensional cellular automata (2D-CA), whose spatial structure is constructed from three types of lattices: triangular, square, and hexagonal. Each of these three cell-partitioned spatial configurations exhibits respective advantages and disadvantages in modeling applications. In the current computer environment, the square lattice is the most widely adopted configuration, and the cell space of the 2D-CA investigated in this paper is arranged in a square lattice structure. Figure 1 provides a brief description of the triangular, square, and hexagonal grids respectively.



(a) triangular grid (b)Four-square grid (c) hexagonal mesh
Fig. 1. Cellular space

C. Cell Neighbor

For the 2D-CA investigated in this paper, the definition and characterization of neighbor cells are relatively complex. When partitioned in accordance with the square lattice commonly adopted in 2D-CA systems, four distinct neighbor configurations are identified, namely the Von Neumann type, Moore type, extended Moore type, and Margolus type.

D. Cellular Rule

In simple terms, the cell rule is a function that uses the current state of a cell and the states of its neighbors to collectively determine the cell's state at the next time step. It can be simply expressed as: $f:S^m \to S$, where S denotes the current state set, m represents the number of cells in the neighborhood, and f is the local transition function, or simply the rule.

The basic components of a cellular automaton (CA) can be simply represented in a diagram, as shown in Figure 2.

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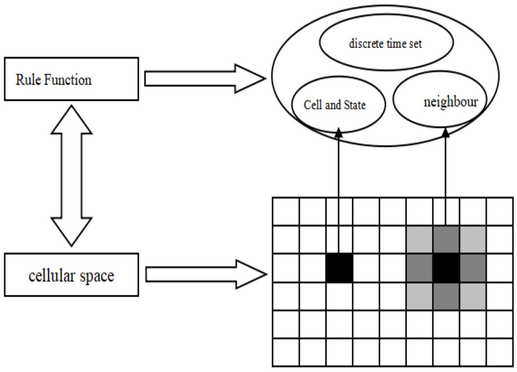


Fig. 2. Composition of Cellular Automata

III. Application of Pattern in Carpet Design

Fractal patterns constitute a visualization form that intuitively embodies the intrinsic aesthetic value of computer algorithms and mathematics. Derived from simple mathematical principles and generated in accordance with specific rules, such patterns exhibit diverse artistic styles, define a novel aesthetic for pattern design, and can provide designers with fresh inspirations, methodological approaches and creative concepts for pattern creation.

Cellular automata (CA) demonstrate dynamic transformations that gradually develop into complex and diverse transient patterns as time progresses. Even when the display ranges and evolutionary rules remain identical, distinct color schemes and cell shapes can yield completely different CA patterns. This research capitalizes on the intrinsic diversity and randomness of CA evolution to generate visually captivating designs with vivid colors, substantially enhancing the creative potential for carpet patterns.

A. *Flowchart Description of Pattern Generation Based on Cellular Automata (CA)*

Based on the characteristics of cellular automata and the flow chart of patterns generated by cellular automata, the flow chart is shown in Figure 3. The algorithmic idea of two - dimensional cellular automata evolution is briefly described as follows:
Step 1: Initialize the two - dimensional cellular automata. For example, define the display range, cell size, evolution rules, and color parameters for initialization.
Step 2: Draw the pattern and judge whether the current pattern meets the user's requirements. If not, reset the parameters and redraw the pattern; if it meets the requirements, save the pattern.
Step 3: If the generated pattern is satisfactory, judge whether to proceed to the next operation. If the answer is no, the pattern drawing is completed; if the answer is yes, parameters such as color, cell size, and cell shape can be further reset to generate new patterns with diverse forms.
Step 4: On the basis of Step 3, judge again whether the user is satisfied with the pattern. If satisfied, save the pattern; if not, reset the parameters and redraw the pattern.

This paper adopts a human - computer interaction mode, which facilitates the flexible modification of parameters and enables the rapid generation of cellular automata (CA) patterns with distinct styles. These CA patterns can be generated efficiently and are convenient for subsequent modification.

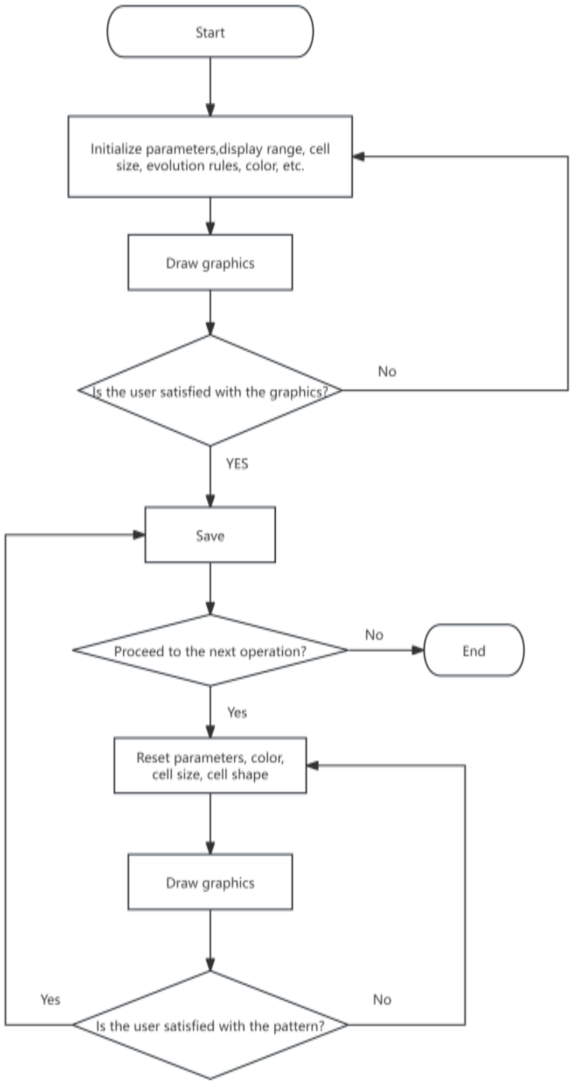
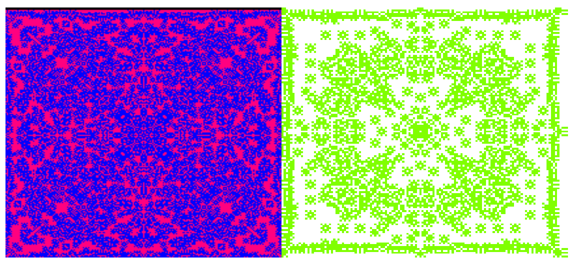


Fig. 3. Flow diagram

Based on the aforementioned algorithm, this paper employs Visual C++ software to generate an extremely diverse range of patterns. From these, relatively satisfactory ones are selected for further design operations. As shown in Figure 4, two patterns are chosen from the numerous ones generated by Visual C++ software. These patterns based on cellular automata break free from the constraints of traditional patterns. If the patterns generated by cellular automata are applied to carpet design, they can offer an entirely new visual experience.



(a) (b)

Fig. 4. Patterns produced by cellular automata

B. Seamless Pattern Connection

Figure 4 illustrates the patterns generated by cellular automata, which boast vivid color palettes and elaborate compositional structures. Nevertheless, the resulting fractal patterns are predominantly composed of isolated motifs, when directly applied to carpet design, such motifs may render the overall design monotonous and fail to deliver a cohesive visual experience. Accordingly, further refinement is required to elevate their holistic aesthetic appeal.

This study employs XFader software [4] for secondary processing. As a professional yet user-friendly image material generator, XFader can create an infinite variety of textures from any bitmap. By applying XFader to fractal patterns generated by cellular automata, the software conducts boundary blending to achieve seamless transitions, allowing for direct application in carpet pattern design.

The pattern generated by the cellular automaton in Figure 4, after being processed using XFader software, is shown in Figure 5. In Figure (a), there is a purple background with lines interwoven and entangled, creating a visual effect similar to vines or scrolling foliage. The overall design showcases a symmetrical decorative style with strong color contrast and visual impact. In Figure (b), a white background is used, and bright - green pixels form the pattern. Each block contains pixel groups that create symmetrical decorative motifs, centered around a radiating pattern resembling flowers, which gives the design a retro decorative feel. The neat grid layout and repetitive motifs bring a strong sense of order and rhythm.

These processed patterns provide designers with new inspiration, offering a stage for "China elements" in carpet design.

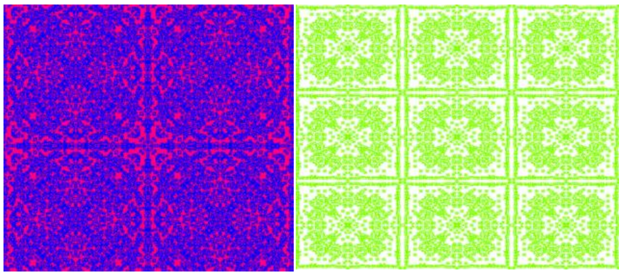


Fig. 5 Rendered image after processing by the XFader software

IV. CONCLUSION

Within the VC++ programming environment, this study explores fractal patterns generated on the basis of cellular automata theory. These patterns manifest a bold and unconstrained aesthetic, with a high level of order concealed within their irregularity. Complex symmetry supersedes simple geometric symmetry, endowing the designs with a more exotic allure and infinite variability. Such patterns can be directly utilized in carpet design, presenting a novel avenue for the application of fractals generated by cellular automata in carpet patterning.

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