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*Paper:* **CHINESE PATTERN DESIGN USING GENERATIVE SHAPE GRAMMAR**

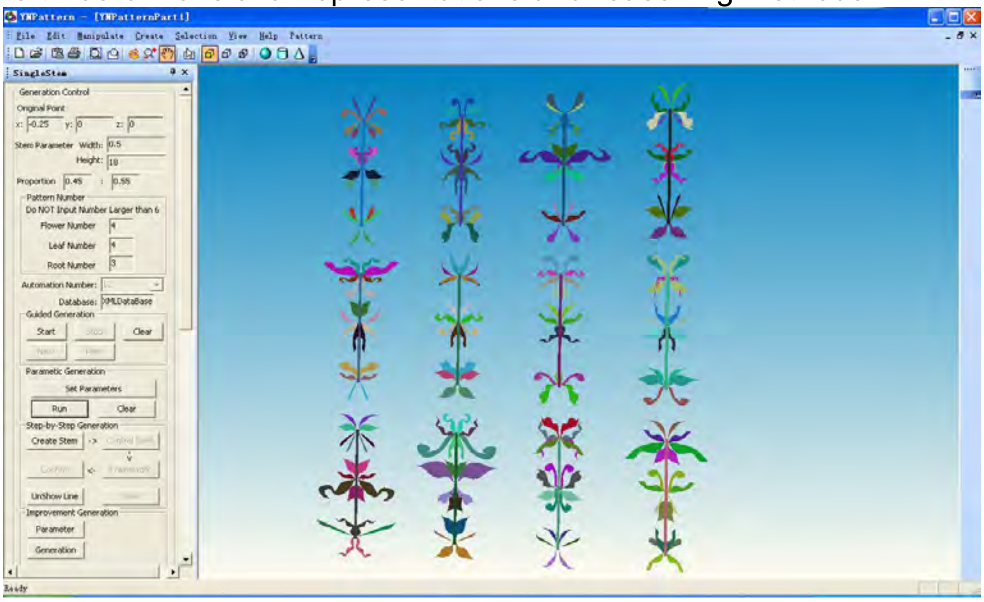
***Abstract:***

Art design, especially graphic design, is an abstractive and intuitive process which is difficult to formulate the result apart from visualization. Shape Grammar is a powerful tool with the tangible language elements—shapes and rule-bases. By using a rule-base, the application of Shape Grammar can orient the future shape development to a promising direction.

Chinese patterns—Yunnan embroidery patterns have a long history and local cultural features. It is created by villagers who lived in the country close to nature, with imaginative natural curves, shapes and colours.

Most of the applications on Shape Grammar are based on the orthogonal lines; however, this study creates curve patterns with different colors by analyzing the characters from the existing embroideries, aiming at achieving auto-generation of new patterns with the similar features. The whole generation process is based on a generative system with a Shape Grammar representation in two-dimensional space. The intent of this study is to show that such SG and representation can support human designers to create newer styles easily, faster and visually.

The further goal of the research is to increase the curves generation methods for a more flexible creating process, with a view to move on to three-dimensional representations and reasoning methods.




*Snapshot of Software Application*

***Topic: Art & Design***

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***Keywords:***
Shape Grammar, Culture, Generative System, Design, Curve Pattern

# CHINESE PATTERN DESIGN USING GENERATIVE SHAPE GRAMMAR

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## Abstract:

Art design, especially graphic design, is an abstractive and intuitive process which is difficult to formulate apart from visualization. Shape Grammar can be a powerful tool using the elements of shapes and rules for transformations. With a rule base, the application of Shape Grammar can orient the future shape development to a promising direction. Yunnan embroidery patterns have a long history and local cultural features. They are created by villagers who lived in the country close to nature, with imaginative natural curves, shapes and colours. Most of the applications on Shape Grammar so far are based on the orthogonal lines. However, this study creates curvy patterns with different colours by analyzing the characters of the existing embroideries created by the villagers, aiming at achieving auto-generation of new patterns with the similar features. The whole process is based on a generative system with a Shape Grammar representation in two-dimensional space. The intent of this study is to show that such SG and representation can support human designers to create newer styles easily, faster and visually.

## 1 Introduction

"Much good design evolves: the design is tested, problem areas are discovered and modified, and then it is continually retested and remodified until time, energy, and resource run out" [1]. This is the characteristic natural design process. During this process, the bad features are changed and good ones are reserved. However, at present, designers face many challenges, including the changing requirements of business, increased pace of society and the fastidious consumers. These challenges do not allow a slow, careful selection of an object over a long time. Many design decisions have to be made quickly during design process.

Originally, as the analysis tools of classical architecture structure, Shape Grammar was introduced by Stiny and Gips in 1972 [2]. Then more and more researchers noticed its excellent potential and creative ability as an assistant method in design.

Although there are many works which showed the validity of the Shape Grammar schema for generating and analyzing new designs, we still argued that it did not make use of the advantages as an explorative and creative design tool to decrease design time and enhance the effectiveness. The first reason is that many designs are produced manually. The instantaneous inspiration and the unfixed design methods make it difficulty to develop a general design model in computers. Secondly, even in a digital system, the applications are mostly restricted in orthogonal fields because of the difficulties in orientation in coordinate systems [3]. The third reason is that multiple knowledge representation for subjective and perceptive design objects does not exist. Lastly, there are some barriers of human-system interaction, which does not only affect human-machine interface, but also the bilateral communication actions.

In this paper, we attempt to overcome the limitations mentioned above. We present an auto-generation system embedding the method of Shape Grammar to design Yunnan embroidery patterns which a have long history in the southwest of China. The features of this system are followed:

- Auto-generation based a computer digital system;
- Curvilinear pattern generation by Shape Grammar;
- Multi-level knowledge representation abstracted from the existing art work; and
- Improved communication between user and system.

## 2 Shape Grammar

### 2.1 Shape Grammar Development on Design

The mature Shape Grammar theory and its wide applications cooperated with computational support can be used as one of the core powers for computational design systems. The digital virtual technology and visual interface can be conveniently used to show the results directly for the designers and consumers. There are some previous works on this field. Tapia [5] presents a general paradigm for a computer implementation supporting computation in 2-dimensional spaces. Smyth and Edmonds [6] describe a system supporting design-aided conception using Shape Grammar for the early stage of design process, i.e., the strategic phase. Chase [7] discusses a Grammar-based production system as a powerful design tool by its ability to generate sets of designs adhering to user-specified constraints. CGA shape [4], which is a powerful adaption of Stiny’s seminal Shape Grammar idea for computer graphics, which can generate the image of massive city models in a short time.

In a generative system, the solutions generated form system may be *unexpected*. Then, these unexpected solutions must be *evaluated* properly. Obviously, computational systems can create more generations than human designers by using the powerful computational ability, with whatever qualities. So, it is possible that some strange and novel creations could stimulate designers’ inspiration. On the other hand, it is difficult to find reasonable and interesting productions in a huge solution space without assessment mechanisms during generation process. An accurate evaluation function, for producing the “good” and “useful” solutions, is necessary for this kind of systems. For these reasons, the evolutionary methods can be combined with Shape Grammar in product design and pattern design applications. Choo [8] integrates Shape Grammar with Genetic Algorithms and demonstrates using a Coca-Cola bottle grammar as a case study. Lee and Tang [9] construct a framework for camera design using shape grammars. O’ Neill [10] makes use of GE for shape representation and grammar rules for more sophisticated product design tasks.

### 2.2 Shape Grammar as a Design Language

The recursively applied rule-bases, visual shape representation and powerful analysis abilities have good work performance for design applications as assistant tools or design models. In our opinion, the role of Shape Grammar in design is similar to that of language grammar to linguistics and that of melodised rules to music composition. There are two main parts in a design application, the ‘outside representation’ and ‘inside representation’. The ‘outside representation’ means what we see from the design, and the ‘inside representation’ means what we feel about the design. The initial shape and the generated shape set by specific rules are elements of the ‘language’ for the outside representation. There is no means for a single shape in the ‘shape set’, while the arrangement of shapes under the guidance of rule-bases will represent the thinking of designers. This same situation can be found in music and art creation. The rules can be used to generate new shapes, just as linguistic grammars provide a finite set of rules capable of generating an infinite set of linguistic constructions [11]. So, when we treat Shape Grammar as a design language, it is possible to generate infinite instances of shape arrangements from the finite shape set and rule-base with the aim to represent special style of the design. Based on this idea, we present a system framework for generating graphic pattern designs – the Yunnan embroidery pattern design – for studying the influence and effect of Shape Grammar on design.

## 3 Shape Grammar application on Yunnan Embroidery Pattern

### 3.1 Yunnan Embroidery Pattern

The Embroidery Patterns come from the weaving work of women artisans in Pingzhai village, Yunnan province, southwest China (see Fig 1). It is created by the resident ancestors who lived in the village. The creators got the inspiration from their labour in nature. The embroidery patterns with natural colourful shapes are evolved and came down from generation to generation by the local artisans. Nowadays, the ethnic designs are integrated with some modern features used to weave shoes, slings, clothes and other accoutrements (see Fig 2).

Fig 1 the Yunnan Embroidery Pattern

Fig 2 the picture of the accoutrement

### 3.2 Modeling of a graphic pattern

In this paper, we divided these embroidery patterns into three categories: the single stem pattern, the double stem pattern and quadrilateral pattern. We focus on the single stem pattern (see Fig 3) as their definite structure and simple combination are easy for analysis and shape rule generation. Through data information collection, we could clearly recognize that the shapes are composed of smooth curves which are difficult to generate using mathematic functions. The B-spine curve is used to depict the curvilinear pattern in pursuit of a natural shape style. We divide three main sections in the work space for different design aim: the flower pattern area, the leaf pattern area and the root pattern area. This kind of method is usually used in the first stage of sculpture and painting generation process. Then, we build a recursive model to create the pattern step by step until the end. The last step is to colour the pattern with specific colour algorithms. The whole process is based on the Shape Grammar theory and method.

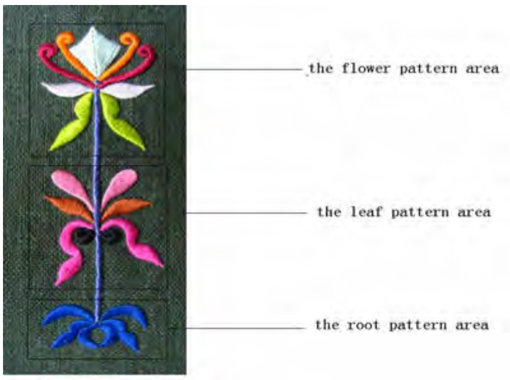



Fig 3 the three design area of single stem pattern

### 3.3 Shape Grammar on Pattern Design

As a design language, Shape Grammar is used to describe the feature of embroidery pattern. The elements of the 'language' are petals of the pattern, which are represented in parametric rectangles for the location at the early stage of process, then changed to the curve shapes at the following stage.

One difficulty for the curve shapes in Shape Grammar is the orientation problem and the sub-shape detection problem. At the early design process, we use the rectangle to locate the petal pattern to the proper position, which can overcome the orientation problem. To the sub-shape detection problem, Ramesh Krishnamurti [12] algorithm is capable of solving the most sub-shape related problems, but not suitable for the curve shape system. So, based his algorithm, we use some reformation methods for this problem in our project. We use the Minimum external rectangle of the petal to represent the position ($P_{lefttop}$, $P_{rightdown}$) in 2D coordinate system, then we use the angle $\alpha$ based X-axis to represent the orientation (See Fig 4). Of course, considering the uncertain shape of the curve petal, there will be more overlaps in the border area. We add another factor 'sub-direction' to the curve petal, which means the main work area in the rectangle. So, we need a triple set to make sure the range and position of a curve petal {($P_{lefttop}$, $P_{rightdown}$), $\alpha$, sub-direction} is properly represented.

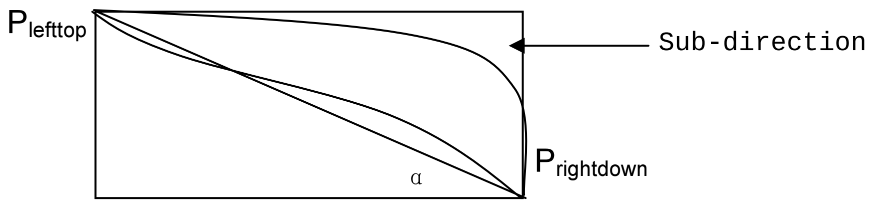


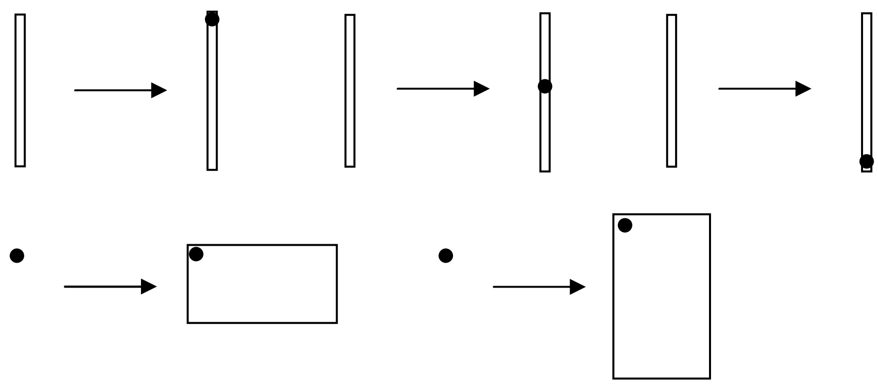

*Fig 4 the triple set for curve shape*

For the rule base, we generate three kinds of rules: the *original rule*, the *transitional rule* and the *terminal rule* for different phases. The *original rule* is used to locate the shape on the different main section (mentioned in 3.2). The *transitional rule* focuses on the recursive generation of petal position. The *terminal rule* is used for the curve petal replacement. The whole shapes in the rule-base are all based on parametric shapes.

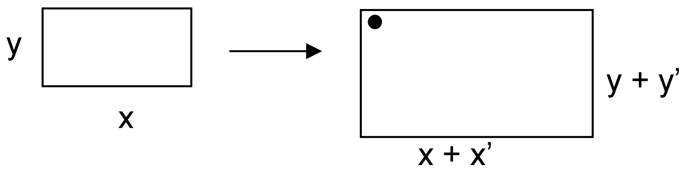
The Shape Grammar on embroidery pattern:

$SG_{pattern}$ = {S, L, R, I}

S = <Rectangle, Petal>
L = < ● >
R = <*original rule*, *transitional rule*, *terminal rule*>
I = < ▯ >
Part of the rules:
Original rule:



Transitional rule




$x' \in R$ and $y' \in R$

Terminal rule

Sub-direction = "up" sub-direction = "down"

# 4 System Framework

## 4.1 Structure of System

For the higher flexibility and compatibility, we present an open structure system, which is composed of four layers: User Layer, Transport Layer, Application Layer and Element Layer. From the higher to the lower, services and data flow are transported from the system under the MFC framework and Message System of the OS. The program can contain the data and services from the same layer and the lower layer, while it only require the services from the higher layer, which is the same as the Ring-Protection Mechanism in Operate System.

This four layers structure allows everyone focus only on their personal function. So, it is convenient to update the system, in order for the designer to concentrate all the efforts on single aspect without many interferential factors. The User Layer mainly collects the data information from the users, such as the mouse movement affairs, keyboard affairs and user-system interaction affairs. The Transport Layer looks like an interpreter which can translate the collecting information into *system calls*. The Application Layer controls the functional operations and takes charge of the main algorithm implementation. The Element Layer is for saving all the operational objects. The reason of increasing to this layer is to separate the operation and operational object for the convenience of enlarging the system implemental range (See Fig 5).

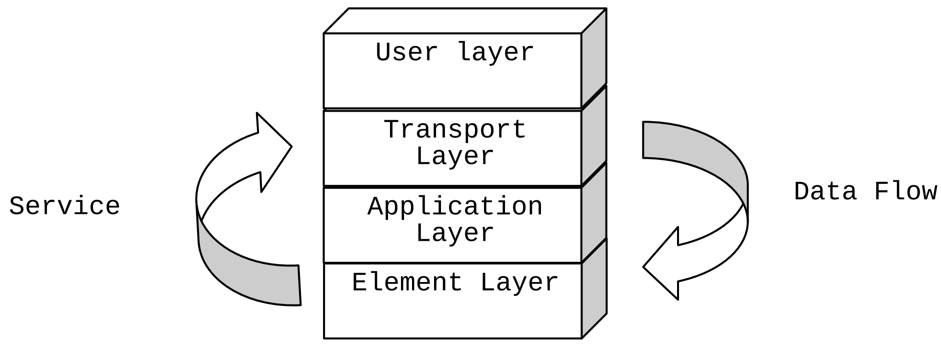



*Fig 5 the system structure*

### 4.2 Knowledge representation

For most art design systems and researches, knowledge representation always becomes the key issue or a difficulty, since the important thing is to bridge between subjectivity and objectivity. Especially in the digital system, to find a reasonable model to represent the knowledge and to introduce a proper paradigm used in computational framework is the essential step to connect the design patterns and the virtual production. Gero and Ding's work [13] give us a good sample for this point.

We introduce a complex net relationship to represent the pattern design knowledge. The top end represents the physical features of the pattern, and the bottom end means the evaluation factors of the system (See Fig 6)

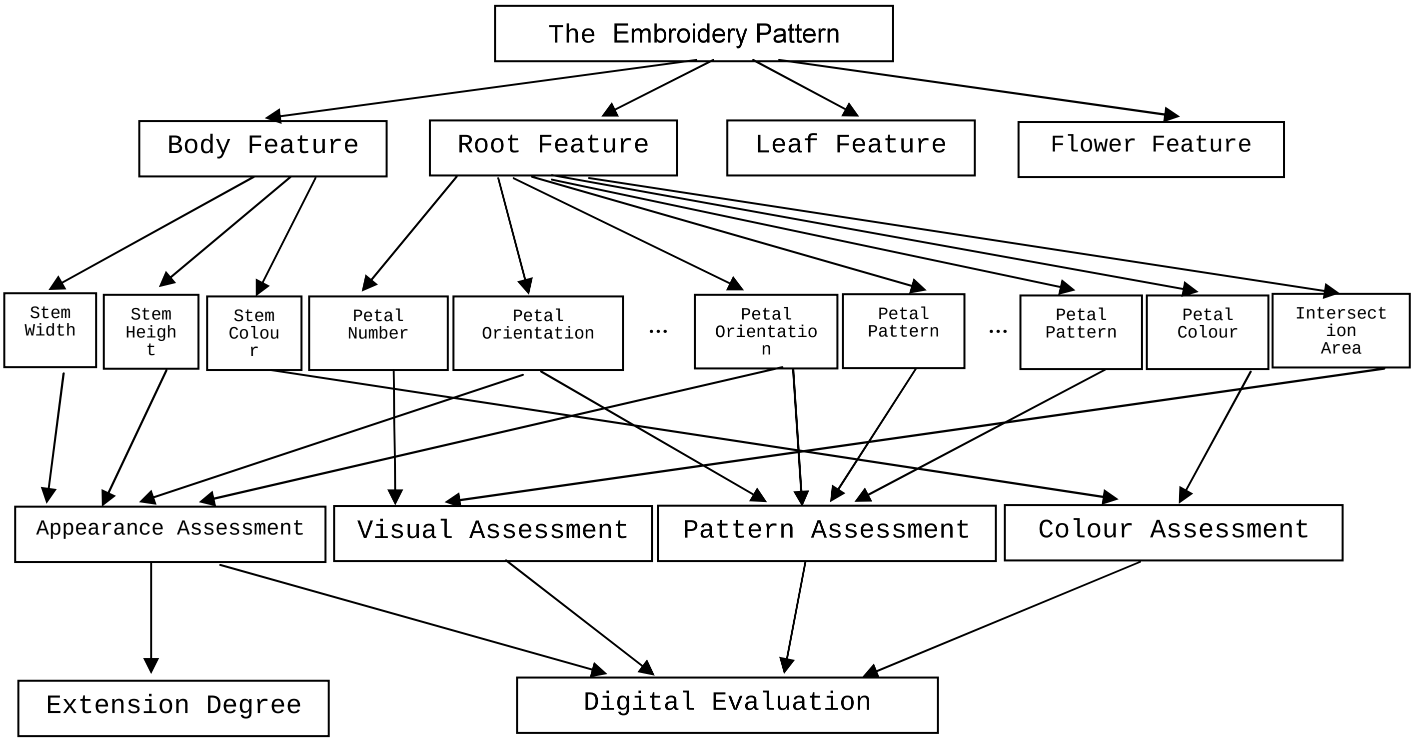



*Fig 6 the Embroidery Pattern representation model*

## 5 Experiment

We present an auto-generation system embedding Shape Grammar to create Yunnan embroidery patterns by the characters of the existing products. The generative computational model is implemented in Microsoft Visual 2003 C++ environment on 2-dimensional space.

### 5.1 Initial Experiment

In this study, we wish to determine if it is possible to generate the similar patterns by the characters abstracted form the real ones. Under the Shape Grammar theory, there are four steps to generate a complete pattern (See Fig 7). With the transitional rules and original rules, we can build many pattern distributions untill we feel satisfied.

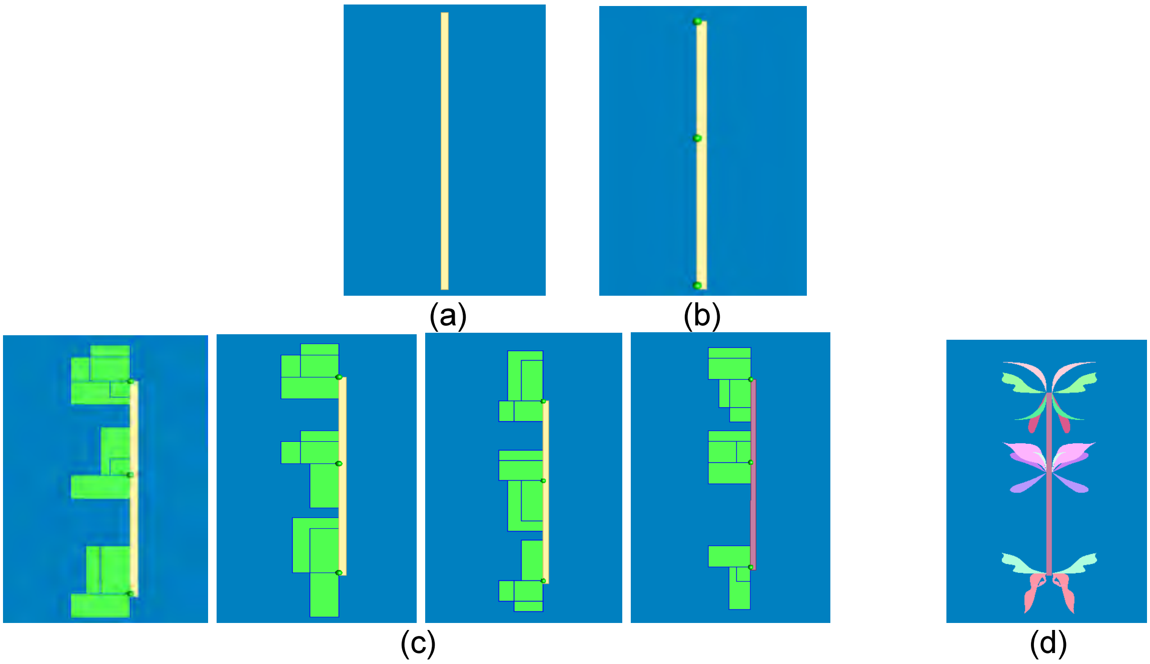



*Fig 7 the snapshot of single step generation*
*(a) Stem Creation Step, (b) Control Point Creation Step*
*(c) Framework Creation Step, (d) Pattern Confirmation Step*

### 5.2 Communicational Interaction

Shape Grammar is treated as a design language in this system. So we add some interaction operations to it. Obviously, the output of the system, the visual result form work space, is what the system tells us. There are two types of input excepted the parameter input: the petal generating input and the evolutionary input.

As the open structure system, we can increase new petal generating method easily by programmer in the Element Layer. What we increased is a generation method, not the specific shape, which is useful to operate by Shape Grammar rules. As a result, system users could choose their favourite petal patterns to save in a XML database for the terminal rules (mentioned in 3.3). We offer the auto-variation function for users to choose the pattern through generative computer model, which is the designer's accepted working way. It means that users could press "variation" button and wait in front of the screen to watch the different visual patterns one by one. When finding the interesting one, they could press "stop" and "save" button to save it to the database. Different system users can build their personal XML database to persist their own design thinking (See Fig 8).

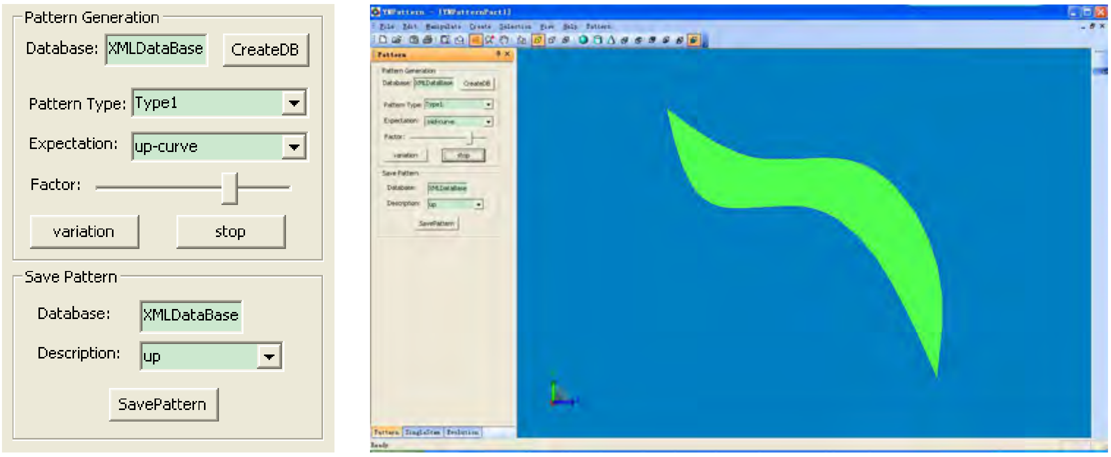



*Fig 8 the snapshot of pattern generation work environment*

### 5.3 Evolution Method

After the initial experiment, we collected some useful data and analysed the rusults. Unfortunately, the result is not satisfactorying as there are many overlaps in the patterns, and some unexpectation transformations appeared in the final pattens as the transitional rules operating. Through Shape Grammar model, we could get various petal patterns in a huge amount, with some interesting but some more uninteresting. To find the best solution in a huge space is not the advantages of Shape Grammar, which is only good at generating. For improving the qualities of products, we need another communicational interaction – Evolution Method.

When the generation is finished, we can evaluate the result by the digital evalutaion. The Appearance Assessment, Visual Assessment and Pattern Assessment are all involved in the evalutation process. Every assessment depends on the auto-evalution by computer and user evalution mechanism. For example, the Visual Assessment focused on the petal numbers and the intersecting area.

$E_{visual} = \alpha * E_{numbe}r + \alpha * E_{intersection} + \beta * E_{user}$, where $\alpha$ , $\beta$ is Impact factor

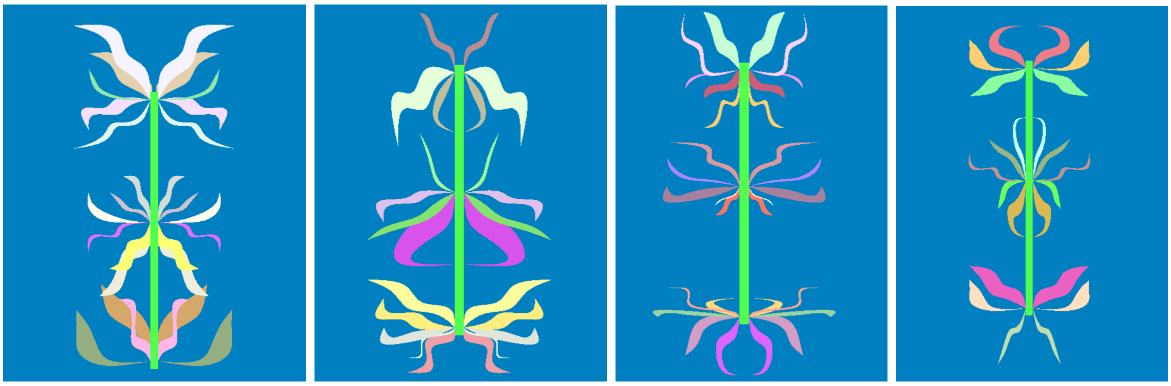
$$E_{number} = \begin{cases} factor1 & number>=5 \\ factor2 & number \in [2, 4] \\ factor3 & number<2\&\&number>=0 \end{cases}$$

, where factor1, factor2, factor3 are impact factors operating in the next generating process.

$E_{intersection}=factor_i$, $(arcsin(abs(y_{Pleft-Pright})/sqrt(x_{Pleft-Pright}{}^2 + y_{Pleft-Pright}{}^2), sub\text{-}direction)$

, where $factor_i$ is impact factors operating in the transitional rules chosen process for the next generation.

The $E_{user}$ is a pipe for user to intervene in the evolutionary direction. User could orient the system development to their favourite direction. Some results of evolution are showed in Fig 9.



(a) (b) (c) (d)

*Fig 9 Part revolution result*

*(a) the 1 generation (b) the 5 generation*

*(c) the 15 generation (d) the 25generation*

## 6 Conclusion and Future Research

In this paper, we presented a generative system embedding Shape Grammar on Yunnan embroidery Pattern design, which can stimulate designers' inspiration and reduce the design time effectively. With the knowledge representation used in this system, we could build the connection between the physical characters of the real products and the digital features of the computer model. The auto-variation petal mechanism is a good beginning on visualizing generative systems, especially for the design environment. It can support plentiful reasonable solutions through the powerful computational ability of the digital system for designers, while the generation method is specified by programmer at present. The communicational function based on the open structure framework proved the improtance between users and system, supporting interactive activities in a cooperative work group.

There are many improvements which need to be done in the future for more practical and valuable purposes. Firstly, the communicational function should be improved with more friendly interface for designers, which can reduce the exception by unintentional operations. A comfortable and easy-operational working environment is our aim. Secondly, how to evaluation the curve lines is always a puzzle in non-orthogonal graphic system, which is important to the petal pattern evalution. Thirdly, a more free general petal auto-variation mechanism is required. The petal pattern generation method should be specified by users, not the programmers, in the same way as the artists' pencil and paper work. Then, color is essential for the visualization system. It is worthy to improve the color algorithm in this system for more pretty visual effect. Lastly, we need do more researches on evolutionary method in order to find more interesting solutions effectively in the solution space.

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