# EXPLORING STYLE EMERGENCE IN ARCHITECTURAL DESIGNS

JOHN S. GERO AND LAN DING
*Key Centre of Design Computing*
*Department of Architectural and Design Science*
*University of Sydney NSW 2006 Australia*
*e-mail:{john,lan}@arch.usyd.edu.au*

**Abstract.** This paper presents an evolutionary approach to style emergence in architectural designs. Emergence is the process of making features explicit which were previously only implicit. Style is considered as a set of common characteristics of a group of designs. It is interpreted using a language model as an analogy and is represented at the genetic level. An evolutionary system based on genetic engineering is developed. It emerges style by locating the genetic structures which produce that style. Preliminary results are presented.

## 1. Introduction

Style is an important aspect of architectural designs. Many studies have dealt with the concept or cognition of style but have lacked any process of deriving style (Simon, 1975). Emergence is the process of making features explicit which were previously only implicit. Emergence in design plays an important role in supporting designers' creativity. Although some process models of emergence have been proposed and implemented (Gero et al, 1995), none has been proposed for emergence of style.

In this work we consider style emergence using an evolutionary system based on genetic engineering. Evolutionary systems have been applied in design domains which involve design optimization and design learning (Bullock, 1995; Gero, Louis and Kundu, 1994). The genetic engineering approach (Gero, 1992) comes from the analogy with human intervention in biological evolution. It examines the performance of sub-populations and locates the genes or gene structures which produce the desired performance and then evolves them as new genes in some appropriate manner. Genetic engineering has two advantages when it is applied in design contexts. Firstly, it can set up the relationships between the design space and the design's performance. Secondly, it can rapidly evolve the design space and generate desired design results.

A style is interpreted using hierarchical levels which map onto the syntax and semantics of designs and the interpretation is represented using genetic descriptions. The syntax space is coded as genotypes and the semantics space contains the fitnesses of the resulting designs. The mapping between style content and its syntactic representation is derived by locating the genetic structures that produce that style.

The organization of this paper is as follows. The concept of architectural style and a language model of interpreting style are presented in Sections 2 and 3. A process model using genetic engineering for style emergence is introduced in Section 4, where a genetic description and a method of fitness evaluation of the semantics are presented. Section 5 introduces some preliminary results and the final section provides some tentative conclusions from this work.

## 2. Architectural Style

Architectural style touches upon many areas which include structure, behaviour, function, society, culture, history and so on. Every style contains a common particular meaning, its semantics (here distinguished as complex semantics) has a unique label. This labels refers to its common complex semantics, e.g. Classical, Gothic, High Tech, Post Modern, Chinese traditional and so on. The common complex semantics can be derived from a set of lower level meanings (here called simple semantics). For example, 'Gothic' can be derived from such a set of simple semantics: dynamic line, emphasis on spire, structural framework using stone to concentrate weights and stresses, etc. 'Chinese tradition' can be derived from such simple semantics as: Chinese cosmos exhibited in symmetrical and orthogonal structure, traditional proportions, wooden frame construction, traditional architectural symbolic representation such colours and the animals decorated on the roof, beautiful and gigantic roof and so on.

Simple semantics are derivable from architectural forms. The same semantics could come from the same forms or different forms. For example, the emphasis of church spire in Gothic style comes from the vertical tower with height; traditional proportions in Chinese traditional style could come from a group of roofs of a pagoda, or come from a group of columns of a temple. The common semantics in same or different forms result from the common decisions of form elements or relationships between the elements.

Therefore, architectural style can be treated as a set of common characteristics of a group of designs. The common characteristics are the representation of common particular meaning, called semantics. Semantics involve simple semantics and complex semantics. They are derived from the forms and result from the common decisions in a design process.

## 3. Language Model of Interpreting Style

The link between design and language has been widely studied (Coyne and Gero, 1986; Edwards, 1945; Zevi, 1978). The method of using language as an analogy enables us to represent design knowledge at hierarchical levels. In a language model of interpreting design (Coyne and Gero, 1986), design is described as a language with vocabularies and grammar. A design grammar defines a legal design syntax. Design syntax is used to generate design sentences. A set of syntaxes produces a design as a context.

According to this model we interpret architectural style utilising hierarchical levels which map onto syntax and semantics. Architectural design may be considered as a process of selecting and ordering syntax. The execution of a design syntax produces a design. Architectural semantics are derived from the architectural form of the design. Simple semantics are derived from the design sentences and are determined by syntax. Complex semantics are derived from a set of simple semantics and are determined by the control of syntax. The common complex semantics in a group of designs produces a style. Thus, an architectural style is a set of common complex semantics and is determined by a particular set of executions of syntax. Figure 1 contains examples of Chinese traditional architectural style. Its interpretation using a language as an analogy is illustrated in Figure 2.
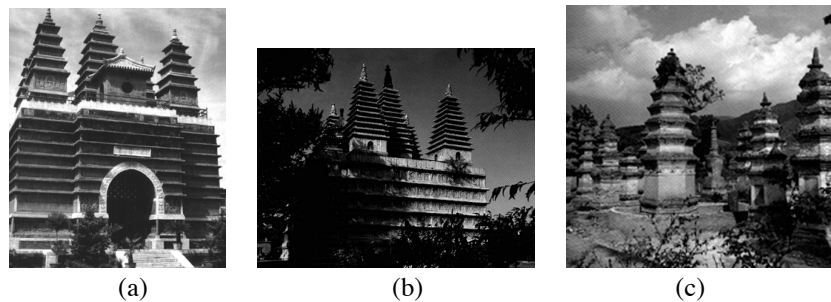


(a)                    (b)                    (c)

*Figure 1.* An example of a Chinese traditional architectural style:
(a) Cideng Si Pagoda; (c) Shaolin Si Pagodas; (b) The Great Enlightenment Temple.

## 4. Genetic Engineering for Style Emergence

We explore style emergence through genetic engineering. The syntax-semantics interpretation of style is represented at the genetic level using an evolutionary system where the mapping between semantics and syntax is developed. The evolutionary system dynamically seeds a syntax space (the genotypes) and generates new design forms (the phenotypes). The semantics are modelled as the fitnesses of the resulting designs. The representation of

the common complex semantics in the design population is its emergent style. The system then derives the emergent style by locating the genetic structures using genetic engineering.
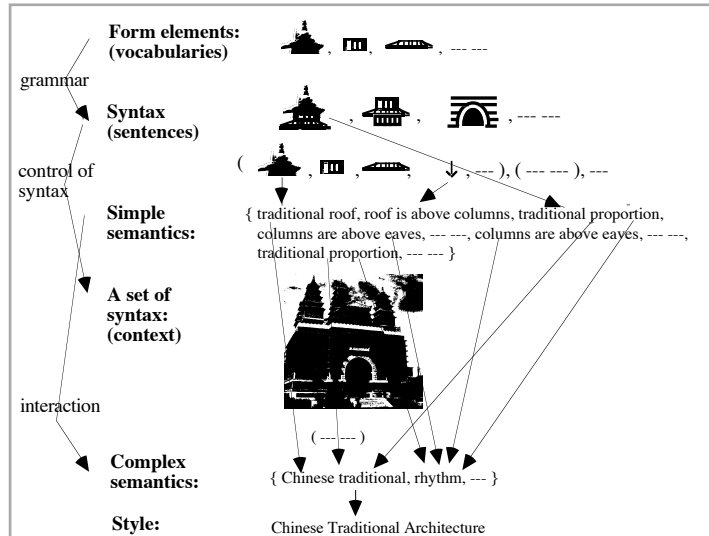


*Figure 2*. An example of interpreting architectural style using the language model.

The genetic engineering manipulation is as follows. The system evaluates design populations against the fitnesses defining semantics. The individuals in design populations are classified as good and bad according to their fitness values. The system finds the common genes and gene structures which are in the genotypes that produced good individuals and not in the genotypes that produced bad individuals. These genes and gene structures are taken as evolved genes and are introduced to existing gene schemas.

The process of deriving the evolved genes occurs hierarchically. The system evaluates the simple semantics and derives the gene structures which map onto different simple semantics first. A gene structure is represented by an evolved gene with a label which links it to the semantics that it maps onto. The system then generates new populations using both initial genes and these evolved genes which now encode the simple semantics. The system then evaluates complex fitnesses and derives the gene structures which map onto different complex semantics. The system then generates new populations using initial genes, evolved genes which map onto simple semantics and evolved genes which map onto complex semantics. Finally, the system evaluates the fitness of a style, ie. the fitness of a set of multiple complex semantics, and derives more complex gene structures.

4.1 GENETIC DESCRIPTION

A design syntax is a set of design rules used to transform design states. We encode syntax rules as initial genes. A set of syntax rules is a set of ordered initial genes, ie. genotypes. The control of syntax maps onto the gene's relationships in the genotype. A style is therefore determined by the genes and their relationships in genotypes.

We construct a gene schema to represent the mapping between genotype and phenotype. The gene schema consists of two parts which involve a plan gene schema and a rule gene schema. i.e.:

$$S = \{S_{rule}; S_{plan}\}$$

The plan gene schema maps onto the planning of a whole facade. A facade is divided into M blocks. Each block involves n form elements and every block is labelled using the number of the form elements in the block. The plan gene schema is a sequence of these:

$$S_{plan} = [n_1, n_2, n_3, -- n_i]$$

Where $S_{plan}$ denotes the plan gene schema, $n_i$ denotes a block of the facade and corresponds to the number of form elements in the block, $M \in (1, i)$. The corresponding phenotype is shown in Figure 3(a).
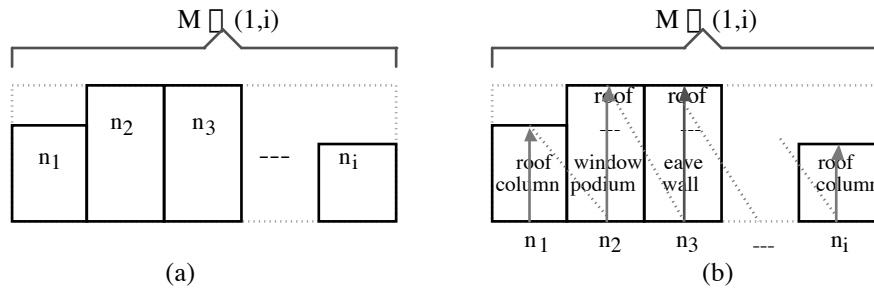


*Figure 3.* (a) The phenotype corresponding to a plan gene schema; (b) the phenotype corresponding to a rule gene schema.

The rule gene schema maps onto the placement of form elements in each block of the facade. Form elements are placed from bottom to top. The rule gene schema is a sequence of form elements. It is represented as:

$$S_{rule} = [n_1E_1, n_2E_2, n_3E_3, -- n_iE_i]$$
$$E_i = [e_1, e_2, e_3, -- e_{ni}]$$

Where $S_{rule}$ denotes the rule gene schema, $E_i$ denotes a set of the form elements placed in block $n_i$, $n_i$ is labelled using the number of form elements in the block, $e_n$ is a form element. The corresponding phenotype is illustrated in Figure 3(b).

In terms of the gene schema the system seeds the plan genes first, then it seeds the rule genes under the plan to produce an individual. The template of the genotype of an individual is illustrated in Figure 4.
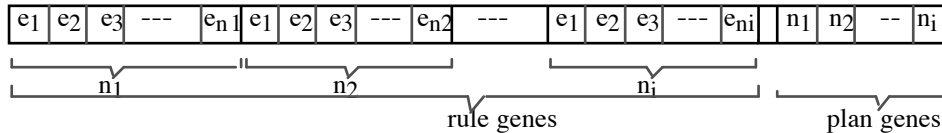


*Figure 4*. The template of the genotype of an individual .

We describe the phenotype using a grid. The phenotype of a design is represented at two levels. At level 1 it is a set of the position descriptions of all form elements in the design. It is used to calculate the relationships properties of form elements for the evaluation of simple semantics. The phenotype of level 2 is a set of the position descriptions of all the simple semantics that have been previously derived. It is used to calculate the relationships properties of simple semantics for the evaluation of complex semantics.

## 4.2  FITNESS OF SEMANTICS

We construct hierarchical fitnesses commencing with simple semantics rising to complex semantics. The simple fitness ($F^0$) is a set of simple semantics of interest. For example, $F^0 = \{$ horizontality, verticality, on_top_of, left_touch, corner_touch, similarity, repetition, etc$\}$. The complex fitness ($F^1$) is a set of complex semantics of interest. For example, $F^1 = \{$repetition, horizontal axis, vertical axis, mirror symmetry, rhythm, movement, etc.$\}$. The fitness of style is a set of multiple complex semantics.

The concept of semantics is represented using a set of properties of form. Simple semantics (I) is represented by a set of relationship properties of form elements. i.e. $I = \{(E_1, E_2);$ Relation_properties$\}$. Complex semantics (C) is represented by a set of relationships properties of simple semantics. i.e. $C = \{[I];$ Relation_properties$\}$.

Th fitness values for simple semantics are either 1 or 0, based on whether that semantics exists or not. The fitness of complex semantics is defined as the best fit to all of the relationship properties of simple semantics which constitute the complex semantics. Fitness values are assigned to individuals using a ranking technique.

## 4.3  LOCATING GENE STRUCTURES TO PRODUCES EVOLVED GENES

The system locates the gene structures which map onto high fitness semantics to produce evolved genes. The interaction of adjacent genes in the genotype that consist of rule genes has a direct influence upon simple semantics. Therefore, the system searches for the neighbouring genes which are common in the 'good' population as simple gene structures and evolves them. The mapping between the evolved gene and simple semantics is confirmed using a check procedure. An illustration of the simple gene structures which are then turned into evolved genes is given in Figure 5.

The system then searches for the complex gene structures in the genotype consisting of rule genes and the genotype consisting of plan genes. These consist of initial genes and simple gene structures. They are common in the 'good' population and are confirmed as evolved genes. An illustration of a complex gene structure which is then turned into an evolved gene is given in Figure 6. The complex semantics that these evolved genes map onto is encoded using the same method as for simple semantics.
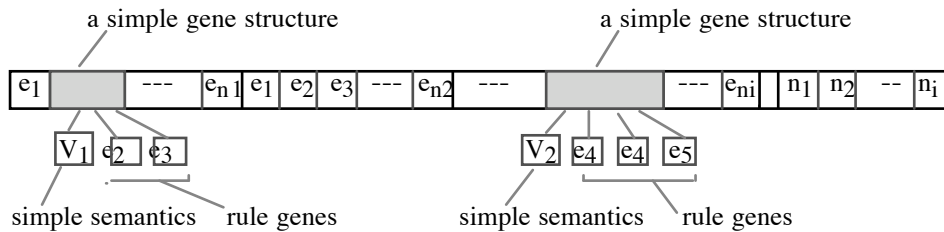


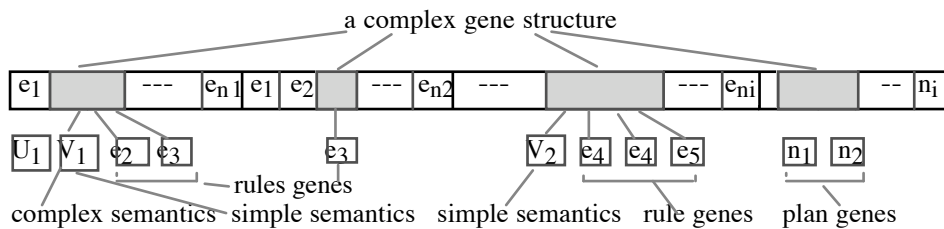Figure 5. An example of the simple gene structures in a genotype.



Figure 6. An example of a complex gene structure in a genotype.

## 4.4  GENERATING POPULATIONS

The initial population is generated using the initial genes and subsequent populations are generated using initial genes and evolved genes. The system manipulates populations through the standard genetic operations of crossover and mutation. When parent genotypes consist of initial genes only,

crossover points are randomly selected between initial genes. When parent genotypes consist of initial genes and evolved genes, crossover points are randomly selected between the initial genes and evolved genes such that the evolved genes are not damaged. The mutation operator is used to randomly modify the genes in the genotype including evolved genes which require a modified mutation operator.

## 5. Preliminary Results

Some preliminary results have been obtained in an early implementation of the evolutionary model for the emergence of style. The system was applied to traditional Chinese architectural facades and was used to generate populations of 150 individuals. The maximum number of generations was set at 100. Each new population was generated with the probability of crossover of 0.77 and the probability of mutation of 0.099.

The form elements in traditional Chinese architectural facades were coded as shown in Table 1. The system seeded a set of syntaxes as the genotypes and generated the phenotypes as the initial population. The system evaluated the designs produced at each generation against the different simple semantics in the context of finding the simple semantics of traditional Chinese roof architecture. The simple semantics are a set $F^0$ = {horizontality, verticality, on_top_of, left_touch, corner_touch, similarity, repetition, etc}. A total of 280 evolved genes were obtained.

| Roof | eave | 0 | Door | door_1 | 7 |
|------|------|---|------|--------|---|
|      | pyramidal | 1 |      | door_2 | 8 |
|      | rolling top | 2 | Column | column_1 | 9 |
|      | gable roof | 3 |      | column_2 | 10 |
| Wall | wall_1 | 4 | Window | window_1 | 11 |
|      | wall_2 | 5 |      | window_2 | 12 |
|      | wall_3 | 6 | Podium | podium_1 | 13 |
|      |        |   |      | podium_2 | 14 |

*Table 1.* Coding of form elements

Figure 7 presents some individuals in the initial population. Where facades (a) and (d) have fitness value 1 for the simple semantics of 'vertical roofs' and facade (c) has the fitness value 0.

Figure 8 illustrates the structures of some evolved genes that map onto the simple semantics of 'vertical roofs'. Where $g_i$ represents an initial gene, i $\in$ (0,14) denotes different initial genes, i > 14 denotes different gene structures which become evolved genes. The lines indicate the derivation of an evolved gene. Gene complexity is defined as follows (Gero and Kazakov,

1996): 0-complexity describes initial genes, 1-complexity describes evolved gene composed of genes of 0-complexity and n-complexity describes evolved gene composed of genes of (n-1)-complexity and possibly of other genes of lower complexity.
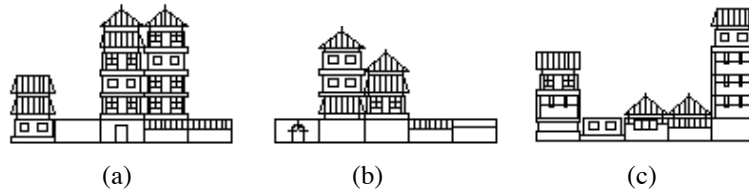


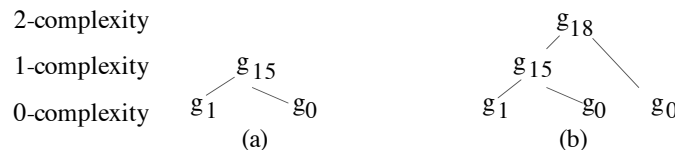*Figure 7*. Some individuals in the initial population.



*Figure 8*. The evolved genes mapping onto simple semantics of 'vertical roofs': (a) an evolved gene derived in generation 1; (b) an evolved gene derived in generation 8.

Figure 9 shows the evolved genes derived in each generation as a percentage of the total evolved genes derived over 100 generations. The data is the average value of ten runs. It shows that genes evolve primarily between generations 20 and 60 for this problem.
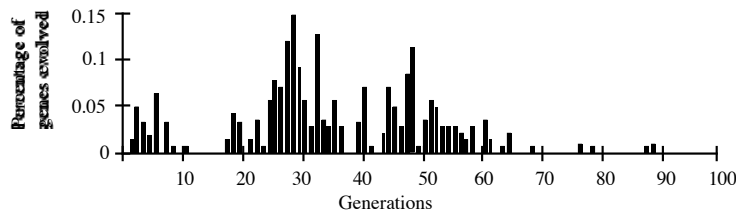


*Figure 9*. The evolved genes of each generation as a percentage of the total evolved genes for 100 generations.

The evolved genes become more and more complex during the evolutionary process. This implies that more and more syntaxes related to a style are derived. These tests have not yet included the derivation of complex gene structures mapping onto complex semantics.

## 6. Conclusion

This research develops an evolutionary model for the style emergence in architectural designs. It interprets architectural style using a language as an analogy. A genetic engineering approach is used to derive the emergent style hierarchically and the evolution of style representation. Preliminary results indicate the utility of the approach with simple semantics already being derived. The utility of the model will be further investigated when deriving complex semantics and then style using rich architectural examples.

This research aims to demonstrate that abstract concepts such as style can be made more explicit through the use of computational processes which derive a computational representation of those concepts. Once such a computational representation exists it can be explored in its own right as well as utilised as a design tool.

## Acknowledgements

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